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A novel special distributed method for dynamic refrigeration system simulation

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Abstract

A novel dynamic mathematical model based on spatially distributed approach has been developed and validated in this paper. This model gives good agreement in predicting the system COP and other parameters. The validated model has been used to enhance the prediction of the micro variations of superheat and sub-cooling. The novel spatial distributed model for the condenser and evaporator in refrigeration system, calculates the two-phase region in gas and liquid field separately since the gas and liquid in the two-phase region have different velocities. Previous researchers have used a pre-defined function of the void fraction in their spatially distributed model, based on experimental results. This approach results in the separate solution of the mass and energy equations, and less calculation is required. However, it is recognized that the mass and energy equations should be coupled during solving for more accurate solution. Based on the energy and mass balance, the spatial distribution model constructed here solves the velocity, pressure, refrigerant temperature, and wall temperature functions in heat exchangers simultaneously. A novel iteration method is developed and reduces the intensive calculations required. Furthermore, the condenser and evaporator models have shown a parametric distribution along the heat exchanger surface, therefore, the spatial distribution parameters in the two heat exchangers can be visualised numerically with a two-phase moving interface clearly shown.

Keywords: Refrigeration; Condenser; Evaporator; Two-phase flow; Superheating; Subcooling; Modelling; Heat transfer; COP

Simulation dynamique d'un système frigorifique à l'aide d'une nouvelle méthode distribuée

Mots clés : Réfrigération ; Condenseur ; Évaporateur ; Écoulement diphasique ; Surchauffe ; Sous-refroidissement ; Modélisation ; Transfert de chaleur ; COP

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Nomenclature

A	area (m^2)
C	specific heat ($kJ\,kg^{-1}\,K^{-1}$)
D	diameter (m)
F	force (N)
G	refrigerant mass flow flux ($kg\,m^{-2}\,s^{-1}$)
g	gravity constant ($m^2\,s^{-1}$)
h	enthalpy ($J\,kg^{-1}$)
i	control variable in a loop
L	length (m)
$\dot{m}$	mass flow rate ($kg\,s^{-1}$)
Q	heat flux ($W\,m^{-2}$)
P	pressure (Pa)
R	gas constant ($J\,kg^{-1}\,K^{-1}$)
Re	Reynolds number
r	radius (m)
T	temperature (K)
T_r	reduced temperature
t	temperature (°C)
T_f	heat transfer fluid temperature (K)
U	overall heat transfer coefficient ($W\,m^{-2}\,K^{-1}$)
VV	volume (m^3)
v	specific volume ($m^3\,kg^{-1}$)
W	velocity ($m\,s^{-1}$)
x	coordinate (m)
X	dryness fraction
Xdif	the cell coordinate (m)
Xcv	the cell interface coordinate (m)
Y	the displacement of the spring in TEV
Greek symbols	
α	heat transfer coefficient ($W\,m^{-2}\,K^{-1}$)
ρ	density ($kg\,m^{-3}$)
λ	thermal conductivity ($W\,m^{-1}\,K^{-1}$)
η_f	fin effectiveness
τ	time (s)
Ψ	void fraction
ϖ	wetted perimeter (m)
Suffix	
Cr	refrigerant side
w	wall
ca	air side
tp	two-phase region
cond	condenser
tev	thermal expansion valve
comp	compressor
sub	sub-cooling
evap	evaporator
sat	saturation or saturation point
f	heat transfer fluid
s	constant entropy process
g	gas
r	reduced parameters, refrigerant
i	inside
r3	the compressor outlet
L	liquid
r4	the condenser outlet or the TEV inlet
n	the nth iteration
r6	the evaporator outlet
o	outside
v	vapour
p	constant pressure

1. Introduction

Generally, in refrigeration system simulation, heat exchanger models dealing with unsteady compressible two-phase flow fall into one of two categories: the lumped parameter approach or the spatially distributed approach [3]. The lumped parameter model (LPM) divides the heat exchangers into mainly three regions, the superheated gas region, the two-phase region, and the sub-cooling region. In each region, average values are used to represent the parameters of the whole region. The spatial distributed parameter method considers the parameters in each region to vary. The complexity of the spatially distributed approach is much greater than the lumped parameter model. The main merit of the spatial model is that the parameter distribution over distance is detailed and the moving two-phase interface is clearly defined. Therefore, the heat exchange processes in the refrigeration system can be displayed numerically but also more precise results can be produced.

During transient operation, the refrigerant mass flow rate is continuously changing, which causes spatial variations in the refrigerant distribution in the system components as well as variable refrigerant states at the inlet and outlet of each component. It is seen that the mass distribution and other parameters within the heat exchangers are functions of time and space. Hence the spatially distributed model has been used by various researchers. The transient simulation of the refrigeration system was reviewed by a number of researchers and their key conclusions in relation to spatial distribution modelling is described below:

Chi and Didion [1] simulated an air-cooled system with moving refrigerant phase boundaries, with each phase region treated as a counter-flow heat exchanger. Refrigerant flow in both heat exchangers is one-dimensional and homogenous. Internal resistances of metallic components were neglected. A direct expansion evaporator for water-cooling was simulated by Yasuda et al.'s [9] model. The refrigerant in each phase in the two-phase region was treated using lumped parameters, while the superheated region was simulated using a finite difference approach. The method considers the heat transfer distribution within the evaporator tube material, secondary fluid and refrigerant phases. This approach was used