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Condensate Impact on Air Friction of Plate Fin-Tube Heat Exchangers

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ABSTRACT

Experimental tests on the air friction of several plate fin-tube heat exchangers were conducted under dry-surface and wet-surface conditions. The impacts of face velocity and condensate rate on the air friction were investigated through the tests. Under dry-surface conditions, the standard face velocity changed from 100 to 2,000 FPM. Under wet-surface conditions, the standard face velocity changed from 300 to 500 FPM. The inlet relative humidity changed from 30% to 90%. Under dry-surface conditions, air-friction is a function of face velocity. Tube size, tube pattern, fin density, number of rows, fin thickness and surface geometry also have an impact on the air friction. Under wet-surface conditions, the additional impact from condensate rate on air friction was found through the experimental tests. At 300 FPM face velocity, the air friction increased as the condensate flow rate increased. When the condensate rate reached a certain level, further increasing of condensate rate did not cause higher air friction. At 480 FPM face velocity, the air friction continuously increased as the condensate rate increased. Condensate carryover was found in such high face velocity conditions and is considered to be the reason.

1. INTRODUCTION

The plate fin-tube heat exchangers are widely used in many residential, commercial and industrial systems, such as HAVC, food freezing/drying, data center cooling, heat recovery, dehumidification, etc.

The air friction of plate fin-tube heat exchanger is a very important factor in the system design. For a certain plate fin-tube heat exchanger, this air friction will determine the air flow rate generated by a fan, which could vary under different surface conditions. The air friction under the dry and clean surface condition has been tested and studied by many researchers in past decades. When fouling of the heat exchanger surface occurred or when condensate formed, the air friction increased dramatically, lowering the air flow rate, and reducing the heat exchanger's capacity.

The air friction on a dry surface has been investigated by many researchers. For a certain tube pattern and fin surface geometry, the air friction is the function of face velocity.

Under the wet-surface condition, ARI standard 410-2001(2001) required that the test shall be conducted with the entire air-side surface actively condensing moisture. To make sure the air-side surface is fully wetted, the following conditions should be ensured.

1. Entering water temperature is between 35 to 55 F (1.7 to 12.8 C)
2. Entering wet-bulb depression (t_1db – t_1wb) is more than 6.0 F (3.3 C)
3. Air sensible heat ratio (Q_s/Q_t) is less than 0.75
4. T_2wb – t_w1 is larger than 5 F (2.8 C)

Eckels and Rabas (1987) measured the air friction under dry and wet-surface conditions for flat-plate finned-tube heat exchangers. Their testing results from one heat exchanger showed that the air friction under the smaller entering wet-bulb depression (7.2 C) has slightly higher value than that under the larger entering wet-bulb depression (8.6 C).

Wang et al. (2000) studied the air-side performance of fin-tube heat exchangers under dehumidifying conditions. The inlet relative humidity in their tests was 50% and 90%. Most of their data on air friction showed the higher value at 90%RH than that at 50%RH for the heat exchangers with a different number of rows, fin surface, and fin pitch.

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2. TEST SYSTEM AND HEAT EXCHANGERS

2.1 Test System

The tested heat exchangers are installed in a close-loop wind tunnel. The blower circulates the air within it (see Figure 1). The air flow direction is perpendicular to the front face of heat exchanger. The condensate that formed on the heat exchanger surface will be felt by gravity or blown off by air flow. A water heater and a glycol cooler are used to control the air temperature inside the tunnel. The hot water is from a hot water tank. The cooling medium in the cooler is a propylene glycol solution which comes from a chiller. A humidifier is used to adjust the air inlet humidity. The air flow rate is measured by a set of air nozzles. The RTD temperature sensors are used to measure the air inlet/outlet temperatures as well as cold water inlet/outlet temperatures. The air's relative humidity is measured at the inlet and outlet. The pressure drop on the air side is measured by differential pressure transducers. The water flow rate is measured with a turbine flow meter. All sensors and meters are calibrated according to ASHRAE standards.

