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A simplified method to evaluate the energy performance of CO_2 heat pump units

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A B S T R A C T

The prediction of the performances of CO_2 transcritical heat pumps demands accurate calculation methods, where a particular effort is devoted to the gas cooler modelling, as the correlation between high pressure and gas cooler outlet temperature strongly affects the cycle performance. The above-mentioned methods require a large amount of input data and calculation power. As a consequence they are often useless for the full characterisation of heat pumps which are sold on the market.

A simplified numerical method for the performance prediction of vapour compression heat pumps working in a transcritical cycle is presented, based only on performance data at the nominal rating conditions. The proposed procedure was validated against experimental data of two different tap water heat pumps. For the considered units, simulation results are in good agreement with the experimental ones. The deviations range from −6.4% to +1.7% and from −3.8% to +5.8% for the COP_H of the air/water heat pump and the water/water heat pump, respectively. The heating capacity deviations stayed within −5.5% and +1.7% range and within −5.0% and +7.9% range for the same units.

The proposed mathematical model appears to be a reliable tool to be used by the refrigeration industry or to be implemented into dynamic building-plant energy simulation codes. Finally, it represents a useful instrument for the definition of tailored approximated optimal high pressure curve considering the operating characteristics of the specific CO_2 transcritical unit. It could also be implemented on board of a real unit control system where it could be used as model coupled to computational intelligence algorithms for pressure optimisation.

1. Introduction

An inverse CO_2 operated cycle is very different from a traditional one, since the high pressure is often supercritical and the resulting refrigerating cycle does not entail condensation, but a simple cooling process of dense fluid accomplished in the so-called 'gas cooler'. As a consequence, unlike the common subcritical cycle, the flow factor of the expansion valve determines the gas cooler pressure, which is no more related only to the temperature of the heat transfer process. Then, for the best utilisation of such a technology, it is necessary that in each working condition the system operates at the optimal value of the cycle high pressure, that is the one which leads to the maximum COP ([1–3]). As a general consideration, the optimal upper pressure value can be regarded, at a rough estimate, as inversely proportional to the gas cooler thermal efficiency [4].

Several authors, Inokuty [5], Kauf [6], Liao et al. [7], Sarkar et al. [8,9], and Chen and Gu [10], faced up transcritical systems high pressure optimisation problem. By means of different simplifying assumption, the same authors theoretically worked out expressions to define the optimal cycle high pressure as a function of the refrigerating cycle variables, which are mainly the gas cooler refrigerant outlet temperature and the evaporating temperature.

In a recent paper, Cecchinato et al. [11] pointed out the strong sensitivity of the gas cooler refrigerant outlet temperature not only from the secondary fluid temperature but also from its capacity rate and from the heat exchanger geometric characteristics, thus demonstrating that literature simplified equations for the optimal high pressure might lead to relevant deviation of *COP* from the optimal one, once implemented on board of a real unit control system. The authors obtained a −22% maximum deviation for the analysed systems. The authors concluded that this control technique might be efficiently used only if the implemented approximated solution is obtained by considering the operating characteristics of the specific refrigeration unit. In order to obtain such a tailored equation, an experimental or simulation campaign is needed for each unit, thus requiring dedicated tuning for each controller.

The design and rating of the gas cooler performance require therefore an accurate modelling, as the correlation between high pressure and gas cooler outlet temperature strongly affects the cycle performance. The gas cooler analysis faces the problem related to the

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