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ABSTRACT

Frost formation on an evaporator causes significant problems by decreasing inlet air flow. It is important for a precise prediction to understand the dominant factor of the frost formation. In this paper, the frost layer on the cold plate is experimentally obtained with different velocities while maintaining a surface temperature at -20 degrees Celsius. The mass and height of the frost layer is measured throughout the experiment. The frost mass rate depends strongly on the absolute humidity and inlet air velocity. The obtained frost density depends on the relative humidity and inlet air velocity. Results show that the effect of the inlet air velocity is minor in regions with high relative humidity.

1. INTRODUCTION

Frost forms on the evaporator of heat pump systems when humid air comes in contact with the evaporator surface which is a temperature that is below the dew point temperature of the inlet air flow. Once frost forms on the evaporator, the reduction of inlet air flow due to frost formation affects the performance of the heat pump systems. Therefore, defrost cycles are periodically executed in the systems. The heat pump systems stop heating during the defrost periods and the environmental comfort adding to the energy efficiency decreases. The predictions of the frost formation on the evaporator leads to optimum duration of defrost cycles for the systems. Therefore, it is important for a precise prediction to understand the dominant factor of the frost formation.

There are several parameters that affect the frost formation, such as air velocity, air humidity, air temperature, and cold surface temperature (Kondepudi and O'Neal, 1989). Ohkubo (2001) proposed a frost deposition curve and concluded that it depends on the cooling surface temperature. However, there is little research work that systematically study frost properties in the region of the heat pump systems usage. We have carried out an experimental evaluation of the frost density with different air conditions and cold surface temperatures under a constant inlet velocity (Tashiro and Hamada, 2009, 2011, 2012). We have shown that the frost density depends on the cold surface temperature and inlet air relative humidity. As the cold surface temperature is lower, the frost density decreases. Also, as the inlet air relative humidity is higher, the frost density decreases. In this experiment, we measured the mass and thickness of the frost layer with different inlet air velocity under constant cold surface temperature. We show the effect of the inlet air velocity and as a result we summarize the dominant factor of the frost density.

2. EXPERIMENTAL APPARATUS AND METHOD

2.1 Experimental Setup

Experimental setup is schematically illustrated in Figure 1. We used a 100mm square acrylic air duct. The length of the duct is 550mm. Inlet air velocity was controlled by a variable speed fan connecting outlet of the duct. We set a metal honeycomb at the inlet of the duct as a flow straightener. The inlet air temperature and humidity were adjusted at the desired condition during the tests.

The cold unit was set in parallel with the air flow direction at 300mm after the metal honeycomb. The cold plate is made of Aluminum (60mm x 60mm t=1mm), which is cooled to a preset temperature by a thermoelectric module. The cold plate and thermoelectric module were covered with a heat insulator to avoid heat leak. Inlet air temperature, humidity and velocity were measured by thermocouples, a dew point meter and velocity sensors, respectively, which were set inside the duct before the cold unit. The obtained data was recorded by a data logger system at intervals of 10 seconds.

We set a digital camera on the duct and took digital photos of the frost layer on the cold plate at intervals of 15 minutes. Comparing the obtained time-interval photos with the initial one, we measured the thickness of the frost layer. At the end of each test we removed the frost layer from the cold plate and measured its mass by a high precision digital scale.

2.2 Experimental Procedure

At the beginning of the test, the cold unit was installed into the duct. Then, the inlet air was set to the desired condition. Once the inlet air reached steady state condition, the damper was set to close and the fan was turned off. The cold plate was cooled down by the thermoelectric module. After reaching surface temperature of the cold plate at a preset one, the fan was turned on and the damper was set to open. At the same time, the digital camera started to take pictures.

2.3 Experimental Conditions

Experimental conditions are shown in Table 1. We kept the surface temperature of the cold plate at -20 degree C. In No.1 through No.3 inlet air temperatures remained constant at -10 degree Celsius, while the absolute humidity varied. The absolute humidity of No.4 and No.5 are equal to No.1 (x_a =1.5). In No.4 and No.6 through No.8 inlet air temperatures remain constant at -5 degree C. The inlet air velocities of No.1 through No.8 are varied in 0.5m/s, 1.0m/s and 1.5m/s.

