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ELSEVIER International Communications in Heat and Mass Transfer 32 (2005) 1253–1265

International Communications in HEAT and MASS TRANSFER

www.elsevier.com/locate/ichmt

Characteristics of heat and mass transfer in vapor absorption of falling film flow on a horizontal tube☆

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Available online 8 June 2005

Abstract

The absorber is an important component in absorption machines and its characteristics have significant effects on the overall efficiency of absorption machines. This article reports on the results of numerical studies on the characteristics of falling film LiBr–H_2O solution on a completely wetted horizontal tube and the associated vapor absorption in the Reynolds number range of $5<Re<100$. The boundary layer assumptions are used for the transport of mass, momentum and energy equations and the finite difference method is employed to solve the governing equations in the film flow. The heat and mass transfer coefficients are expressed in the forms of Reynolds number, Prandtl number and Schmidt number, at the usual absorber pressure and inlet solution concentration. The results can be used as a reference in designing actual absorption chiller.

Keywords: Absorption; Heat and mass transfer; Falling film; Horizontal tube

1. Introduction

Absorption of vapor into liquid films is encountered in many applications. One of the most considerable one is the process occurred in the absorber of absorption chillers. In the absorber, the water vapor produced by the evaporator is absorbed by a concentrated lithium bromide solution

☆ Communicated by J. Taine and A. Soufiani.

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doi:10.1016/j.icheatmasstransfer.2005.05.011

flowing over cooled horizontal tubes. The absorption of vapor at the interface of the liquid film is an exothermic process, so, the coolant water flowing into the tubes removes the excess heat from the film.

The combined heat and mass transfer process over horizontal tubes does not lend itself easily to mathematical analysis. Most of the published literature deals with modeling the absorption process in a laminar film flowing down an inclined plane.

The first model that attempted to solve a complete formulation of this problem was published by Grigoreva and Nakoryakov [1]. A series solution was used to solve the governing partial differential equations. After that they used similarity solution to the previous problem in a second paper [2]. Grossman [3,4] carried out theoretical analysis to calculate the absorption of gases in both laminar and turbulent liquid film. He also considered the effect of non-absorbable gases on the combined heat and mass transfer process in another paper [5]. A detailed theoretical model was developed for the film, taking into consideration the bulk movements in the vapor and liquid phases in the direction perpendicular to the molar flux due to concentration gradients in the absorbent and the vapor.

Andberg and Vliet [6] presented a simplified model for absorption of vapor into liquid films flowing over cooled horizontal tubes with the aid of boundary layer assumptions for transport of mass, momentum and energy. Choudhary [7] developed a finite difference method based on boundary layer assumptions and the method of contour lines and profiles for various conditions and studied the effect of some parameters on the heat and mass transfer process.

Several experimental studies have been performed for absorption of water vapor into an aqueous lithium bromide solution. Cosenza and Vliet [8] presented heat transfer coefficient in terms of film Nusselt number as a function of film Reynolds number. Deng and Ma [9] reported the results of experimental studies on the characteristics of a falling film absorber made up of 24 row horizontal smooth tubes. The results show that while the mass transfer coefficient is increased as the spray density increases, the heat transfer coefficient is increased only in small spray density range. Kyung and Herold [10] studied the effect of absorber inlet sub-cooling, solution flow rate, mass fraction and concentration of additives on heat transfer coefficient.

Finally, Killion and Garimella [11] provided a comprehensive review of the significant efforts that researchers have made to mathematically model the coupled heat and mass transfer phenomena that occur during falling film absorption. Their extensive review of the previous works did not revealed any analytical relationships for modeling the falling film absorption over horizontal tubes.

In the previous numerical works, the heat and mass transfer phenomena studied qualitatively based on some flow inlet conditions. Also, because the falling film flow over horizontal tubes is a difficult matter to be studied experimentally due to very thin film structure, the experiments were performed under certain and limited flow conditions by each researchers different from the others. Therefore most of the results of the previous works could not be used in analytical procedures by design engineers.

The main object of this study is to model the heat and mass transfer phenomena by the well known dimensionless numbers which could be used easily in analytical procedures. Therefore, the heat and mass transfer relationships are extracted from the numerical procedure, based on the flow fundamental and well-known parameters which are Reynolds, Prandtl and Schmidt numbers. The boundary layer assumptions were used for calculating the heat and mass transfer coefficients. The finite difference method is employed for solving the governing equations.