

available at [www.sciencedirect.com](http://www.sciencedirect.com)journal homepage: [www.elsevier.com/locate/ijrefrig](http://www.elsevier.com/locate/ijrefrig)

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

Christian J.L. Hermes<sup>a,\*</sup>, Cláudio Melo<sup>a</sup>, Cezar O.R. Negrão<sup>b,1</sup>

<sup>a</sup>POLO Research Laboratories for Emerging Technologies in Cooling and Thermophysics, Department of Mechanical Engineering, Federal University of Santa Catarina, 88040-970 Florianópolis, SC, Brazil

<sup>b</sup>Thermal Science Laboratory, Postgraduate Program in Mechanical and Materials Engineering, Federal University of Technology – Paraná, Av. Sete de Setembro 3165, 80230-901 Curitiba, PR, Brazil

### ARTICLE INFO

#### Article history:

Received 18 November 2006

Received in revised form

19 April 2007

Published online 18 May 2007

#### Keywords:

Household refrigerator

Heat exchanger

Evaporator

Modelling

Experimentation

### 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  $\pm 1.5^\circ\text{C}$  and  $\pm 6\%$ , respectively.

© 2007 Elsevier Ltd and IIR. All rights reserved.

## Modèle de simulation numérique pour les évaporateurs à plaque et serpentin

Mots clés : Réfrigérateur domestique ; Échangeur de chaleur ; Évaporateur ; Modélisation ; Expérimentation

### 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

\* Corresponding author. Tel.: +55 48 3234 5691; fax: +55 48 3234 5166.

E-mail addresses: [hermes@polo.ufsc.br](mailto:hermes@polo.ufsc.br) (C.J.L. Hermes), [melo@polo.ufsc.br](mailto:melo@polo.ufsc.br) (C. Melo), [negrao@utfpr.edu.br](mailto:negrao@utfpr.edu.br) (C.O.R. Negrão).

<sup>1</sup> Tel.: +55 41 3310 4658; fax: +55 41 3310 4432.

## Nomenclature

### Symbols

$A$	channel cross-sectional area [m <sup>2</sup> ]
$A_k$	wall surface area [m <sup>2</sup> ]
$Bi$	Biot number ( $=hl/k_w$ ) [dimensionless]
$C_a$	thermal capacity of dry air [J K <sup>-1</sup> ]
$C'''$	thermal capacity per unit of volume [J m <sup>-3</sup> K <sup>-1</sup> ]
$d$	channel diameter [m]
$F$	view factor between surfaces [dimensionless]
$f$	Darcy's friction factor [dimensionless]
$G$	refrigerant mass flux ( $=\rho\vartheta$ ) [kg s <sup>-1</sup> m <sup>-2</sup> ]
$h$	specific enthalpy of the refrigerant [J kg <sup>-1</sup> ]
$h_o$	overall specific enthalpy of the refrigerant ( $=h + \vartheta^2/2$ ) [J kg <sup>-1</sup> ]
$h_e$	convective heat transfer coefficient between the evaporator surfaces and the cabinet air [W m <sup>-2</sup> K <sup>-1</sup> ]
$h_i$	convective heat transfer coefficient between the refrigerant and the channel walls [W m <sup>-2</sup> K <sup>-1</sup> ]
$J$	radiosity [W m <sup>-2</sup> ]
$K_g$	overall conductance of the gasket [W m <sup>-1</sup> K <sup>-1</sup> ]
$l$	thickness [m]
$m$	refrigerant mass flow rate [kg h <sup>-1</sup> ]
$p$	pressure [kPa]
$P_d$	sealed perimeter of the door [m]
$Pe$	Péclet number ( $=\vartheta d/\alpha$ ) [dimensionless]
$P_i$	inner perimeter of the channel [m]
$q_e$	convective heat flux between the evaporator surfaces and the cabinet air [ $=h_e(T_a - T_w)$ ] [W m <sup>-2</sup> ]
$q_i$	convective heat flux between the refrigerant and the channel walls [ $=h_i(T_w - T)$ ] [W m <sup>-2</sup> ]
$q_r$	radiative heat flux on the surfaces of the evaporator plate [ $=(q_{r,7} + q_{r,8})/2$ ] [W m <sup>-2</sup> ]

$t$	time [s]
$T$	refrigerant temperature [K]
$T_a$	air temperature within the refrigerated compartment [K]
$T_e$	environment air temperature [K]
$T_w$	evaporator surface temperature [K]
$U$	convection heat transfer coefficient between the air and the $k$ -th wall [W K <sup>-1</sup> ]
$w$	thickness of the evaporator plate [m]
$x$	dimensionless enthalpy [kJ kg <sup>-1</sup> ]

### Greek letters

$\alpha_w$	thermal diffusivity of the aluminum [m <sup>2</sup> s <sup>-1</sup> ]
$\alpha_k$	thermal diffusivity of the insulation [m <sup>2</sup> s <sup>-1</sup> ]
$\varepsilon$	surface emissivity [dimensionless]
$\sigma$	Stefan–Boltzman constant [W m <sup>-2</sup> K <sup>-4</sup> ]
$\rho$	specific mass of the refrigerant [kg m <sup>-3</sup> ]
$\theta$	generic temperature [K]
$\vartheta$	average flow velocity [m s <sup>-1</sup> ]
$\phi$	generic variable per unit of mass
$\tau_w$	shear stress on the channel wall ( $=fG\vartheta/8$ ) [Pa]
$\tau$	time constant [s]

### Subscripts

$k$	each of the nine cabinet internal surfaces (see Fig. 4)
$d$	advective flux through the downstream control surface
$u$	advective flux through the upstream control surface
$w$	evaporator wall

### Superscripts

*	value from the previous iteration
0	value from the previous time-step

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 reasonable performance – compared to plate-and-tube heat exchangers – has led to a steady increase of its application.

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 lumpers. More recently (Grühle and Isermann, 1985; Nyers and Stoyan, 1994; Jia et al., 1995; Judge and Radermacher, 1997; García-Valladares et al., 1998; Stevanovic 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

متن کامل مقاله

دریافت فوری ←

**ISI**Articles

مرجع مقالات تخصصی ایران

- ✓ امکان دانلود نسخه تمام متن مقالات انگلیسی
- ✓ امکان دانلود نسخه ترجمه شده مقالات
- ✓ پذیرش سفارش ترجمه تخصصی
- ✓ امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله
- ✓ امکان دانلود رایگان ۲ صفحه اول هر مقاله
- ✓ امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب
- ✓ دانلود فوری مقاله پس از پرداخت آنلاین
- ✓ پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات