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# Theoretical evaluation of absorption and desorption processes under typical conditions for chillers and heat transformers

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ABSTRACT

A comparison of absorption and desorption is conducted using a detailed model describing heat and mass transfer. First, the influences of various assumptions have been evaluated. Second, typical conditions for both absorption chillers and heat transformers have been defined. The performance of absorption and desorption processes have been analysed for a flow length of 0.1 m. In an absorption chiller, during desorption, the viscosity is lowered and the mass diffusivity is increased. These circumstances cause a 46% higher transfer rate as compared to absorption. Thus, the overall performance of the process is determined by the absorber component. In a heat transformer, during absorption at an elevated pressure and temperature level, the viscosity is lower and mass diffusivity is higher as compared to desorption. Therefore, the transfer rate of during absorption is 10% higher as compared to desorption. Hence, the desorber performance is somewhat more influential to the overall system performance.



# Evaluation théorique des processus d'absorption et désorption sous des conditions caractéristiques pour des refroidisseurs et des transformateurs de chaleur

*Mots clés :* Absorption ; Désorption ; Données de propriété ; Diffusion unidirectionnelle ; Transfert de chaleur ; Transfert de masse

## 1. Introduction

According to Killion and Garimella (2001) the absorber is the most critical part in an absorption chiller, both in terms of cycle performance and system cost. In this article we would like to shed some light on the reasons and illustrate circumstances under which a desorber becomes the more restrictive component in an absorption cycle. Therefore, we compare the absorption process with the desorption process under typical

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**Nomenclature**

| | |
|---|---|
| $c_p$ | heat capacity (J kg$^{-1}$ K$^{-1}$) |
| $D$ | mass diffusivity (m$^2$ s$^{-1}$) |
| $g$ | gravitational acceleration (m s$^{-2}$) |
| $h$ | enthalpy (J kg$^{-1}$) |
| $\bar{h}$ | partial massive enthalpy (J kg$^{-1}$) |
| $\dot{m}$ | mass flux (kg m$^{-2}$ s$^{-1}$) |
| $p$ | pressure (Pa) |
| $\dot{q}$ | heat flux (W m$^{-2}$) |
| $T$ | temperature (K) |
| $u$ | longitudinal velocity (m s$^{-1}$) |
| $v$ | transversal velocity (m s$^{-1}$) |
| $x$ | longitudinal coordinate, streamwise (m) |
| $y$ | transversal coordinate (m) |

*Greek letters*

| | |
|---|---|
| $\dot{\Gamma}$ | mass flow per unit length (kg m$^{-1}$ s$^{-1}$) |
| $\Delta h_{sor}$ | heat of sorption (J kg$^{-1}$) |
| $\delta$ | film thickness (m) |
| $\lambda$ | thermal conductivity (W m$^{-1}$ K$^{-1}$) |
| $\mu$ | dynamic viscosity (Pa s) |
| $\xi$ | mass fraction (–) |
| $\rho$ | density (kg m$^{-3}$) |

*Subscripts*

| | |
|---|---|
| $_0$ | inlet condition |
| $_{abs}$ | absorption |
| $_{avg}$ | average |
| $_A$ | absorbate e.g. water in liquid state |
| $_{des}$ | desorption |
| $_{eq}$ | equilibrium |
| $_{if}$ | interface |
| $_S$ | solution of absorbent e.g. LiBr–$H_2O$ |
| $_V$ | vapour e.g. steam |
| $_W$ | wall |

conditions for both absorption chillers and heat transformers. We also investigate which typical simplifications and assumptions have an impact and should not be applied any more.

Falling films are often used in absorption chillers and heat pumps. The liquid solution is spread over horizontal tubes and droplets detached from one tube fall on subsequent ones. However, even if the real behaviour may cause local turbulences, most authors simplify the problem and assume a laminar flow regime over an inclined plate. Sometimes the hydrodynamic behaviour is simplified to a fully developed laminar flow starting the inlet of the film. Furthermore, properties are held constant, two-directional diffusion or a constant film thickness is assumed. However, when these common assumptions are relaxed the hydrodynamics are linked to heat and mass transfer even in a laminar film. The link is caused by occurring interactions among a changing film thickness, uni-directional diffusion and a change in properties. In the model which is used to conduct this study, most common assumptions, such as constant property data and constant film thickness, have been cancelled. Still we assume a laminar falling film in order to only investigate said effects for absorption and desorption on a sound basis for further, more applied studies.

## 2. State of the art

Analytical models usually assume constant properties (Kim and Infante Ferreira, 2009) or simplified hydrodynamics (Meyer, 2015). The authors of early numerical models such as Grossman (1983) and Yang and Wood (1992), for example, also assumed constant properties and a constant film thickness. Brauner (1991) could show the convective term at the free interface ought to be accounted for. However, from the activities summarised by Killion and Garimella (2001) one can see that most authors neglected transversal velocity components. In latest numerical studies distinct details have been investigated. Karami and Farhanieh (2011) studied the effect of film flow rate and plate angle on the heat and mass transfer. They concluded that at plate angles between 85° and 90° mass and heat transfer exhibit the highest values. Hofmann and Kuhlmann (2012) accounted for uni-directional diffusion and found an optimal Reynolds number for the absorption process, which can be interpreted as an optimal film thickness. Some authors focus on detailed hydrodynamic phenomena such as droplets and solitary waves. Islam et al. (2009) investigated the effects of solitary waves using a finite difference approach. They showed that solitary waves produce recirculation in the fluid and this recirculation moves the cool solution to the interface and thus enhances absorption. Albert et al. (2014) also examined the influence of wave regimes on mass transfer using a VOF method. They investigated vortices and recirculation and found that the former is irrelevant with respect to mass transfer enhancement, but the latter significantly determines mass transfer rates into the liquid film. Killion and Garimella (2004) conducted a 3-D simulation of the hydrodynamics of a liquid falling film over horizontal tubes. Their visual comparison of the simulation with an experiment shows that the model can predict the fluid behaviour. Based on this, a fully coupled model incorporating 3-D fluid flow with heat and mass transfer was developed by Subramaniam and Garimella (2009) to resolve the respective transfer phenomena on a local level, both on the horizontal tube and in the inter-tube region. They provide local gradients and transfer rates, and their spatial and temporal variations in the film and inter-tube regions.

Although many details have been investigated, a comprehensive comparison between absorption and desorption is missing. Therefore, this paper is focussed on the comparison of these two processes for both absorption heat pumps and heat transformers. Since the definitions of heat transfer coefficients in literature are ambiguous as reported in Kim and Infante Ferreira (2009), the evaluation of absorption and desorption is based on the mass fluxes transferred at the liquid vapour interface.