EFFECT OF FROST ON THE HEAT TRANSFER OF FIN-TUBE WITH MULTIPLE FINS

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Abstract : The present study investigated frost characteristics of a fin-tube with multiple fins for heat pump application under heating condition. The key parameters were number of fins. Key experimental conditions were air temperature of 2℃, absolute humidity of air of 3.67g/kg_{DA}, air velocity of 0.5m/s, and surface temperature of the refrigerant of -10℃. The coolant was 50% ethylene-glycol aqueous solution.

Local frost thickness and frost mass were measured for the fin-tube modelled as large scale for easy measurement. The frost thickness is influenced on air flow and fin surface temperature. Moreover, the frost thickness for the case of 1 fin can be predicted using dimensionless correlations. However, it is difficult to predict the frost growth using present dimensionless correlations with growing fin number due to difficulty in measurement of all fin surface temperature or change in air flow cased by boundary layer between fins. After solving these problems, frost growth on the whole heat exchanger can be predicted with prediction of frost growth for the case of multiple fins using fin by fin method.

Key Words: frost, fin-tube, multiple fins, heat pump

NOMENCLATURE

C_p	specific heat at constant pressure [kJ/kgK]
H	fin height [m]
L	length [m]
Q	heat transfer rate [W]
T	temperature [℃]
t	time [min]
V	velocity [m/s]
W	width of the flat plate [m]
w	absolute humidity [kg/kg_{DA}]

Greek symbols

α	thermal diffusivity [m/s]
δ	Frost thickness [mm]
μ	viscosity [N·s/m^2]
Φ	relative humidity [%]

Subscriptions

a	air
f	frost

lat latent
r refrigerant
sen sensible
sv solid to vapor
tp triple point
w wall

1 INTRODUCTION

The heat pump generates heat of high temperature using heat source of lower temperature such as air, geothermal heat or water heat. In terms of heat supply without combustion, the heat pump is an air conditioning unit with the great effect of reducing CO_2. It has advantages of high efficiency and eco-friendly system. However, when the air temperature during winter is below the freezing temperature of water, the porous frost layers on heat exchangers are generated. The frost layer on the evaporator acts as a resistance to heat transfer and reduces the air flow rate. For those reasons it is necessarily solved to predict frost on outdoor unit heat exchanger and reduce its effect. Previous studies on frost growth have been one item of heat exchanger, flat plate, circular tube or larger fin shape. They mainly focused on investigation on change in the overall performance on one item of heat exchanger such as the frost growth, heat transfer rate and pressure drop with respect to kind of fin (Silva et al. 2010) or measurement of heat transfer rate, pressure drop with fin pitch (Lee et al. 2010) rather than prediction about local frost properties. In case of the flat plate or circular tube, some researcher observed frost growth and expressed dimensionless correlations. These proposed dimensionless correlations are applied to predict frost on the fin tube heat exchanger. There are proposed correlations of thermal conductivity with frost density (Ostin and Anderson 1991) or dimensionless correlations of frost thickness or frost density (Yang and Lee 2004). However, in the past, researchers mainly suggested correlations based on conditions of refrigerator at room temperature. Although some researchers have recently investigated on correlations in order to apply to heat pump (Kim et al. 2008), they have not yet considered frost growth on actual heat exchanger. (Kim et al. 2008) has developed correlations on the flat plate as a fundamental research in order to apply to actual heat exchanger, but it is difficult to directly apply to actual heat exchanger considering the shape of heat exchanger and specimen.

The objective of present study is to apply previous correlations (Yoon et al. 2009, 2010) on the flat plate and circular tube for the larger fin tube shape as a fundamental research in order to predict local frost mass. Furthermore, the present study investigated the change in heat transfer rate with increasing number of fins.

2 EXPERIMENTAL APPARATUS AND DATA REDUCTION

2.1 EXPERIMENTAL APPARATUS

The schematic diagram of the experimental apparatus simulating the fin-tube heat exchanger is shown in Fig. 1. In this work, the experimental setup contains a test section, measuring instruments, refrigerant system, data acquisition, and psychrometric calorimeter. The role of psychrometric calorimeter is maintaining temperature and humidity of air side and its control range is -10 to 50℃ of dry bulb temperature and 30 to 95% of relative humidity. Figure 2 represents the fin-tube model which is installed at the centre of test section horizontally. The experiment was conducted with different number of fins. The size of this fin-tube model is approximately three times bigger than Φ7 utilizing for a commercial heat exchanger. Detailed fin-tube specifications are shown in Table.1. The refrigerant system has refrigerating capacity of 660W and continues to supply Ethylene glycol meeting the experimental conditions. The experimental data were recorded by using Data acquisition system every 2 seconds for 120 minutes. The experimental conditions and parameters are shown in Table 2.

