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PERFORMANCE ANALYSIS OF PLATE HEAT EXCHANGERS USED AS REFRIGERANT EVAPORATORS

ABSTRACT

In this study the heat transfer and frictional pressure drop performance characteristics of plate heat exchangers (PHE's) used as refrigerant liquid over-feed evaporators were investigated. PHE's have been gaining new applications in the refrigeration industry, especially as evaporators, during the last few decades, but the available information in the open literature for operation in this mode is rather limited. This study aims to extend the knowledge of PHE evaporator performance and to develop a model for use in evaluating heat transfer and pressure drop over as wide a range of operating conditions as possible.

A laboratory experimental facility was constructed and the thermal-hydraulic characteristics of three middle-size industrial PHE's were measured. The exchangers all had 24 plates of the same size but with different chevron angle combinations of 28°/28°, 28°/60°, and 60°/60°. Two sets of tests were carried out with the three units: single-phase performance tests with water, and evaporator performance tests with R134a and R507A, for which the exchangers operated as refrigerant liquid over-feed evaporators. The tests with water served to provide accurate water-side heat transfer information for the evaporator performance analysis which is the primary purpose of this study. In the evaporator performance tests, refrigerant flow boiling heat transfer and two-phase pressure drop data were obtained under steady conditions, over a range of heat flux from 1.9 to 6.9 kW/m^2, refrigerant mass flux from 5.6 to 31.4 kg/(m^{2}s), outlet vapour quality from 0.2 to 0/95, and saturation temperatures from 5.9 to 13.0 °C. Additional field data of thermal performance were collected on an ammonia and a R12 PHE water chiller, operating as thermo-siphon evaporators at their design working conditions.

All experimental data were reduced and analyzed to obtain the refrigerant-side heat transfer coefficients and frictional pressure drops in the PHE evaporators. The heat transfer results showed a strong dependence on heat flux and a weak dependence on mass flux, vapour fraction and the chevron angle. Along with the

observations from the ammonia and R12 evaporators, it is concluded that the dominating heat transfer mechanism in this type of evaporator is nucleate boiling rather than forced convection. In contrast to the heat transfer characteristics, the refrigerant two-phase frictional pressure drop was found to be strongly influenced by mass flow rate, vapour fraction and also the chevron angle. An almost linear increase of the frictional pressure drop with the homogeneous two-phase kinetic energy per unit volume was observed for both refrigerants.

Based on the experimental data, correlations were developed for predicting the refrigerant boiling heat transfer coefficient and two-phase frictional pressure drop in PHE liquid over-feed evaporators. Two correlations were developed for boiling heat transfer, one of these reflecting the *h*-*q* relationship in pool boiling, the other with all constants and exponents determined by regression analysis. The mean absolute errors are respectively 7.3% and 6.8% for these correlations. For two-phase frictional pressure drop, data were correlated using two established methods, namely the homogeneous and the Lockhart-Martinelli methods, with means absolute errors of 6.7% and 4.2%, respectively. The homogeneous model showed a slightly higher discrepancy with the experimental data but is likely to be more physically sound for PHE evaporators, and is much simpler to apply. Validation of these correlations with other data has been difficult due to the shortage of published information. For other refrigerants operating at comparable conditions, these correlations should serve as a guide, while more accurate design or evaluation may need to be based on further testing.

The performance analysis carried out in this study was based on systematic experimental investigations and field tests on industrial PHE units. Correlations were developed covering a rather extensive range of flow parameters, plate geometry and various refrigerants. Such correlations have not been reported previously for PHE liquid over-feed evaporators. The results simplify the performance analysis of PHE evaporators and provide a reliable thermal-hydraulic model of PHE liquid over-feed evaporators, which can be used for system modeling of water-chilling machines employing this type of evaporator.