International Journal of Heat and Mass Transfer 124 (2018) 586–614

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ijhmt

Review on the measurement and calculation of frost characteristics

Mengjie Song, Chaobin Dang *

Department of Human and Engineered Environmental Studies, Graduate School of Frontier Sciences, The University of Tokyo, Chiba, Japan

ARTICLE INFO

Article history:
Received 12 March 2018
Received in revised form 20 March 2018
Accepted 26 March 2018

Keywords:
Frost characteristics
Frost layer thickness
Measurement method
Modeling study
Correlation

ABSTRACT

As a common physical phenomenon, frost deposition is inevitable and always has significant negative effects on several industry fields, such as aerospace, aviation, and heating, ventilation, air conditioning, and refrigeration. To accurately predict and control a frosting–defrosting cycle, there is a need to understand the interrelated heat, mass, and momentum transport phenomena within the frost and at the air–frost interface, which is a moving boundary condition. Consequently, during the past several decades, there has been a continuous effort to advance the understanding and modeling of frost formation on cold surfaces on the basis of experimental, semi-empirical, theoretical, and numerical approaches. To provide an overview of the analytical tools for scholars, researchers, product developers, and policy designers, a review and a comparative analysis of the available literature on frosting characteristics, correlations, and mathematical models are presented in this study. The mechanisms of the frost formation process and its influence will be first introduced, followed by the presentation of methods for the measurement of the frost layer thickness and the frosting rate. Then, the frost characteristics, including the accumulation, the density, the thermal conductivity and morphology, and the heat and mass transfer coefficients, will be summarized. The existing gaps in the research works on frost will be identified, and recommendations will be offered as per the viewpoint of the present authors. Finally, the conclusions of this study will be given.

Contents

Abbreviations: ASHP, air source heat pump; CCD, digital charge coupled device; CFD, computational fluid dynamics; CG, crystal growth; COP, coefficient of performance; DBG, densification and bulk growth; DCA, dynamic contact angles; DWC, dropwise condensation; FEV, frosting evenness value; FLG, frost layer growth; FLFG, frost layer full growth; LNG, liquefied natural gas; RH, relative humidity; SPM, scanning probe microscope; STG, solidified liquid tip growth; TEPS, tube encircled photoelectric sensors.

* Corresponding author.
E-mail address: dangcb@k.u-tokyo.ac.jp (C. Dang).

https://doi.org/10.1016/j.ijheatmasstransfer.2018.03.094
0017-9310/© 2018 Published by Elsevier Ltd.

1. Introduction

Inevitably, frost will form and accumulate on the surface of evaporators under operating conditions in various freezers and refrigeration systems. Consequently, frost formation results in (1) a decrease in the heat transfer rate, and (2) the blockage of the air passage. Therefore, frost ultimately decreases the design capacity of the equipment that is rated for dry conditions. To maintain the operating efficiency of the refrigeration system at high levels, various defrosting devices along with their control strategies have been developed and experimentally investigated [1,2]. To accurately predict and control a defrosting cycle, the complex relations between the frost formation process and the operating conditions of the system should be first clarified, particularly the measurement of the characteristics of frost accumulation.

In past few decades, different studies on the frosting process at the frost media level and the system level have been widely reported. The correlations between the frost layer thickness, the frost thermal conductivity, and the heat transfer coefficient on the frosting surfaces were summarized by O'Neal and Tree [3] for the period between 1960 and 1980, and by Iragorry et al. [4] for the period between 1980 and 2000. After 2000, researchers published numerous studies on the accurate prediction or the measurement of the time-dependent frosting/defrosting process. Therefore, it is purposeful that the existing literature be summarized today. The present work will reflect the advances in the measurement of frost characteristics, formed on various types of plate surfaces and on the airside of heat exchangers, and will elucidate the future research needs.

1.1. Frost formation process

Frost deposition is inevitable once moist air is exposed to a cold surface, the temperature of which is below the water triple point and the air dew point [5]. To clearly understand the frosting mechanism, the published findings of an experimental study on frost formation phenomena on a flat plate surface are shown in Fig. 1 [6]. In this study, the frost formation process under forced convection was divided into three periods according to the growth timeline, namely (1) the crystal growth (CG) period, (2) the frost layer growth (FLG) period, and (3) the frost layer full growth (FLFG) period. As shown, the CG period started from a droplet-type crystal that evolved in a rod-type crystal. The ice crystals were far apart from each other and grew in the form of a vertical column [7,8]. Depending on the speed of the airflow, the pattern of the tip growth would be replaced by a tree-growth pattern or other patterns. The entire process of the frost branch formation was referred to as the FLG period when frost branches would form at the top of the ice crystals. These frost branches grew in three dimensions and connected to the neighboring frost branches, thus forming a flat

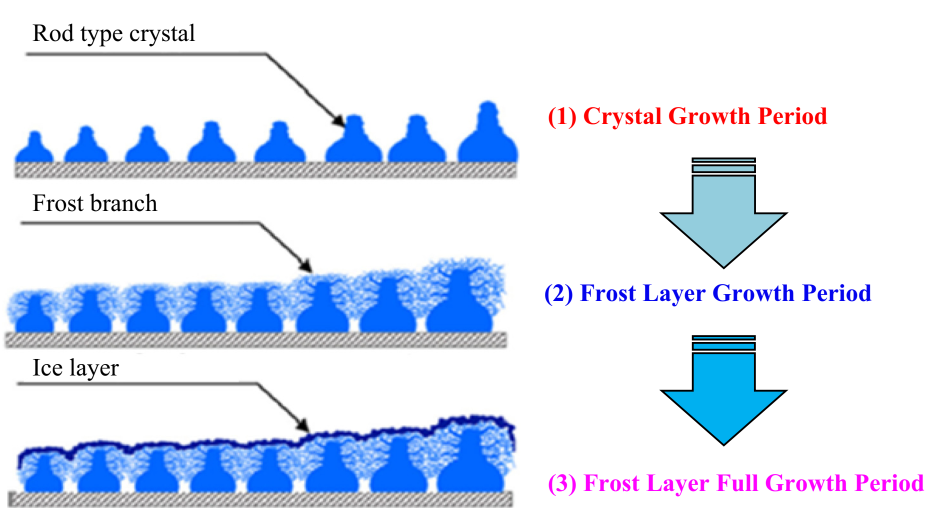

Fig. 1. Frost growth periods as defined by Hayashi et al. [6].