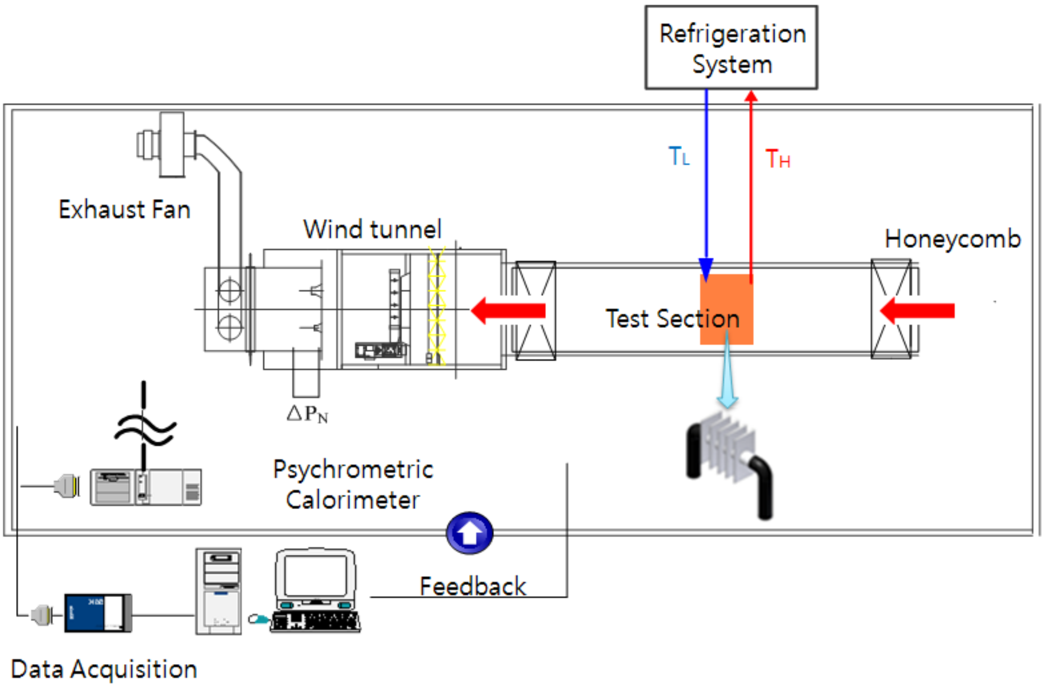

Figure 1: Schematic diagram of the experimental apparatus

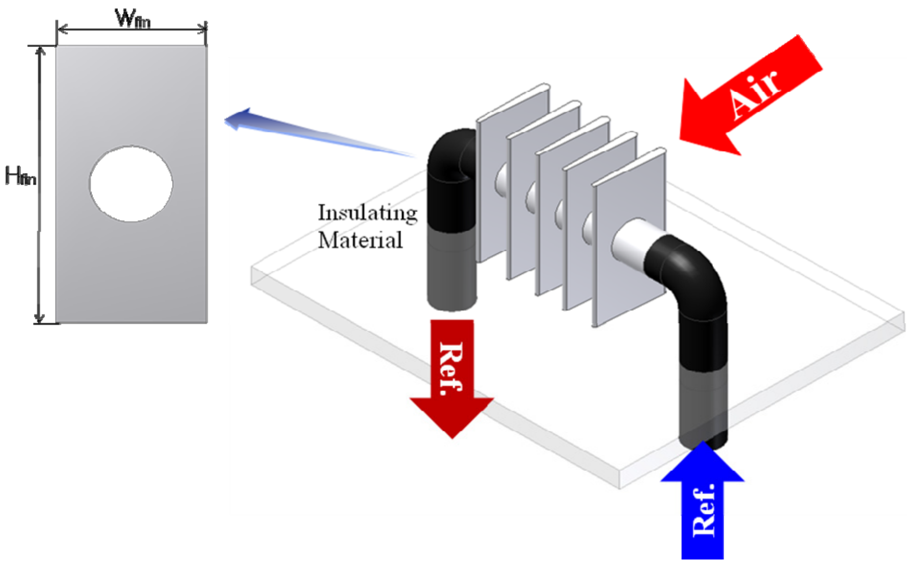

Figure 2: Test section

Table 1: Fin-tube Specification

W_{fin}×H_{fin}×t_{fin}(mm)	40×72.6×0.6
Fin pitch (mm)	4.5
Outer diameter of tube (mm)	20