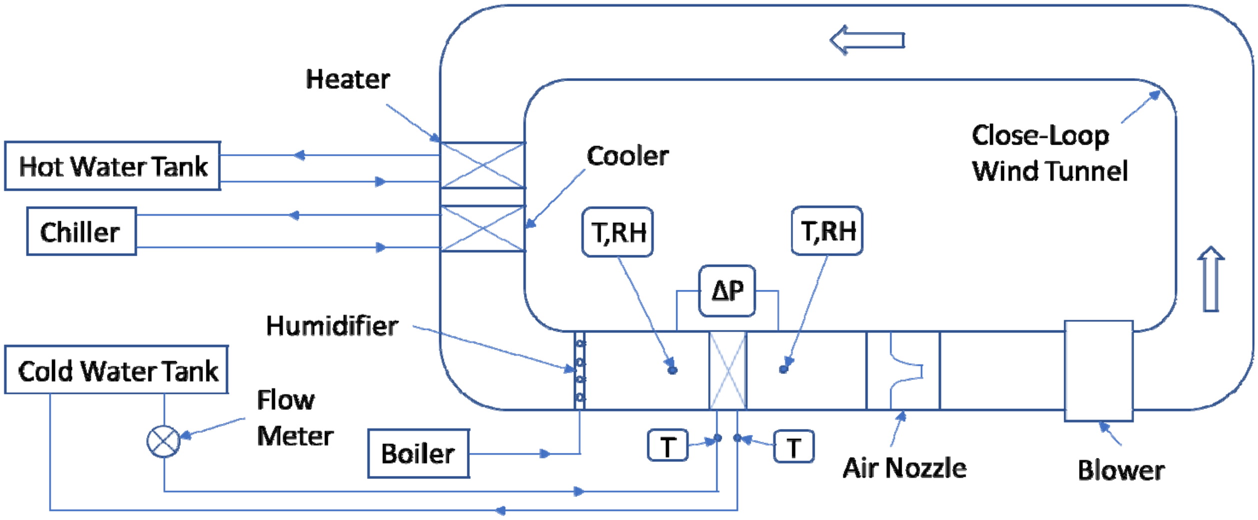

Figure 1 Schematic testing system and main components

2.2 Tested Heat Exchangers

Three different heat exchangers were tested in this study. All three heat exchangers were plate-fin coil type. The tube was copper. The fin was aluminum. The detailed specifications of these heat exchangers are listed in Table 1.

Table 1 The specifications of tested heat exchangers

HX	Face Dimensions in (mm)	Tube Pattern	Row #	Tube OD in (mm)	Fin Surface	Fin Density FPI (FPM)	Fin Thickness in (mm)
1	24 x 24 (610 x 610)	Staggered	10	5/8 (15.9)	Corrugated	10 (394)	0.0095 (0.24)
2	24 x 24 (610 x 610)	Staggered	4	3/8 (9.52)	Flat	10 (394)	0.0075 (0.19)
3	24 x 24 (610 x 610)	Staggered	6	0.198 (5)	Raised Lanced	12 (473)	0.0075 (0.19)

2.3 Testing Procedure

All tests were conducted in the wind tunnel lab at Super Radiator Coils. The ANSI/ASHRAE Standard 33-2016 was followed throughout the test. All sensors and meters were calibrated according to ASHRAE standards every 12 months. The air friction data was recorded from the dry-surface cooling tests and wet-surface cooling tests. During the dry-surface cooling tests, the water inlet temperature was controlled to remain higher than the air dew-point temperature at the inlet condition to avoid any condensate inside the fin bundle.

The air face velocity, the inlet air dry-bulb temperature, the air inlet humidity, the water inlet temperature and flow rate were maintained and recorded under the steady-state condition during the test. The condensate that formed inside the heat exchanger was captured by a pan which was underneath the test heat exchanger and the water's weight was measured every 30 min.

3. Results and Discussion

3.1 Test Results for Heat Exchanger #1

Heat exchanger #1 was tested under dry and wet-surface conditions. This heat exchanger was a 10-row coil. The fin was corrugated. The fin density was 10 FPI (394 FPM). The fin thickness was 0.0095 in (0.24 mm). The circuitry was a pure thermal counter flow configuration. The air friction vs. face velocity under dry-surface condition is shown in Figure 2. The air friction was directly measured across the heat exchanger. The face velocity was calculated by

FV = SCFM/(FL x FH)

