CFD simulation of the influence of contact angle in falling film heat exchangers

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Abstract

This works presents the influence of the contact angle in the flow behaviour and the wettability of falling film heat exchangers (FFHX) based on CFD unsteady simulations. Multiphase model simulations have been carried out in order to define the influence of the contact angle in the flow behaviour and the wetting area between the tube wall and the liquid phase.

Key words: *Absorption, H_2O-LiBr Absorber, Falling Film Heat Exchangers, CFD, Contact Angle, Wettability.*

1. Introduction

The uncertainty of the future related to the sources of energy supply, the cost of the energy and the need to reduce the carbon emissions have created in many companies the necessity of proposals to decrease the energy requirements [1]. In many processes the energy of the process is not re-used. In general, economically feasible waste heat recovery and revalorisation technologies have been limited primarily to medium-to-high temperature waste heat sources (> 250ºC). Emerging technologies will make possible to recover lower temperature waste heat sources, then allowing the reutilization and recycling of the energy source. Absorption Heat Transformers (AHT) are identified as especially suitable for this purpose because they are driven by thermal energy, upgrading the temperature of waste heat energy using only negligible quantities of electrical energy. AHTs will be theoretically able to recuperate and revalue mentioned low-exergy waste heat from industrial processes. AHTs uses low temperature waste heat in order to obtain half part of its capacity but at high quality, i.e. upgrading its temperature and become useful for using into the industry requirements, being capable of raising low heat temperatures (in the range of 70-100ºC) by 50 K, having a COP of 0,5 approximately [2][3].

Different fluid pairs (FP) are used in AHTs. [4]. This study will focus on the AHT system using Water – Lithium bromide (H_2O-LiBr) solutions with water as the refrigerant. Among all the components of the AHT cycle, the absorber has the largest size because the low heat and mass transfer coefficients of the fluid pair [5]. In addition, the Second Law of Thermodynamics indicates the most exergy destruction in AHT occur in the absorber due to the temperature difference between the absorber and the surroundings [6]–[8]. The present research work will focus on FFHX absorbers. In this kind of absorbers, the FP is introduced from the top in liquid state and falls by the effect of gravity, wetting the tube. Outside the solution water in vapour phase is located. The liquid mixture absorbs the water vapour and the heat generated in this process is absorbed by the water liquid that circulates through the interior of the tubes.

Many works analysing falling film absorbers performance have been presented in the last 30 years [9]–[14]. However, large discrepancies between heat and mass transfer coefficients are presented. It is pointed out that one of the main reasons of the difference is that the prediction of the wetting area is not taken into account in these coefficients calculations, which drastically affect to the absorber performance. The wetting area estimation may be done in different ways, such as theoretical studies, numerical studies and experimental studies. The present research work analyses the behaviour of the wettability of FFHXs through CFD models. The results of the models will be correlated in a test bench.

In this work, the preliminary results of numerical models of the influence of the contact angle in the wetting area and the flow behaviour of FFHXs tubes are presented

2. Numerical model

For the numerical simulations, the commercial software Ansys Fluent 17.1 based on the finite volume method has been used. The discretized equations have been linearized and solved in a first order implicit manner. Continuity and momentum have been discretized with second order upwind scheme. The Pressure-Implicit with Splitting of Operators (PISO) have been used to pressure correction. In this work, the influence of the contact angle on the flow behaviour and the wettability of the falling film tube have been analysed.

2.1 Computational model and boundary conditions

As we can see in Figure 1, the three dimensional model includes three tubes. In order to decrease the computational cost, the model is reduced to ¼ of the entire model because its symmetry. Geometry considerations and boundary conditions are listed in Table 1 and Table 2.

Table 1: Simulation geometry

Geometry	
1st tube diameter	12.7 mm
2nd and 3rd tubes diameter	15.9 mm
Tube pitch	35.8 mm

Table 2: Boundary conditions

Boundary Conditions	
Top wall	Pressure inlet
Bottom wall	Pressure outlet
Lateral walls	Symmetry
Solution inlet	Velocity inlet (0.011 m·s^{-1})
Tube walls	Wall
Outside wall	Pressure inlet
Inside wall	Symmetry