Table 2 : Experimental conditions and parameters

Experimental condition	**Refrigerant flow rate (kg / min)**	2.0
	Refrigerant	Ethylene glycol(50 wt %)
	T_w(°C)	-10
	w_a(g/kg_{DA})	3.67
	T_a(°C)	2
	V_a(m/s)	1.5
Experimental parameters	**Number of fin**	1,2,3,4,5,10, 15

2.2 DATA REDUCTION

The inlet and outlet air dry bulb temperatures, relative humidities, and air velocity were measured by anemometer that is installed in the duct as shown in Table 3. Air flow distribution was uniform by utilizing honeycomb. Temperature distribution at the exit of duct was not uniform due to effect of fin-tube shape. TC grid was installed using T-type thermocouple at the end of acrylic duct in order to obtain bulk temperature at the exit of duct. The amount of heat transfer was yielded using inlet and outlet temperatures, humidity as shown in eq.(1).

$$Q = Q_{sen} + Q_{lat} = \dot{m}_a C_p (T_{a,i} - T_{a,o}) + \dot{m}_a h_{sv} (w_{a,i} - w_{a,o}) \quad (1)$$

The frost thickness was obtained using CCD Camera and that on the middle of fin was measured with micrometer attached thermocouple at 30, 60, 90 and 120 minutes after experiment started. Fin surface temperature was measured with welded thermocouple after putting in the hole on the fin surface.

The frost mass was measured by comparing the mass before and after the formation of frost using electronic scale with uncertainty of 0.1mg. Proposed correlations in previous study(Yoon et al. 2010) are used. Measured frost thickness on the flat plate was compared with predicted value by using eq.(2) .

$$\delta_{f,plate} = 3.782(L^*)^{-1.352}(w_a)^{1.704}(Fo)^{0.6803}(T^*)^{2.035}(\mathrm{Re}_L)^{0.251}$$

$$\bar{\delta}_{f,plate} = \frac{\int_0^L \delta_{f,plate}\,dx}{L} \qquad (2)$$

$$T^* = \frac{T_{tp} - T_w}{T_a - T_w} \qquad L^* = \frac{x}{L} \qquad \mathrm{Re}_L = \frac{\rho_a V_a L}{\mu_a} \qquad Fo_L = \frac{\alpha_a t}{L^2}$$

Table 3: Measurement instruments and their uncertainty

Instrument name	Measured value and Range		Uncertainty
IR Thermometer	Surface Temp.	-35~950 ℃	± 0.7 ℃
Flow meter	Refrigerant flow rate	0~18kg/min	± 0.5 %
Electronic scale	Frost mass	0~210g	± 0.1mg
Hot-wire anemometer	Temp.	-10~60 ℃	± 0.3 ℃
	Relative Humidity	5~98%	F ± 2.5%
	Velocity	0.05~10m/s	± 0.05m/s

3 RESULTS AND DISCUSSIONS

Figure 3 shows frost thickness with respect to fin position in case of 1 fin at 120min. The frost thickness at the leading edge side of the air flow is thicker than that at the trailing edge side and this result is well agreed with data on flat plate. The difference from result on the flat plate is that the closer to tube position is, the thicker frost is. Otherwise the frost becomes thin toward the end of fin due to effect of tube. Figure 4 shows measured fin surface