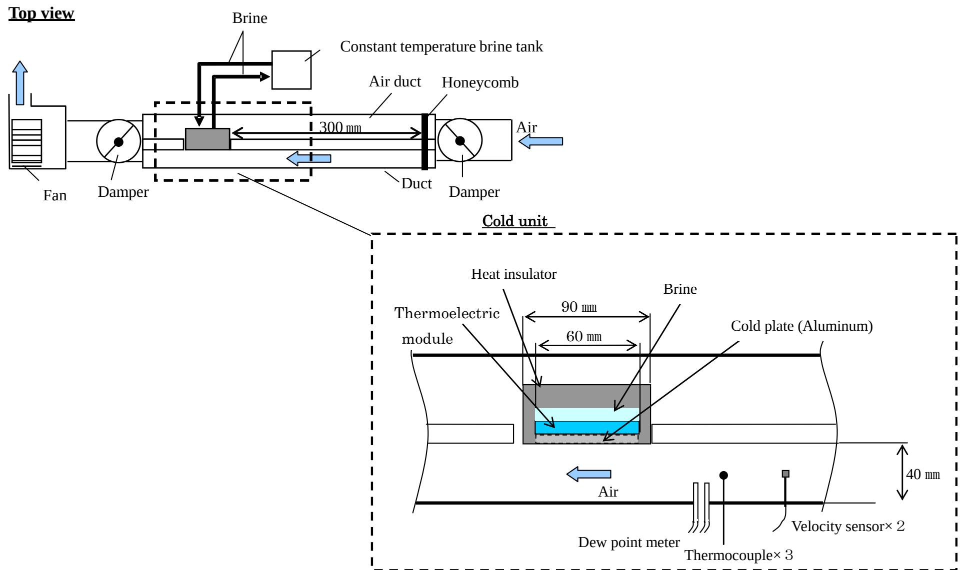

Figure 1: Experimental setup

Table 1: Experimental conditions (T_s=-20).

No.	1	2	3	4	5	6	7	8
T_a	-10	-10	-10	-5	0	-5	-5	-5
x_a	1.5	1.4	1.2	1.5	1.5	2.0	1.9	1.7
T_d	-12	-13.5	-15	-12	-12	-8.2	-8.7	-10.5
ϕ	83.6	73.0	63.6	54.1	35.6	75.8	72.6	61.9
u	0.5,1.0,1.5	0.5,1.0,1.5	0.5,1.0,1.5	0.5,1.0,1.5	0.5,1.0,1.5	0.5,1.0,1.5	0.5,1.0,1.5	0.5,1.0,1.5

3. EXPERIMENTAL RESULT AND DISCUSSION

3.1 Frost Mass

The time variation of the frost mass in *u*=1.5 are shown in Figure 2. In No.1 through No.8 the thickness of the frost layer at the end of the test was below 5mm and far smaller than the distance from the cold plate to the duct wall so that the inlet air velocity was constant during the test. Also, shown in Figure 2 the frost mass increases linearly with time.

We approximately linearized the frost mass in Figure 2 and show the rate in Table 2. The rate in No.6 is higher than the other tests. This is because the absolute humidity of the inlet air in No.6 is higher than the other tests. Higher absolute humidity results in providing more moisture to the frost layer. The rate depends heavily on the absolute humidity. However, the lower the inlet air temperature is, the smaller the rate is. This is seen by comparing No.1, No.4 and No.5. This is because the mass transfer rate decreases at the lower inlet air temperature, because the temperature difference between the inlet air and the surface temperature is small.

In Figure 3, we plot the time variation of the frost mass in No.4 at different inlet air velocity. As the inlet velocity increases, the frost mass also increases. This is because mass flow rate increases in higher inlet velocity. The similar results have been obtained for the other tests.

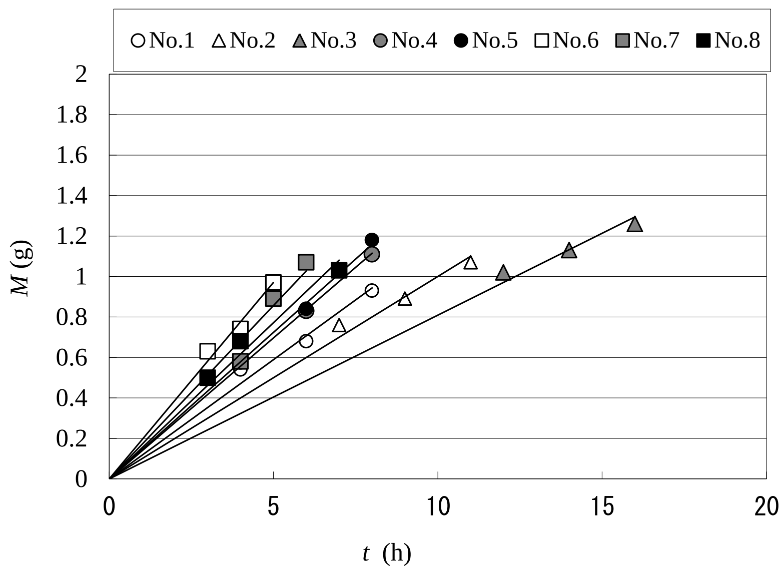

Figure 2: The measured frost mass as a function of time at *u*=1.5.

Table 2: The rates of the frost mass in Figure 2.

