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Modeling and Experimental Study of Force Convection Frost Formation over a Curved Surface

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ABSTRACT: Frost formation has important effects in many fields, such as refrigeration industry, air-conditioning, aviation, etc. Frost develops when humid air contacts with a cold surface at its freezing water temperature. Frost formation is a complicated transient phenomenon in which a variety of heat and mass transfer mechanisms are taking place simultaneously. In this research formation of frost on horizontal cylinder in force convection conditions was investigated experimentally. An experimental system of frost formation on cold cylinder surface in a wind tunnel was used and the effects of cold surface temperature, air temperature, air velocity, and air relative humidity on the frost thickness and density were studied. Result shows that as relative humidity increased and surface temperature decreased, frost thickness increased and frost density decreased. In addition as air temperature increased and air velocity decreased, frost thickness and frost density decreased. Finally, a correlation presented based on obtained experimental data and effective parameters which have been shown.

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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 cold surface at its water freezing temperature [1]. This phenomenon improves the performance of heat exchangers due to the increase of surface of the heat transfer at the start of process. Nevertheless with the lapse of time, the frost acts as insulation causing a drop in heat transfer and performance of the system [2]. Frost action is a fundamental problem contributing to the instability of infrastructure embankments in regions of seasonal ground freezing, and often results in railway and highway engineering difficulties [3].

In this study experiments were conducted in four conditions to study the effects of various cylinder surface temperatures, entering air temperature, humidity, and Reynolds number on frost thickness over the cylinder. Tests were carried out with three cylinder temperatures ranging from -8.3 to -14.6 °C, three entering air temperatures of 15, 17 and 18 °C, three relative humidity values, 21, 27 and 36 percent and three flow velocity based on cylinder diameter (0, 0.3 and 0.6 meter per second). Finally, dimensionless correlation based on the experimental data for frost thickness is proposed.

2- Experimental Setup

Figs. 1 and 2 illustrate the system designed in this experiment. It consists of a test section, a channel with a large cross section, a diffuser, and a channel with small cross section connecting to air chamber that includes fan, heater, and humidifier.

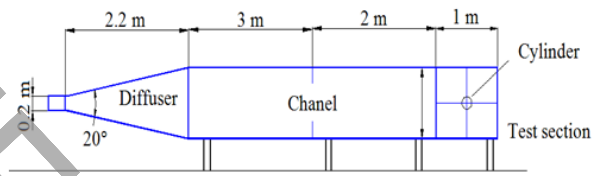

Fig. 1. Side view of the wind tunnel apparatus

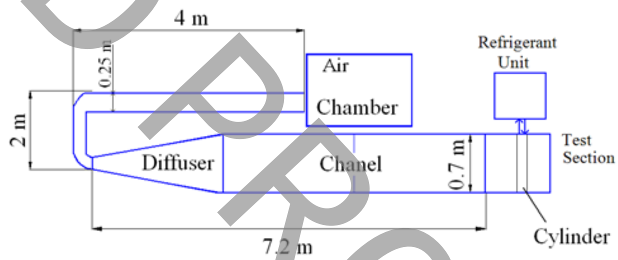

Fig. 2. Plan view of the wind tunnel apparatus

Cooling system includes a ¾ hp compressor functioning with R502 coolant. Evaporator is a cylinder, which measures 16 cm in outer diameter. The outer cylinder is Aluminum of thin plate, which measures 0.2 mm in thickness and covers the evaporator channel. The evaporator channel is a 36 m copper tube that was coiled and fitted around a hollow aluminum cylinder. The inner surface of the hollow cylinder is fully insulated.

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3- Results and Discussion

Figs. 3, 4 and 5 show frost thickness for different cylinder temperature, relative humidity and air temperature, respectively. As could be seen in Fig. 3, cylinder temperature decreases, frost thickness increases because of mass and temperature potential increase.

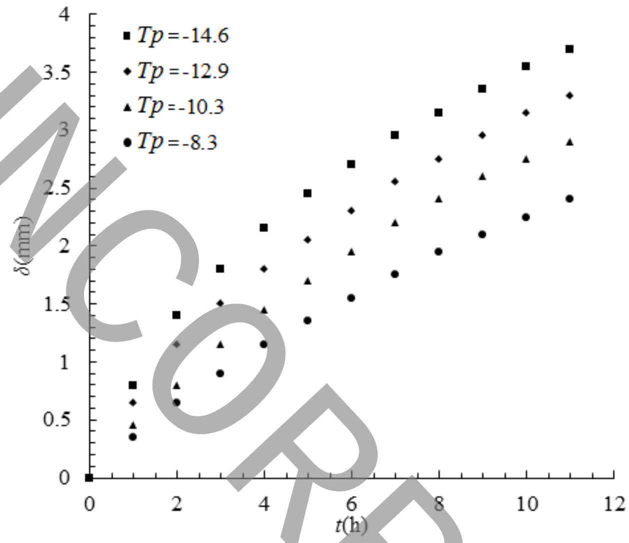

Fig. 3. Frost thickness on top of cylinder at T_a=17°C, *Φ*=36% and *u*=0.6 m/s

According to Fig. 4, as relative humidity increases, frost thickness increases.