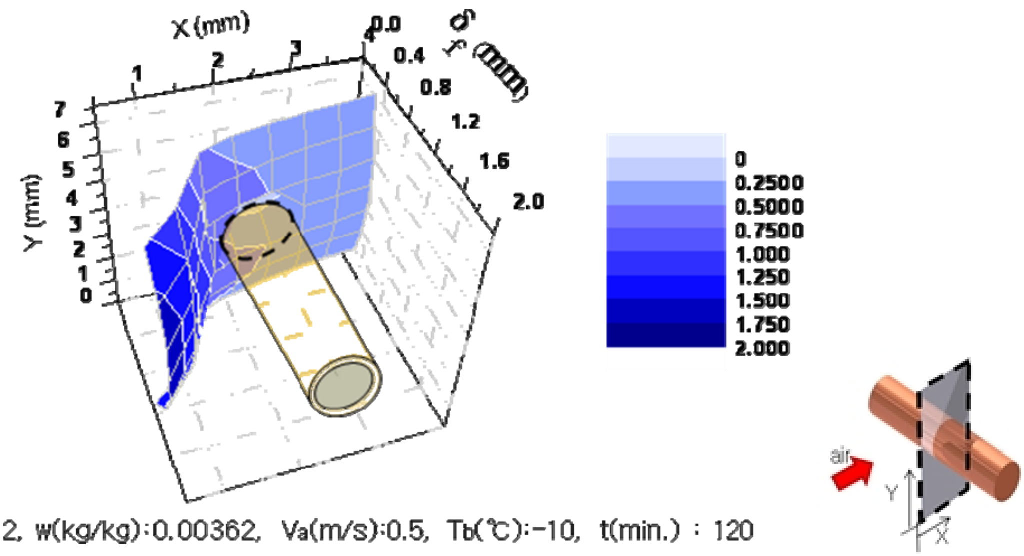

Figure 3: Local frost thickness

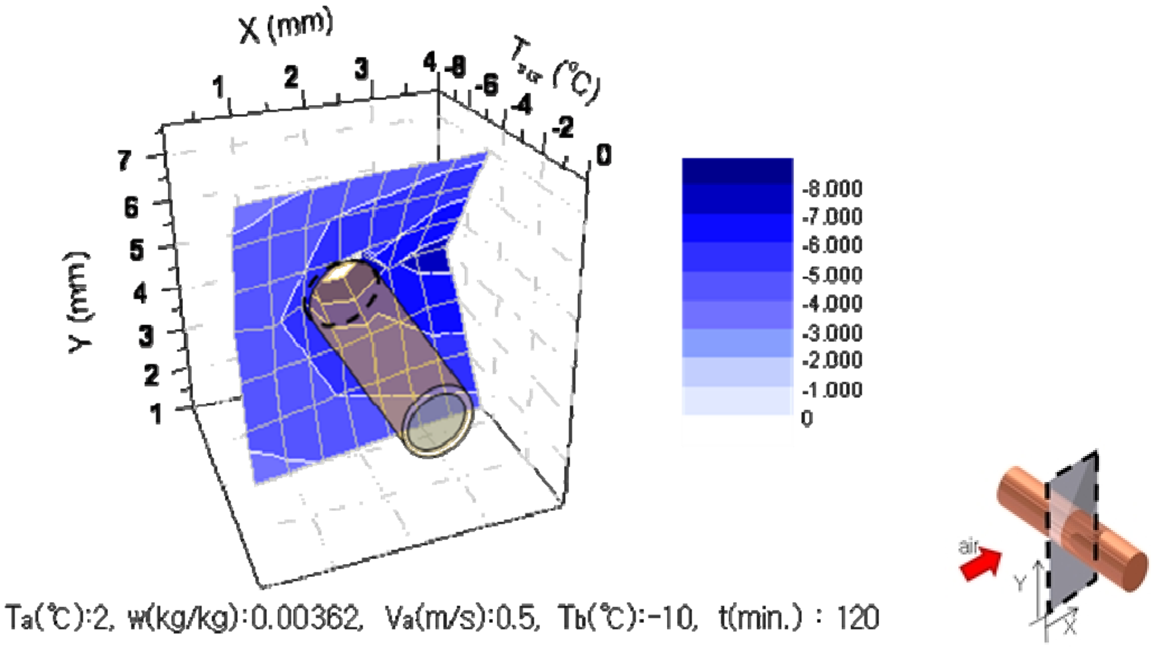

Figure 4: Local fin surface temperature

temperature tridimensionally. The fin surface temperature is low at the position close to tube and becomes high toward the end of fin. This tendency is influenced on the frost thickness as mentioned above. Figure 5 shows comparison of measured frost thickness with predicted one in case of 1 fin. Both predicted and measured frost thickness on the fin surface show similar trend and frost thickness can be predicted within 10% with relevant properties. However, it is difficult for relevant correlations to apply directly to whole heat exchanger in case that number of fins increases because of problems such as change in air flow between adjacent fins, difficulty in all fin surface temperature or effect of boundary layer between fins.