No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
T_a	-10	-10	-10	-5	0	-5	-5	-5
x_a	1.5	1.4	1.2	1.5	1.5	2.0	1.9	1.7
ν x10^{-5}	3.28	2.78	2.25	3.89	4.03	5.47	4.75	4.31

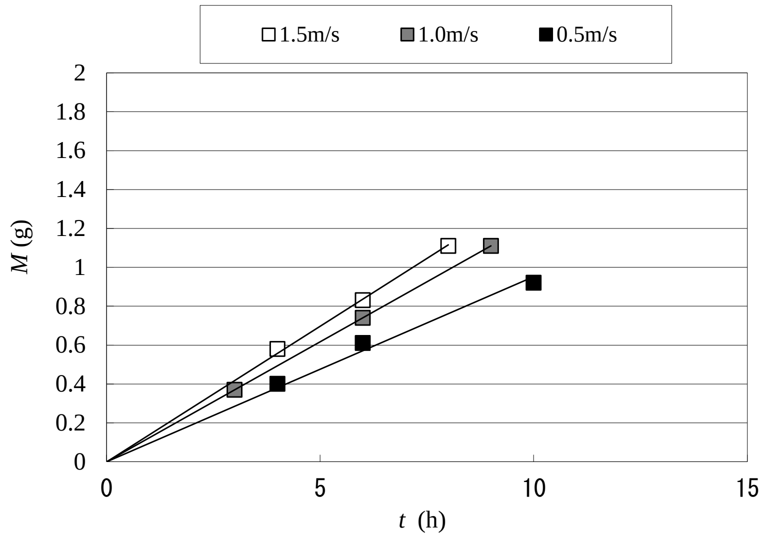

Figure 3: The effect of the inlet air velocity under constant air condition in No.4.

3.2 Frost Density

The obtained frost density is plotted as a function of inlet air relative humidity in figure 4. The frost density is calculated in Equation 1, where M=1 in every test, h_f is frost thickness, and A is the cold plate area.

$$\rho_f = \frac{M}{Ah_f} \tag{1}$$

As the relative humidity is higher, the frost density decreases. The frost density for different inlet air velocities is also plotted in Figure 4. With increasing inlet air velocity, the frost density increases. We speculate that the higher inlet velocity reduces the thickness of the frost layer due to high heat transfer at the surface and makes the frost layer denser. Thus the inlet air velocity had a significant effect on the frost density. At the high relative humidity, the effect of the inlet air velocity is minor compared to the low relative humidity region.

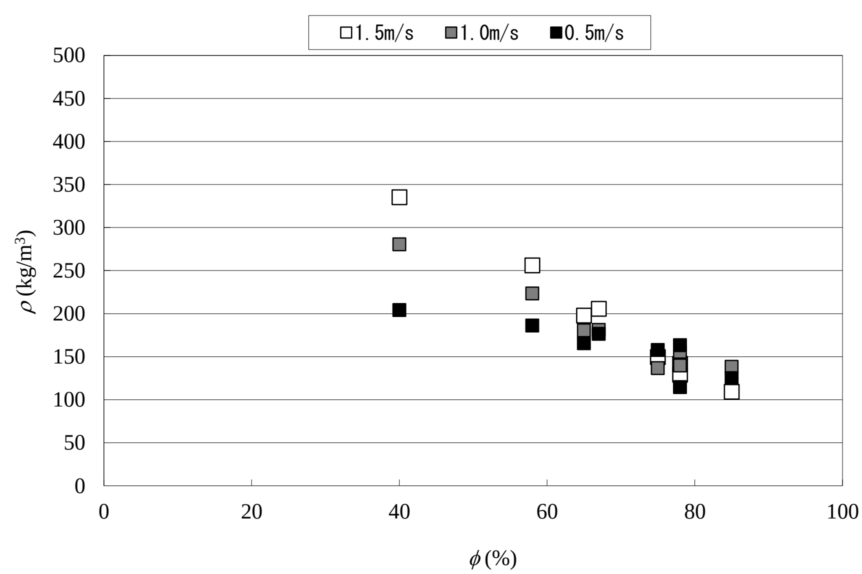

Figure 4: The obtained frost layer as a function of the relative humidity with different inlet air velocity.

4. CONCLUSIONS

In this paper, we measured the mass and thickness of the frost layer on the cold surface. We experimentally derived the frost density with different inlet air velocity.

- Frost mass rate depends on the absolute humidity of the inlet air and inlet air velocity.
- Frost density depends on the relative humidity and inlet air velocity.
- In the region of high relative humidity, the effect of the inlet air velocity is minor.

NOMENCLATURE

A	surface area	(m^2)
h	thickness	(mm)
T	temperature	(degree Celsius)
x	absolute humidity	(g/kg’)
u	velocity	(m/s)
M	frost mass	(g)
t	time	(h)
ϕ	relative humidity	(%)
ν	frost mass rate	(g/s)
ρ	density	(kg’/m^3)

Subscript

a	inlet air
d	dew point
s	surface
f	frost

REFERENCES

Kondepudi, S.N., O’neal, D.L., 1989, Effect of frost growth on the performance of louvered finned tube heat exchangers, *Int. J. Refrig*., vol. 12, p. 151-158.
Ohkubo.H., 2001, 7th International Symposium on Thermal Engineering and Sciences for Cold Region,: p. 73-78.
Tashiro, Y., Mamoru, H., 2009, *Proc. 2009 JSRAE annual conference*,: E-224
Tashiro, Y., Mamoru, H., 2011, *Proc. 2011 JSRAE annual conference*,: E-224
Tashiro, Y., Mamoru, H., 2012, *Proc. 2012 JSRAE annual conference*,: E-322