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Switching moving boundary models for two-phase flow evaporators and condensers

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ABSTRACT

The moving boundary method is an appealing approach for the design, testing and validation of advanced control schemes for evaporators and condensers. When it comes to advanced control strategies, not only accurate but fast dynamic models are required. Moving boundary models are fast low-order dynamic models, and they can describe the dynamic behavior with high accuracy. This paper presents a mathematical formulation based on physical principles for two-phase flow moving boundary evaporator and condenser models which support dynamic switching between all possible flow configurations. The models were implemented in a library using the equation-based object-oriented Modelica language. Several integrity tests in steady-state and transient predictions together with stability tests verified the models. Experimental data from a direct steam generation parabolic-trough solar thermal power plant is used to validate and compare the developed moving boundary models against finite volume models.

1. Introduction

Heat Exchanger (HEs) play a very important role in industry. Reliable control systems are required to efficiently manage HEs. The model of the system acquires more relevance when considering advanced control strategies, not only accurate but fast dynamic models are required, e.g. model-based control. Indeed, in the context of real-time simulation, dynamic system optimization and design of advanced control schemes, where fast computation is required, the moving boundary method seems to be appropriate.

Common computational fluid dynamics techniques and their counterparts in heat exchange modeling are the finite-volume distributed-parameter method [1] and the moving-boundary lumped-parameter method [2]. Moving boundary models (MBMs) are low-order and much faster models than finite volume models [3–5]. Additionally, they can describe the dynamic behavior of evaporators and condensers with high accuracy [5].

The moving boundary method divides the evaporator in different regions, also called Control Volume (CVs), depending on the fluid phase. These regions are: subcooled liquid (SC), two-phase flow (TP) and superheated steam (SH). They are represented by Fig. 1(a)–(c) respectively. In each CV, the lumped thermodynamic properties are average; the barrier is not fixed and it may move between adjacent CVs. Considering these three basic flow regions, compounded configuration can be

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Nomenclature

A	cross-sectional area
c_p	specific heat capacity
d	diameter
h	specific enthalpy
l	length
$\dot{m}$	mass flow rate
p	pressure
$\dot{Q}$	heat flow rate
$\dot{q}$	heat flux per length
S	surface area
T	temperature
t	time
u	specific internal energy
x	static quality
z	horizontal spatial coordinate

Greek symbols

ϵ_r	percentage relative error
γ	void fraction
ρ	density
ε	emissivity

Superscripts

χ'	χ of saturated liquid
χ''	χ of saturated vapor
$\bar{\chi}$	mean χ value

Subscripts

a	left boundary
amb	ambient
ap	aperture
b	right boundary
he	heat exchanger
i	inner
in	inlet
o	outer
out	outlet
ptc	parabolic-trough collector
sc	subcooled liquid
sh	superheated vapor
tol	tolerance
tp	two-phase flow
w	pipe wall

created. In Table 1, general, flooded and dry evaporator and condenser configurations are enumerated. Their corresponding representations are shown in Fig. 2.

Outstanding MBM reviews for two-phase flow HEs are presented in [6,7]. Dynamic switching between different configurations is an important aspect when developing MBMs, because switching between two different configurations implies that during the simulation the model must represent both configurations. The main problem that the modeler faces is that different configurations can have different number/type of equations or variables, thus leading to a variable-structure model.

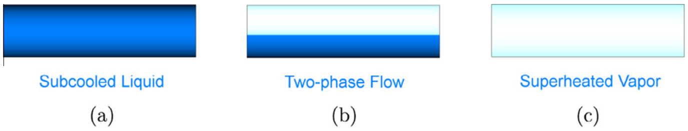

Fig. 1. Basic flow states.