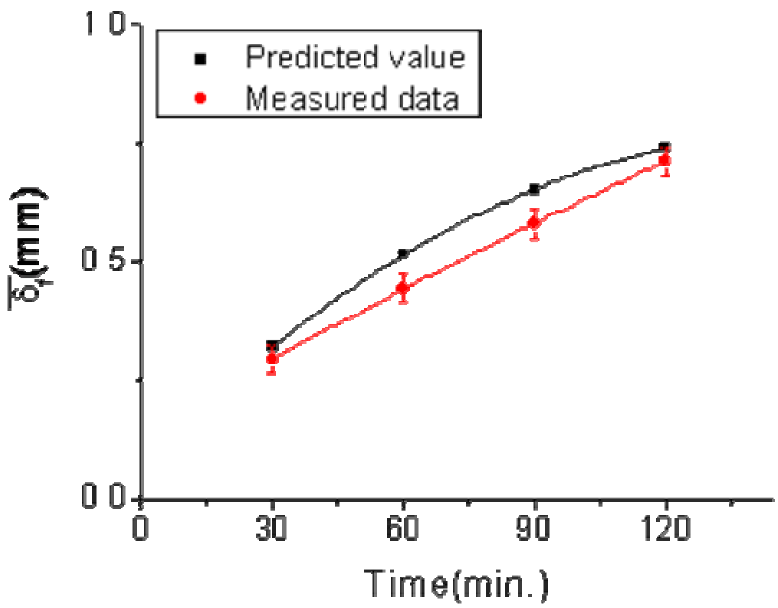

Figure 5: Comparison of the predicted frost thickness with measured

Thus, it is necessary to confirm if the frost growth on the heat exchanger using fin by fin method can be predicted after solving multiple fin surface temperature or boundary layer between fins. Figure 6 shows prediction of the frost growth on the heat exchanger using fin by fin method is reasonable by showing change in heat transfer rate with multiple fins. The heat transfer rate for the fin-tube with 15 fins was compared with the case applying the result of different number of fins such as 10 and 5 at -10°C of refrigerant temperature as shown in Fig. 6. In the comparison of heat transfer rate for the case of 15 fins and that of sum of 10 and 5 fins at refrigerant temperature of -10°C, difference between them was 16 to 23%. On the other hand, predicted result applying the heat transfer rate with 5 fins at -8°C of inlet temperature which is measured for case of 10 fins was well agreed within 9%. Therefore, the frost growth on whole heat exchanger can be predicted with prediction of frost growth on the multiple fins.

This present study shows that the frost growth on 1 fin can be predicted using dimensionless correlations. Moreover, matters out of correlation of range such as difficulty in measurement of fin surface temperature, effect of boundary condition between fins or change in air flow with growing fin number are solved and the frost growth on whole heat exchanger can be predicted by applying results from fewer fins.

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4 CONCLUSIONS

1) The frost thickness is influenced on air flow and fin surface temperature.
2) The frost thickness for the case of 1 fin can be predicted using dimensionless correlations.
3) It is difficult to predict the frost growth using present dimensionless correlations with growing fin number due to difficulty in measurement of all fin surface temperature or change in air flow cased by boundary layer between fins.
4) The frost growth on the whole heat exchanger can be predicted with prediction of frost growth for the case of multiple fins using fin by fin method.

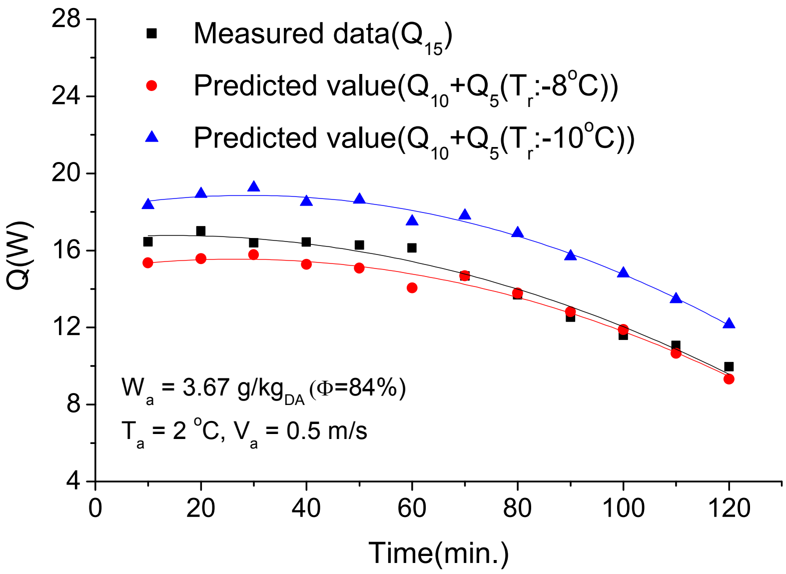

Figure 6: Comparison of total heat transfer rate (5, 10,15 fins)

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