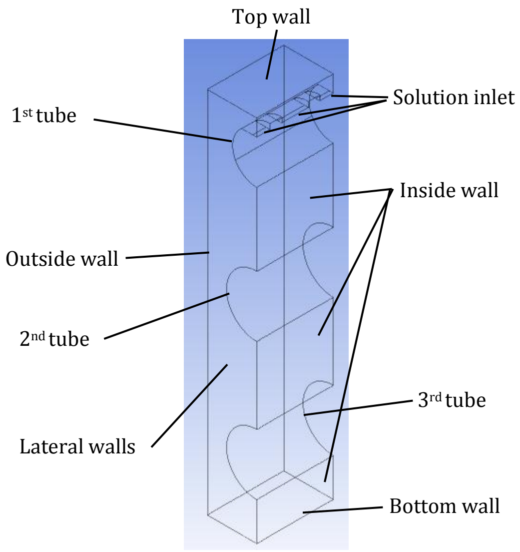

Figure 1: Geometry and boundary conditions

2.1. Assumptions and fluid properties

The following assumptions are made: 1) the thermophysical properties of each phase are constant 2) the temperature remains constant 3) there is no mass transfer between phases 4) the flow is incompressible and Newtonian 5) the flow is laminar 6) No slip condition in the wall 7) pressure remains constant at atmospheric pressure (p = 101325 Pa).

In these simulations, the gas phase is air and is considered at atmospheric pressure. The liquid phase is H_2O-LiBr and is considered as a single liquid with mixture properties (53,4 wt. % LiBr). The properties of the fluids are summarized in Table 3.

Table 3: Summary of properties at 25 °C [15]

	ρ (kg·m^{-3})	μ (kg·m^{-1}·s^{-1})	σ (N/m)
Air	1.225	1.7894·10^{-5}	
H_2O-LiBr	1564	4.1·10^{-3}	9.1·10^{-2}

In this preliminary work, two different contact angles between wall, gas phase and liquid phase have been analysed. These contact angles have been set to 20° and 95°.

2.2. Governing equations

Taking into account above assumptions, the continuity equation for 3D Cartesian coordinate system is:

$$\frac{\partial \rho}{\partial t} + \nabla(\rho \vec{v}) = 0 \qquad (1)$$

where ρ is the density of the fluid, t the time and $\vec{v}$ is the velocity vector.

The momentum equation is written as:

$$\frac{\partial}{\partial t}(\rho \vec{v}) + + \nabla(\rho \vec{v} \vec{v}) = -\nabla p + \nabla(\overline{\overline{\tau}}) + \rho \vec{g} + \vec{F} \qquad (2)$$

Where p is the static pressure, $\overline{\overline{\tau}}$ is the stress tensor and $\vec{F}$ and $\rho \vec{g}$ the external body forces and the gravitational body forces, respectively.

With the mentioned assumptions, the unique external body force that acts in the domain is the surface tension. The surface tension is a surface force, but is turned to a body force using the method of Brackbill *et al.* [16].

$$\vec{F} = \vec{F}_\sigma = \sigma \frac{\rho \kappa \nabla \alpha}{0.5(\rho_l + \rho_v)} \qquad (3)$$

Where σ is the surface tension coefficient, ρ the volume-averaged density, the subscripts l and v, stand for liquid phase (H_2O-LiBr solution) and vapour phase (air), respectively, κ is the interface curvature and $\nabla \alpha$ is a function ensuring that the force is only acting at the interface between both phases.

The tracking of interphase is achieved with the volume of fluid equation (VOF) with the Geometric Reconstruction scheme.

3. Results

Figure 2 shows the interphase of gas and liquid phases in time step = 1.6 s. In Figure 2a, the contact angle is 20° and in Figure 2b 95°. It can be seen that the flow behaviour and the wetting area are different in both cases, being wetting area drastically reduced when the solution is hydrophobic ($\theta > 90°$).

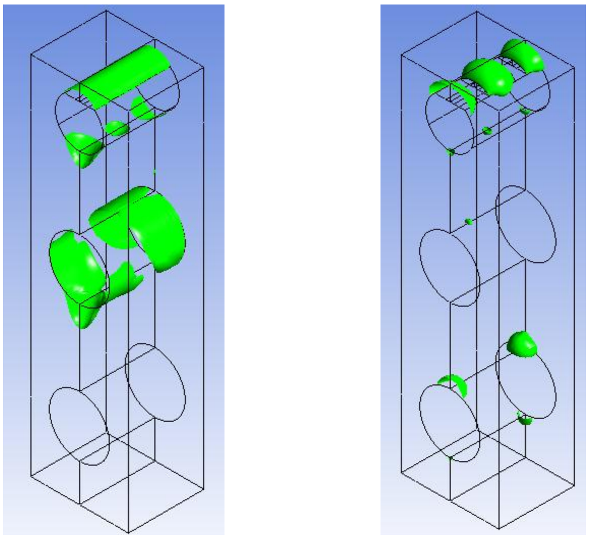

Figure 2: Interphase of both phases in t = 1.6 s with contact angle of a) 20°, b) 95°

This study is limited by the assumptions made, such as the absence of heat and mass transfer. A more in-depth analysis of the wettability with the addition of heat and mass transfer will be conducted in future studies based on these CFD models.

Acknowledgements

The author would like to thank the support of Mondragon Goi Eskola Politeknikoa and Tecnalia Research and Innovation

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