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Film condensation on a finite-size horizontal wavy plate bounded by a homogenous porous layer

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Abstract

Steady filmwise condensation on a finite-size horizontal wavy plate which covers a homogeneous porous medium layer filled with a dry saturated vapor has been investigated by boundary layer approximations. The dimensionless average Nusselt number $\overline{Nu}$ and dimensionless liquid film thickness on the wavy surface are evaluated as a function of seven parameters: Darcy number Da, Jacob number Ja, the wave number n, Prandtl number Pr, modified Rayleigh number Ra, suction parameter S_w and the wave amplitude α. It is shown that the condensation heat transfer coefficient can be enhanced by increasing the contact area of the condensate, which corresponds to increasing values of the wave number and amplitude of the wavy surface, and when suction exists at the condensate surface.

Keywords: Laminar filmwise condensation; Porous medium; Darcy model

1. Introduction

The film condensation problem was first investigated by Nusselt [1]. Nusselt's analysis for laminar film condensation was further developed over the years in [2–7]. In addition, the laminar film

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Nomenclature

C_p	specific heat at constant pressure, $\mathrm{J\,kg^{-1}\,K^{-1}}$
Da	Darcy number defined in Eq. (13), dimensionless
F	the non-dimensional wave amplitude defined in Eq. (13), dimensionless
g	acceleration of gravity, $\mathrm{m\,s^{-2}}$
h	heat transfer coefficient, $\mathrm{W\,m^{-2}\,K^{-1}}$
h_{fg}	latent heat of vaporization, $\mathrm{J\,kg^{-1}}$
Ja	Jacob number defined in Eq. (13), dimensionless
k_{a}	apparent thermal conductivity, $\mathrm{W\,m^{-1}\,K}$
K	intrinsic permeability of a porous, $\mathrm{m^2}$
L	half-length of a finite-size horizontal wavy plate, m
$\dot{m}_{\mathrm{c}}$	critical condensate mass flow rate defined in Eq. (10), $\mathrm{kg\,s^{-1}}$
n	the wave number, dimensionless
Nu	Nusselt number defined in Eq. (18), dimensionless
P	pressure, Pa ($\mathrm{N\,m^{-2}}$)
Pr	Prandtl number defined in Eq. (13), dimensionless
q	heat flux defined in Eq. (17), $\mathrm{W\,m^{-2}}$
Ra	Rayleigh number defined in Eq. (13), dimensionless
Re_{w}	Reynolds number at surface defined in Eq. (13), dimensionless
S_{w}	suction parameter at surface defined in Eq. (13), dimensionless
T	temperature of liquid film, K
ΔT	saturation temperature minus surface temperature, K
u	velocity in x-direction, $\mathrm{m\,s^{-1}}$
v	velocity in y-direction, $\mathrm{m\,s^{-1}}$
v_{w}	suction velocity at the plate surface, $\mathrm{m\,s^{-1}}$
x	horizontal coordinate axis, m
y	vertical coordinate axis, m

Greek symbols

α	the wave amplitude, m
δ_{L}	local liquid film thickness, m
η	dimensionless liquid film thickness defined by δ_{L}/L, dimensionless
Θ	a parameter is defined as $\Theta = h_{\mathrm{fg}} + C_p\Delta T/2$, $\mathrm{J\,kg^{-1}}$
ξ_1	a variable is defined as $\xi_1 = \eta$, dimensionless
ξ_2	a variable is defined as $\xi_2 = \eta'$, dimensionless
μ_{f}	viscosity of condensate, Pa s
ρ	density of condensate, $\mathrm{kg\,m^{-3}}$
σ_{w}	surface geometry function of the wavy plate defined in Eq. (1), m

Superscripts

*	indicates dimensionless quantity
–	indicates average quantity