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Experimental investigation of frost formation on a horizontal cold cylinder under cross flow

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ABSTRACT

In the present work, frost formation on a horizontal cold cylinder was investigated experimentally. An apparatus was designed and carried out on a physical model which was included an air tunnel and a cold cylinder exposed to humid air flow. It was found that the frost layers formed on the front and rear surfaces of the cylinder were thicker than the top surfaces where the flow separation was nearly or wholly initiated. The effects of air flow parameters such as flow Reynolds number, entrained air temperature, absolute air humidity and temperature of cylinder surface on the frost thickness and density formed over the cylinder were studied. In this paper, the dew point temperature of the inlet air was above the freezing point and also the earlier transition time was investigated.

Etude expérimentale sur la formation de givre sur un cylindre horizontal refroidi avec un écoulement croisé

Mots clés : Écoulement croisé ; Formation de givre ; Cylindre horizontal ; Mesure ; Air humide ; Banc d'essai

1. Introduction

Frost formation is a common phenomenon in the industrial and household heat exchangers. The frost develops when a humid air comes into contact with a cooler surface then to its freezing point. The thermal performance of the heat exchanger shall somewhat improved at early stages of the frost formation due to heat transfer area, but with the passage of time, it deteriorates as the frost takes the role of thermal insulator between the cold surface and free air current.

Tao and Besant (1992) and K.S. Lee et al. (1997) suggested a one dimensional model for prediction of frost characteristic and to examine validity of proposed model; experiments over flat plate were done. Raju and Sherif (1993) presented a transient model to predict the frosting process over a cylinder in a cross flow of humid air. The boundary layer equations were

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Nomenclature

ρ	frost density (kg m^{-3})
$\forall$	frost volume (m^3)
δ	frost thickness (m)
m	frost weight (kg)
d	cylinder diameter (m)
l	evaporate length (m)

Subscripts

frost	frost
0,90,180,270	angular position from stagnation point

solved to obtain the local heat and mass transfer rate. Empirical correlations for thermal conductivity and density were utilized to solve for frost grow rate. The results had a high correlation with experimental data in the applicable temperature and humidity range of the density and conductivity correlations. Ismail et al. (1997) suggested a two-dimensional model which permitted the evaluation of the local properties during the frost formation. To determine the local coefficients of heat and mass transfer they solved the flow, temperature and humidity fields. To solve the flow field, the governing equations were developed in terms of the stream and vorticity functions. A numerical solution was obtained for low Reynolds number up to 400. Sengupta et al. (1998) reported on results of an experimental investigation where the emphasis was placed on obtaining empirical correlations for the frost thickness-time history and the heat transfer coefficient-time history for a cylinder in humid air cross flow. The correlation given by them was obtained for the following ranges of parameters: $26 < Nu < 72$, $1200 < Re < 3500$, $0.71 < Pr < 0.73$, $0.01 < w < 0.02$, and $126 < Fo < 1006$.

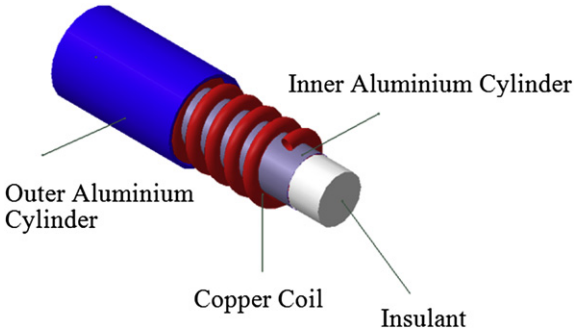

Fig. 2 – A 3-D views of evaporator.

Y.B. Lee and Ro (2001) preformed experiments over cold cylinder and kept the dew point below the triple point of water. Mago and Sherif (2003) proposed a semi-empirical model describing heat and mass transfer on a cylinder surface in humid air cross flow under supersaturated frosting conditions. They proposed some correlations which needs further experimental investigations. Na and Webb (2004) investigated a theoretically based numerical model at supersaturation condition on the frost surface with experiment over the flat plate. Yang and Lee (2004) and Kim et al. (2008) did experiments on the flat plate and cold cylinder and then expressed dimensionless correlations for frost properties in term of Reynolds number, Fourier number, absolute humidity, and dimensionless temperature. Kwon et al. (2006) also did experiments on the flat plate and developed an algorithm to analyze the results. Marandi et al. (2009) and Lenic et al. (2009) proposed a numerical approach for prediction of frost formation and for validating of the results; experiments over flat plate were preformed.

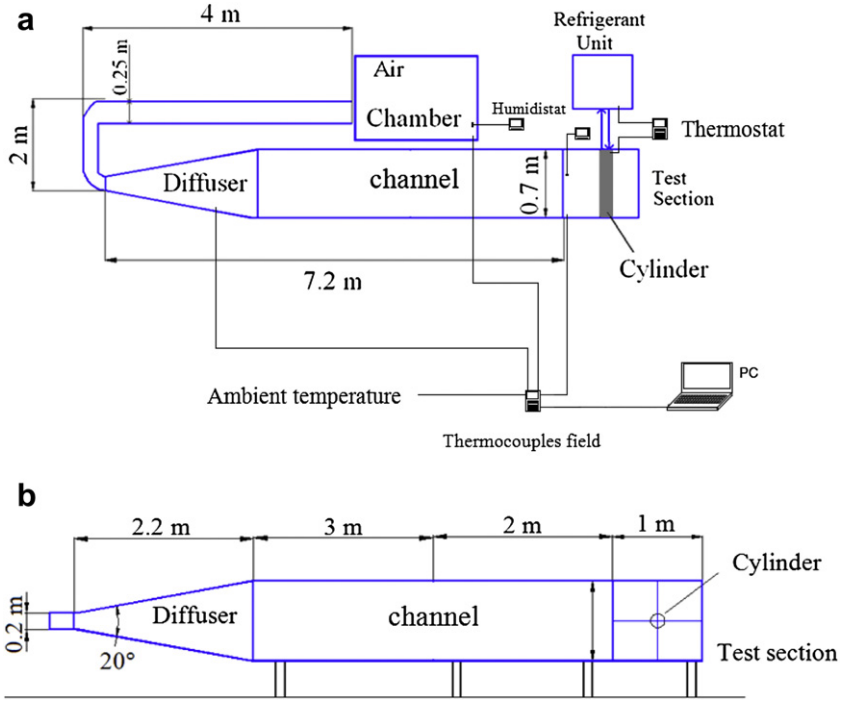

Fig. 1 – a) Plan view of the apparatus. b) Side view of the apparatus.