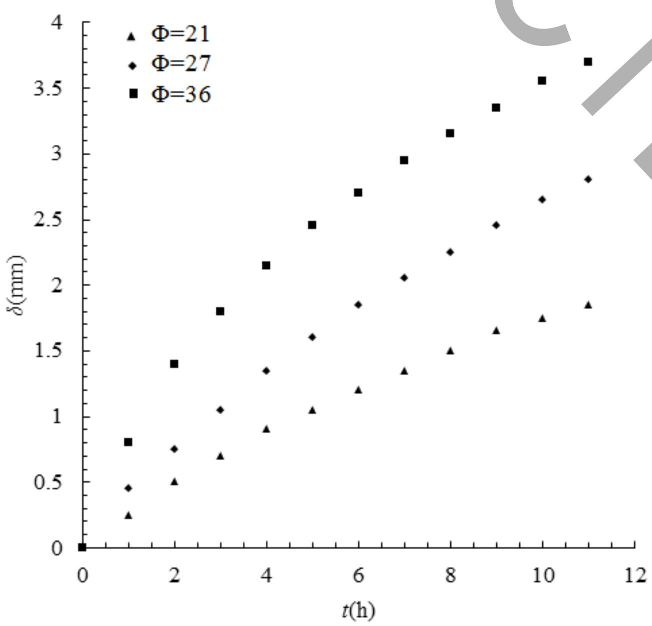

Fig. 4. Frost thickness on top of cylinder at T_a=17°C, T_p=-14.6°C, *u*=0.6 m/s and different relative humidities

Fig. 5, shows frost thickness increases as surrounding air temperature decreases.

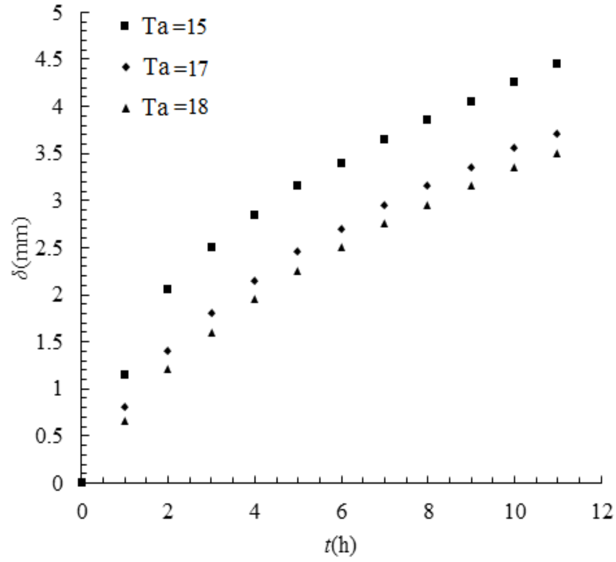

Fig. 5. Frost thickness on top of cylinder at T_p=-14.6°C, *Φ*=36%, *u*=0.6 m/s and different surrounding air temperatures

Fig. 6 illustrates frost thickness for different air velocities. while *u*=0 depicts the natural convection process. Further, the figure indicates that the frost thickness increases as air velocity increases.

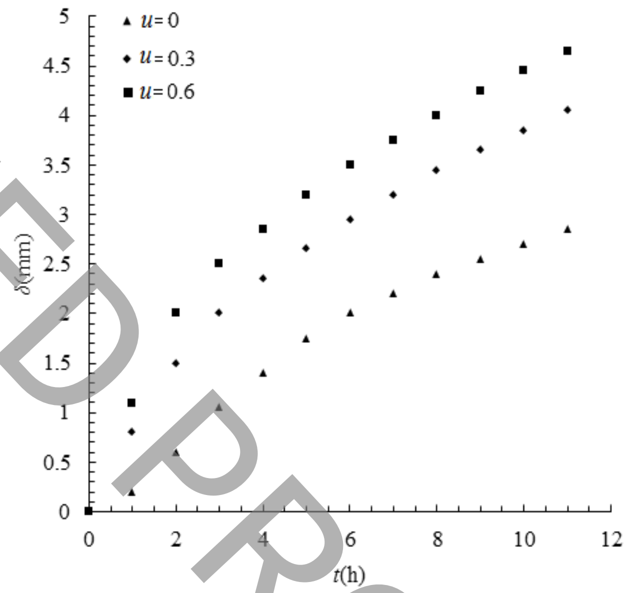

Fig. 6. Frost thickness on top of cylinder at T_p=-14.6°C, *Φ*=36%, T_a=17°C and different surrounding air velocities

For force convection flow, dimensionless frost thickness is proposed according in following equation based on obtained experimental data:

$$y_f^* = \frac{\delta_f}{d} = 2.6211(\mathrm{Re})^{0.1267}(\mathrm{F}o)^{0.5533}(\omega_{air})^{1.1572} (T_a^*)^{-38.0284}(T_p^*)^{-20.1011} \quad (1)$$

The ranges of applicability of this equation are:

- $3000 \le \mathrm{Re} \le 6400$
- $3.18 \le Fo \le 34.96$
- $0 \le t \le 11\,\mathrm{hr}$
- $0.0022 \le \omega_a \le 0.0111$
- $15^{\circ}\mathrm{C} \le T_a \le 21^{\circ}\mathrm{C}$
- $-15^{\circ}\mathrm{C} \le T_p \le -8^{\circ}\mathrm{C}$

4- Conclusion

In this study, frost formation on horizontal cylinder in force convection conditions was investigated experimentally. Effects of cold surface temperature, air temperature, air velocity, and air relative humidity on frost thickness and density were studied. The result shows:

- As surface temperature decreased, frost thickness increased and frost density decreased.
- As relative humidity increased, frost thickness increased and frost density decreased
- As air temperature increased, frost thickness and frost density decreased.
- As air velocity decreased, frost thickness and frost density decreased.
- On top and at the bottom of cylinder, frost thickness is thinner and at the behind of cylinder, frost thickness is thicker.
- Correlation based on experimental data and effective parameters has been presented.

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