A numerical simulation model for plate-type, roll-bond evaporators

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**Abstract**

This study presents a first-principles mathematical model developed to investigate the thermal behavior of a plate-type, roll-bond evaporator. The refrigerated cabinet was also taken into account in order to supply the proper boundary conditions to the evaporator model. The mathematical model was based on the mass, momentum and energy conservation principles applied to each of the following domains: (i) refrigerant flow through the evaporator channels; (ii) heat diffusion in the evaporator plate; and (iii) heat transmission to the refrigerated cabinet. Empirical correlations were also required to estimate the shear stresses, and the internal and external heat transfer rates. The governing partial differential equations were discretized through the finite-volume approach and the resulting set of algebraic equations was solved by successive iterations. Validation of the model against experimental steady-state data showed a reasonable level of agreement: the cabinet air temperature and the evaporator cooling capacity were predicted within error bands of \(\pm 1.5^\circ C\) and \(\pm 6\%\), respectively.

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Modèle de simulation numérique pour les évaporateurs à plaque et serpentin

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1. Introduction

Refrigerators and freezers are responsible for approximately 8.5% of energy consumption in Brazil (PROCEL, 1998). As the major part of this energy is wasted by the system components (compressor, condenser, evaporator, and capillary tube) due to irreversible processes, studies to understand such thermodynamic losses may lead to the development of higher efficiency products. Jakobsen (1995) quantified the thermodynamic losses in a 325-l refrigerator and investigated various means of energy optimization. He found that such losses occurred mainly in the hermetic compressor and in the

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evaporator, and also that the latter showed the best system/ component performance ratio, i.e., the highest system performance improvement with the lowest component-level investment.

In Brazil, the most widely used evaporator for household refrigerators is known as the plate-type, roll-bond evaporator. Basically, it consists of a plate formed by two powder-coated aluminum sheets, with channels in which the refrigerant evaporation takes place, while a buoyancy-driven air circulation occurs at the outer side. The combination of low cost and performance improvement with the lowest component-level investment.

In order to better understand this component performance, a research program has been conducted at the Federal University of Santa Catarina. Firstly, an experimental study on the heat and fluid flow in a roll-bond evaporator was carried out by Silva et al. (1999), who developed an in situ calorimeter test facility. Melo et al. (1998), based on the expertise gained by Silva et al. (1999), investigated alternative channel geometries, such as that shown in Fig. 1. Although this component was investigated experimentally, there is still a need for mathematical models for predicting its thermal behavior. Numerical simulation models for vapor compression systems have been developed since the early 1980s (Chi and Didion, 1982; Yasuda et al., 1983; MacArthur, 1984; Murphy and Goldschmidt, 1985, 1986; Sami et al., 1987; Jansen et al., 1988; Melo et al., 1988). At the beginning both heat exchangers (condenser and evaporator) were treated as even lumps. More recently (Gruhle and Isermann, 1985; Nyers and Stoyan, 1994; Jia et al., 1995; Judge and Radermacher, 1997; García-Valladares et al., 1998; Stevanvic and Jovanovic, 2000; Aprea and Reno, 2002) new modeling approaches were introduced that allowed a distributed simulation of the heat exchangers, but none of them are applicable to roll-bond evaporators.

The aim of the present study is to report on a numerical modeling approach for roll-bond evaporators similar to that shown in Fig. 1, which can be used for both steady-state and transient simulations. In order to supply the proper boundary conditions to the evaporator model, the refrigerated cabinet illustrated in Fig. 2 was also taken into account.

2. Mathematical modeling

The mathematical model proposed in this study was divided into three sub-models: (i) the evaporator channels, (ii) the
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