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Optimization of a compact falling-droplet absorber for cooling power generation

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Abstract

Refrigeration has become a necessary component for comfort living. Absorption refrigeration is a valid option for waste-heat-to cool conversion. Coupling this technology with cheap heat energy sources is an interesting prospect, however downsizing of this type or chiller for small environments has been proven difficult, especially regarding the absorber. Large interface area between the two operating fluids returns higher absorption rates, but lack of control on the fluid distribution results in an inefficient use of the space available. This study proposes a space-efficient design based on finned-plate technology coupled with a droplet flow regime. Manufacturing through 3D printing technique is used to study the effect of fins shape. Droplet behaviour is firstly studied with an analytical model based on the variational approach. Experimental results were obtained using a high speed camera employed to validate the analytical results and obtain qualitative and quantitative data to complete the analysis. The results show that the analytical model reproduces with sufficient accuracy the droplet dynamics in some regions. The rhomboidal geometry with 120° angle proved able to produce the smallest droplets without allowing merging of more droplets, ensuring the maintenance of droplet flow. Disturbances in the droplet profiles were observed, caused by the pin-droplet interaction. Further study is required to refine the model (to account for these disturbances) and obtain a more precise prediction of the droplet sizes.

Keywords: Refrigeration; Absorption; Absorber; Droplet Flow; Fluid Dynamics

1. Introduction

The next years will see a great increase in demand for cooling, which might reach a value ten times higher than the current one by 2050 according to Isaac and Van Vuuren (2009).

Heat-driven cooling systems might help reduce the potential stress on electricity usage, especially if the driving force can be provided by cheap solar energy (Kim and Infante Ferreira, 2008) or waste heat (Ammar et al., 2012). In this field many options are available, but absorption refrigeration is one of the main technologies for effective low-grade heat-to-cool conversion (Little and Garimella, 2011), thanks to its direct heat-to-cool conversion (Cola et al., 2016). However, implementation of absorption refrigeration in fields such as domestic and automotive air-conditioning is hindered by the large footprint of this chiller. A few attempts have been made at developing a small scale chiller, such as the device of Determan and Garimella (2012). The main obstacle to face in this regard is the absorber downsizing (Killion and Garimella, 2001). Extensive research has been focusing on how to improve its performance and consequently reduce its size. Raisul Islam et al. (2003) used film inverting techniques, while flat fins by Mortazavi et al. (2015) and a herringbone structure by Bigham et al (2013) are notable examples of film perturbation strategies that can improve the solution mixing and cooling, and consequently the absorption process.

The use of an adiabatic absorber can allow for more diverse strategies. The efficacy of droplet and column flow for the solution has been assessed by Li et al. (2015) while the use of flat fan sheets of solution by use of a vee-jet nozzle has been studied by Palacios et al. (2009). The use of an adiabatic absorber does increase the contact area between refrigerant and solution, but this comes at the cost of reduced solution mixing.

The authors here propose a solution to solve the internal mixing issue while keeping the design flexibility of an adiabatic absorber. The absorber consists of a pin-finned plate coupled with a droplet flow regime (see Figure 1), which is shown to return a better absorption mass flux than a film flow regime, according to Ben Hafsia (2015).

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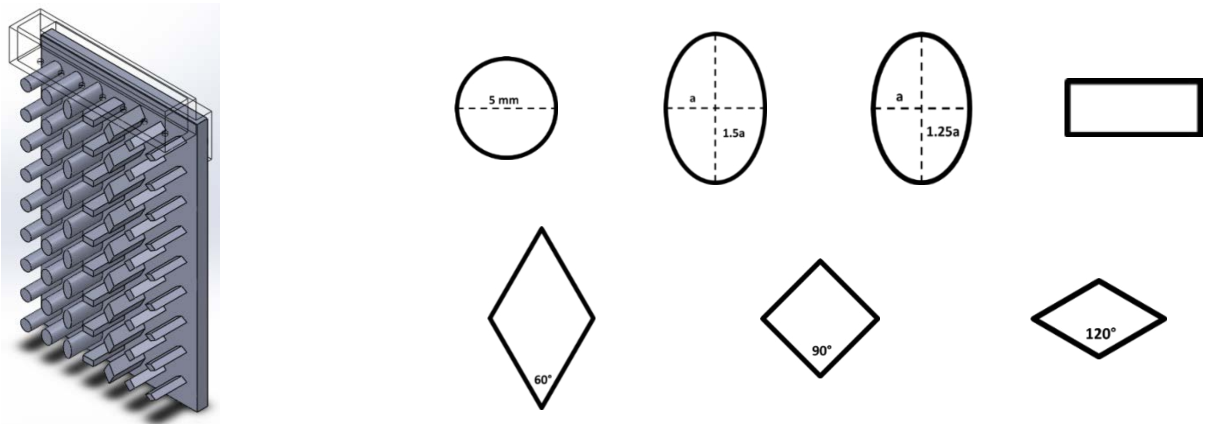

Figure 1: Design for new pin finned plate absorber and detail on pins geometry

This study deals with the shape analysis of the plate structure. In particular, shape of the pins is investigated from the point of view of droplet formation phenomena, in order to find the configuration that increases the contact area of the solution the most, by reducing the droplet size and by preventing droplet coalescence on the pins. In Figure 1 a summary of the cases investigated is given.

2. Theory and modelling

To ensure that the droplet flow regime is maintained, droplet formation at the pins bottom is studied. Specifically, it needs to be ensured that droplets are not merging; this translates to the requirement that the droplet formed at the pins be smaller than the one calculated using equation 1, where d is the diameter of the orifices generating the droplet flow, d_m the droplet diameter.

$$d_m/d = \left(3\pi/\sqrt{2}\right)^{1/3}(1+3Oh)^{1/6} \tag{1}$$

An analytical model is used, based on the variational approach previously employed by Pitts (1974) and Babu (1987). The model considers the balance between the surface tension force, the potential gravitational energy and the interfacial energy of the droplet (Figure 2). The droplet profile can then be calculated by finding the minimum of the droplet energy at constant volume. This translates into the Euler-Lagrange equation, which can be reformulated into the following system of differential equations:

$$dX/dS = \cos\phi \qquad dZ/dS = sin\phi \tag{2}$$

$$d\theta/dS + \sin\phi/X = 2/B - Z \tag{3}$$

Where X and Z are the geometrical coordinates, S is the arc length and B the curvature radius at the droplet axes, after non-dimensionalization by multiplication of the respective dimensional variables by the factor C:

$$C = \sqrt{(\rho_d - \rho_L)g/\sigma} \tag{4}$$

Where ρ_d and ρ_L are the droplet and the surrounding fluid density respectively, and σ is the surface tension. The system of equations is then solved using the following boundary conditions and assuming fully wetted condition of the pins.