Technical University of Denmark

Popular science summary of the PhD thesis

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Title of the PhD thesis	Experimental investigations and modeling of natural refrigerant mixtures in low-charge heat pumps
PhD school/Department	DTU Construct

Science summary

Buildings worldwide still rely on fossil fuels heavily contributing to CO_2 emissions and global warming. Heat pumps are a key technology that can enable the shift to a more sustainable heating sector. Heat pumps can efficiently provide space heating, domestic hot water, and space cooling. However, their working media have been raising environmental concerns. The great majority of heat pumps in the market contain fluorinated refrigerants with a high Global Warming Potential. According to the last revision of the F-gas Regulation, in heat pumps with a heating capacity below 12 kW, fluorinated refrigerants will be banned by 2035. Natural refrigerants are among the most suited alternatives. However, their adoption in indoor applications is still limited, often due to safety restrictions and the related additional costs. Mixtures of natural refrigerants can increase the range and applicability of natural fluids in heat pumps, increasing their performance and reducing unwanted characteristics, but available experimental data are limited. This work explored the potential of natural refrigerant mixtures in residential heat pump applications. The research included modeling activities and three experimental investigations, allowing the developed models to be validated. The work was divided into three main sections.

(i) Initially, a mathematical model was developed in Python to characterise the performance characteristics of low-charge heat pumps in design and off-design conditions. To determine the refrigerant charge requirements from standards, methods to assess the Lower Flammability Limits (LFL) of natural mixtures were investigated and implemented. The model was then adopted in a refrigerant screening procedure. The most promising refrigerants and their mixtures were identified through multi-criteria decision-making techniques and an economic analysis. Dimethyl Ether, Propylene and low amounts of CO_2 were found to be consistently among the most performing refrigerants and showed up to 12 % potential reduction of the levelized cost of heat.

(ii) Further investigations on the interaction between refrigerant and oil were prioritised. Experimental studies were carried out on the solubility of Propylene and DME in a low-solubility oil. The data were used to fit semi-empirical models from the literature. Moreover, empirical correlations were proposed, and their accuracy was studied. A novel correlation with a single solubility coefficient (SSC) was formulated in a compact and explicit form, and it was also found to be robust with a limited dataset. The SSC correlation was then adopted to develop a thermophysical model of the compressor charge. A test bench and a heat pump prototype were designed to validate the model. Four refrigerants were tested. It was found that a refrigerant with higher solubility in oil does not necessarily relate to a higher refrigerant charge in the compressor.

(iii) The experimental campaign on the heat pump prototype continued focusing on the energy performance of additional non-fluorinated refrigerants. The zeotropic mixtures Propane-CO_2, Propylene-CO_2, DME-CO_2 and Propylene-DME were tested at different compositions. Heating capacities ranged between 3.7 kW and 12.2 kW, and COP ranged between 4.0 and 7.2. At low source and sink glides, Propylene and its mixtures were the best performing. At medium and high glide source and sink conditions, mixing low amounts of CO_2 showed performance enhancements, especially on Propylene and DME. Compared to Propane, DME-CO_2 showed 12 % COP enhancement, 16 % lower heating capacity and 50 % higher limit heating capacity at the maximum allowed charge. A new proposed mixture, the NM-490, was able to improve all three indicators. Moreover, the measurements suggested that the circulating composition of the refrigerant differed from the nominal one. Considering the circulating composition, the overall model was validated, resulting in average deviations of the performance and charge predictions below 5 % and 10 %, respectively. An exergy analysis revealed that the compressor was the component with the highest exergy destruction, particularly for DME mixtures, followed by the evaporator. An advanced exergy analysis was conducted on the heat exchangers. A compressor customised for DME-based mixtures and minimising refrigerant maldistribution in the evaporator were recommended to maximize the benefits these refrigerants can offer.

Mixtures containing DME, Propylene, and low amounts of CO_2 were found to be attractive options for low-charge heat pumps, and further investigations were recommended. Future research, demonstration, and certification efforts on natural mixtures may allow the development of residential heat pumps with low GWP and sustainable refrigerants, conventional operating conditions, extended heating capacity ranges, and enhanced efficiency.