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Global modeling of heat and mass transfers in spiral tubular absorber of a water–lithium bromide absorption chiller

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ABSTRACT

In this work, a simplified nonlinear coupled model and a simplified linear coupled model are examined in order to determine the model that better approaches the global mass and heat transfers during water vapor absorption by a falling film of LiBr solution in a spiral tubular absorber of an absorption chiller. The linear coupled model gives up analytical expressions that are used to determine overall heat and mass transfer coefficients from the experimental measurements taken at the inlet and outlet of absorber. These coupled overall transfer coefficients are used with the uncoupled ones that are deduced from the LMD method to determine the simulated absorption parameters along the absorber area. The comparison between the two models based essentially on the different parameters values at the inlet and the outlet of the absorber shows that nonlinear model approaches better experimental results. It shows also that the use of overall coupled transfer coefficients is not significant at low solution flow rates usually encountered in absorption chiller application and therefore the use of the overall transfer coefficients extracted from LMD method approaches well experimental data. The nonlinear model which is the approved model points up that the absorbed water vapor quantity and the overall effective mass transfer coefficient for the spiral tubular absorber increase with decreasing cooling water temperatures.

Modélisation globale des transferts de chaleur et de masse dans l'absorbeur tubulaire en spirale d'un refroidisseur à bromure de lithium-eau

Mots clés : refroidisseur à absorption ; modèles linéaires et non linéaire ; coefficients de transfert ; transfert couple ; méthode de décomposition de la moyenne locale (LMD)

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Nomenclature

- a constant in equilibrium relation
- A absorber area (m^2)
- A_t total area of absorber (m^2)
- b coefficient in equilibrium relation (K^{-1})
- C_{pw} water thermal capacity ($J\ kg^{-1}\ K^{-1}$)
- C_s solution thermal capacity at constant LiBr fraction ($J\ kg^{-1}\ K^{-1}$)
- C_w enthalpy constant ($J\ kg^{-1}$)
- cd wall tube conductivity ($W\ m^{-1}\ K^{-1}$)
- d_t external tube diameter (m)
- h_0 thermal transfer coefficient from the liquid–vapor interface to bulk solution ($W\ m^{-2}\ K^{-1}$)
- h_{ab} absorption mass enthalpy ($J\ kg^{-1}$)
- h_{pv} partial water enthalpy at the liquid vapor interface ($J\ kg^{-1}$)
- h_s solution mass enthalpy ($J\ kg^{-1}$)
- h_w convective thermal transfer coefficient of cooling water ($W\ m^{-2}\ K^{-1}$)
- h_i thermal transfer coefficient from solution to the wall ($W\ m^{-2}\ K^{-1}$)
- h_v water vapor enthalpy at the interface ($J\ kg^{-1}$)
- K_{ef} effective mass transfer coefficient from interface to the solution ($m\ s^{-1}$)
- K_m mass transfer coefficient from interface to the solution ($m\ s^{-1}$)
- $M_{abs}{}^*$ total absorbed vapor mass flow ($kg\ s^{-1}$)
- M_l mass flow of pure LiBr ($kg\ s^{-1}$)
- M_w mass flow of cooling water ($kg\ s^{-1}$)
- m_{sv} absorbed vapor mass flow ($kg\ s^{-1}$)
- M_s solution mass flow ($kg\ s^{-1}$)
- L single tube length (m)
- T_{ev} evaporator temperature (°C)
- Q_{abs} absorption thermal power (W)
- Re_f film Reynolds number ($Re_f = M_s/\mu L$)
- T temperature (°C)
- U_{bw} effective heat transfer coefficient from solution to cooling water ($W\ m^{-2}\ K^{-1}$)

Greek symbols

- ρ density ($kg\ m^{-3}$)
- ω LiBr mass fraction
- θ temperature difference between solution and coolant
- μ dynamic viscosity of solution

Subscripts

- ex absorber exit
- 0 absorber inlet
- s solution
- sb solution bulk
- w cooling water
- m mean value
- if vapor–solution interface

1. Introduction

The modeling of coupled mass and heat transfers in the absorber of absorption cooling systems has been studied by several researchers in recent literature. Critical review of different modeling techniques was presented by Killion and Garimella (2001). There were a number of efforts to develop suitable models for designing absorber as heat and mass counter or cross current exchanger in both vertical and horizontal configurations. Van der Wekken and Wassenaar (1988) and Patnaik et al. (1993a) solved the heat and mass transfer equations describing the water vapor absorption in a laminar falling film. Andberg and Vliet (1987) and many other authors developed simplified models for falling film absorbers. Yuksel and Shlender (1987a,b) studied the variation of heat and mass transfer coefficients in a falling film of an aqueous Libr solution. Their work highlighted the importance of coupling between mass and heat transfers at the liquid vapor interface. The mass and heat transfer simulation in the absorber are performed using physical models with varying complexity (Killion and Garimella, 2001). The numerical models in which the conservation equations of mass, momentum and energy are solved simultaneously were the most detailed and treated (Van der Wekken and Wassenaar, 1988). The formulations that follow the traditional analysis of mass and heat exchangers require overall mass and heat transfer coefficients data for falling film. The experimental data analysis to determine these coefficients was mainly based on the LMD method approach (logarithmic mean difference) (Islam et al., 2006; Nosoko et al., 2002; Ruander and Vinod, 2011; Lee et al., 2012; Harikrishnan et al., 2011). The results obtained by this method often differ from one author to another (Islam et al., 2002). The object of this work is to exploit the nonlinear coupled model and the linear coupled model presented by Islam et al. (2002) to describe the global absorption kinetic using overall effective mass and heat transfer coefficients in a spiral tubular absorber treated as a vertical flat plate and to determine the model that approaches better the experimental data. These overall mass and heat transfer coefficients are determined using analytical expressions derived from the linear model which take in to account of mass and heat transfer coupling effect or using the LMD formulation that does not take in to account of this effect.

2. Presentation of the absorption chiller

The chiller is a double effect absorption refrigerating machine with double condensers in parallel mode flow (Fig. 1).

It uses LiBr–H_2O as working couple and gas as fuel supplying the high temperature generator (GHT). The functioning principle is described by the diagram given in Fig. 2.

The refrigerant in liquid phase (distilled water) leaves the condenser to the evaporator through an expansion valve. A rapid vaporization takes place using the heat provided by the cooling water. The refrigerant vapor thus produced, passes through the absorber where it is absorbed by the LiBr poor solution. The obtained dilute solution is divided on tow fluxes. One flux feeds the high temperature generator (GHT),