SpringerBriefs in Applied Sciences and Technology

Thermal Engineering and Applied Science

Series editor

Francis A. Kulacki, University of Minnesota, Minneapolis, MN, USA

SpringerBriefs present concise summaries of cutting-edge research and practical applications across a wide spectrum of fields. Featuring compact volumes of 50 to 125 pages, the series covers a range of content from professional to academic.

Typical publications can be:

- A timely report of state-of-the art methods
- An introduction to or a manual for the application of mathematical or computer techniques
- A bridge between new research results, as published in journal articles
- A snapshot of a hot or emerging topic
- An in-depth case study
- A presentation of core concepts that students must understand in order to make independent contributions

SpringerBriefs are characterized by fast, global electronic dissemination, standard publishing contracts, standardized manuscript preparation and formatting guidelines, and expedited production schedules.

On the one hand, **SpringerBriefs in Applied Sciences and Technology** are devoted to the publication of fundamentals and applications within the different classical engineering disciplines as well as in interdisciplinary fields that recently emerged between these areas. On the other hand, as the boundary separating fundamental research and applied technology is more and more dissolving, this series is particularly open to trans-disciplinary topics between fundamental science and engineering.

Indexed by EI-Compendex, SCOPUS and Springerlink.

More information about this series at http://www.springer.com/series/8884

Yang Liu • Francis A. Kulacki

The Effect of Surface Wettability on the Defrost Process

Springer

Yang Liu
Graduate School at Shenzhen
Tsinghua University
Shenzchen, China

Francis A. Kulacki
Department of Mechanical Engineering
University of Minnesota
Minneapolis, MN, USA

ISSN 2191-530X ISSN 2191-5318 (electronic)
SpringerBriefs in Applied Sciences and Technology
ISSN 2193-2530 ISSN 2193-2549 (electronic)
SpringerBriefs in Thermal Engineering and Applied Science
ISBN 978-3-030-02615-8 ISBN 978-3-030-02616-5 (eBook)
https://doi.org/10.1007/978-3-030-02616-5

Library of Congress Control Number: 2018959755

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2019
This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
The publisher, the authors, and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

Frost formation and anti-icing methods have been investigated for decades. In refrigeration systems, a number of studies were focused on the influence of surface treatment in delaying the time of frost formation. There are far fewer studies on the effect of surface wettability on the defrost process. The literature contains experimental results on defrost time for different surfaces, but the results can be different based on individual experimental conditions.

In this monograph, the influence of surface wettability on the defrost process is investigated analytically and experimentally. The melting process is divided into three stages based on behaviors of the meltwater. Water saturation and meltwater draining velocity are formulated for the absorption and drainage stages separately. The melting rate, permeation rate, and draining velocity determine meltwater behaviors, which influence the defrost process and defrost mechanisms. Water accumulation at the surface decreases the adherence of the frost column to the surface, and thus, frost slumping is a potential method for frost removal. A slumping criterion is formulated based on the analysis of interfacial forces and the body force on the frost column. The slumping condition of the model depends on the contact angle on hydrophilic surfaces and the contact angle hysteresis on hydrophobic surfaces.

Experiments on frost and defrost process on vertical surfaces with different wetting conditions are conducted in a laboratory environment. The experiments show that defrost time and efficiency are determined by system design, surface heating method, heat flux applied at the surface, and surface wettability. Defrost mechanisms vary with surface wettability. During the defrost process, the frost column detaches from a superhydrophobic surface and falls off as a whole piece. While on the superhydrophilic and plain surfaces, the frost column melts, and the water film or retained water evaporates. Defrost time and efficiency are not significantly different on the test surfaces at the point that the frost melts and water film or retained droplets remain on the surface. However, defrost time and efficiency are improved noticeably on the superhydrophobic surface for a complete defrost process in which the water evaporation time is included.

This research serves as a supplement to current studies on the effect of surface wettability in refrigeration systems. In application, the choice of surface wettability factors depends on practical operation requirements and system design.

Shenzchen, China Yang Liu
Minneapolis, MN, USA Francis A. Kulacki

Contents

Nomenclature

b	Slip length (m)
bl	Gap between fins (m)
c_p	Specific heat at constant pressure (J kg^{-1} K^{-1})
g	Gravitational acceleration (m s^{-2})
h	Heat transfer coefficient (W m^{-2} K^{-1})
k	Thermal conductivity (W m^{-1} K^{-1})
m	Mass (kg)
m''	Mass flux (kg s^{-1} m^{-2})
p	Permeability power law constant
q	Capillary pressure power law constant
q''	Heat flux (W m^{-2})
r	Aspect ratio of the width to the length of the test surface
t	Time (s)
t^+	Dimensionless time
u	Velocity in x-direction (m s^{-1})
u^+	Dimensionless velocity
u_s	Slip velocity (m s^{-1})
u_B	Velocity at the water–permeation interface (m s^{-1})
v	Velocity in y-direction (m s^{-1})
x	Direction parallel to gravity (m)
x^+	Dimensionless location
y	Direction normal to the test surface (m)
v_b	Bulk flow rate (m s^{-1})
v_s	Slip velocity (m s^{-1})
A	Area (m^2)
Bi	Biot number, $\mathrm{hL_c/k}$
C	Entry capillary pressure (N m^{-2})
CAH	Contact angle hysteresis (°)
CFM	Cubic feet per minute

D	Diameter (m)
F	Force (N)
FR	Force ratio of gravity to surface tension
Fr	Froude number, u/(gl)$^{1/2}$
G	Gravity (N)
Gr	Grashof number
H	Height (m)
K	Permeability or intrinsic permeability (m^2)
L	Length (m)
L_f	Latent heat of fusion (kJ kg^{-1})
Nu	Nusselt number
P	Pressure (Pa)
P^+	Dimensionless pressure
P_ca	Capillary pressure
Pr	Prandtl number
Pwr	Power (W)
Q	Heat transfer (J)
T	Temperature (K)
U	Characteristic velocity (m s^{-1})
V	Volume (m^3)
W	Width (m)
Re	Reynolds number
R_th	Thermal resistance (W K^{-1})
S	Water saturation, the volume fraction of water to the pore volume

Greek Symbols

α	Thermal diffusivity (m^2 s^{-1})
β	Dimensionless parameter depending on the material
δ	Thickness (m)
ε	Porosity
η	Efficiency
θ	Contact angle (°)
Θ	Dimensionless temperature
ϕ	Slope angle (°)
ϕ	Relative humidity
μ	Dynamic viscosity (N s m^{-2})
μ_s	Average viscosity of the near-to-wall layer (N s m^{-2})
ρ	Density (kg m^{-3})
γ	Surface tension (J m^{-2} or N m^{-1})

τ	Shear stress (N m^{-2})
ω	Filtering velocity of water in the permeation layer (m s^{-1})
Ω	Volumetric flow rate (m^3 s^{-1})

Subscripts

0	Initial
a	Air
adv	Advancing
Al	Aluminum
avg	Average
b	Bulk
c	Cold
ca	Capillary
ch	Chamber
cond	Conduction
conv	Convection
d	Drain
df	Defrost
eff	Effective
f	Frost
g	Gas
h	Hot
i	Ice
in	Input
kp	Key point
lat	Latent
m	Melt
p	Permeation
rec	Receding
s	Surface
sat	Saturation
sen	Sensible
s-p	Solid–permeation interface
s-w	Solid–water interface
tot	Total
tp	Test plate
v	Vapor
w	Water
w-p	Interface at water film and permeation layer