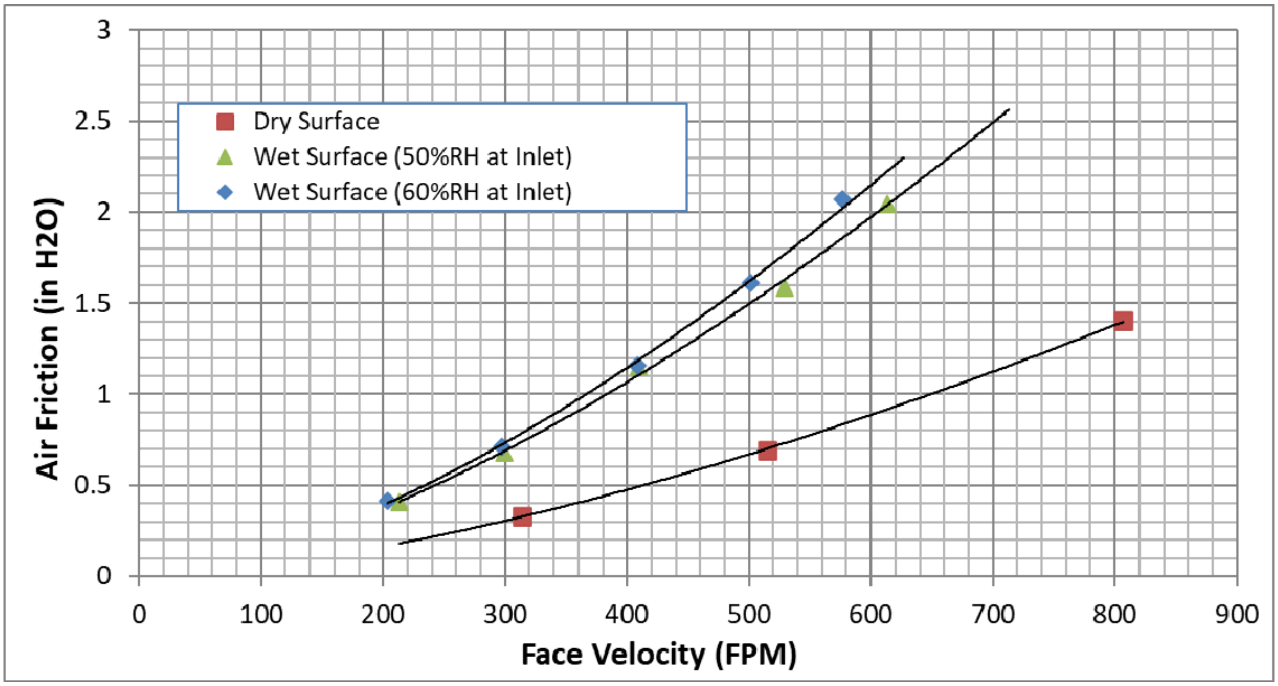

Figure 2 Air friction for heat exchanger #1 under dry and wet-surface conditions

Figure 2 shows the measured air friction for heat exchanger #1 under dry and wet-surface conditions. The dry-surface condition means there is no condensate on the heat exchanger surface. The air friction under dry-surface condition is the function of the face velocity. The higher face velocity leads to the higher air friction. When the condensate occurs on the heat exchanger surface, the air friction becomes much higher than that under the dry-surface condition. The reason for the difference in air friction between dry surface and wet surface is the condensate. The condensate in the heat exchanger bundle blocks the passage of air, creating additional resistance for the air flow.

Figure 2 also shows two sets of tests under wet-surface conditions – 50% RH and 60% RH at air inlet. During these wet-surface tests, the inlet air temperature, inlet water temperature and flow rate were kept constant. The air friction at 50%RH condition was about 200% higher than that under the dry surface condition at 210 FPM (1.07 m/s) face velocity. That difference in air friction increases to 225% at 310 FPM (1.57 m/s) and 230% at 510 FPM (2.59 m/s). The air friction at 60% RH condition is higher than that of 50% RH condition at each face velocity. When the face velocity is lower than 310 FPM (1.57 m/s), the difference in air friction is relatively small. As the face velocity increases, the difference in air friction at wet-surface condition increases as well. At 510 FPM (2.59 m/s) face velocity, the air friction at 60% RH is about 6.7% higher. When the face velocity is over 510 FPM (2.59 m/s), the condensate carry-over becomes significant.

Figure 3 shows the impact of condensate rate on air friction at the same face velocity for heat exchanger #1. In this figure, the face velocity is fixed at 310 FPM (1.57 m/s). The air inlet temperature, air inlet relative humidity, cooling water inlet temperature and cooling water flow rate were varied to create different condensate rate. The maximum condensate rate was 180 Lb/hr (22.78 g/s). The minimum condensate rate was 0.1 Lb/hr (0.013 g/s). The maximum air friction was about 0.668 inH2O (166.4 Pa). The minimum air friction was 0.427 inH2O (106.4 Pa). The higher the condensate rate, the higher the air friction. From Figure 2, the air friction at the same face velocity on dry surface condition is about 0.3 inH2O (74.7 Pa). So, the air friction could increase over 40% with very little condensate. When the condensate rate is higher than 120 Lb/hr (15.12 g/s), the air friction reached the maximum value and did not increase further.

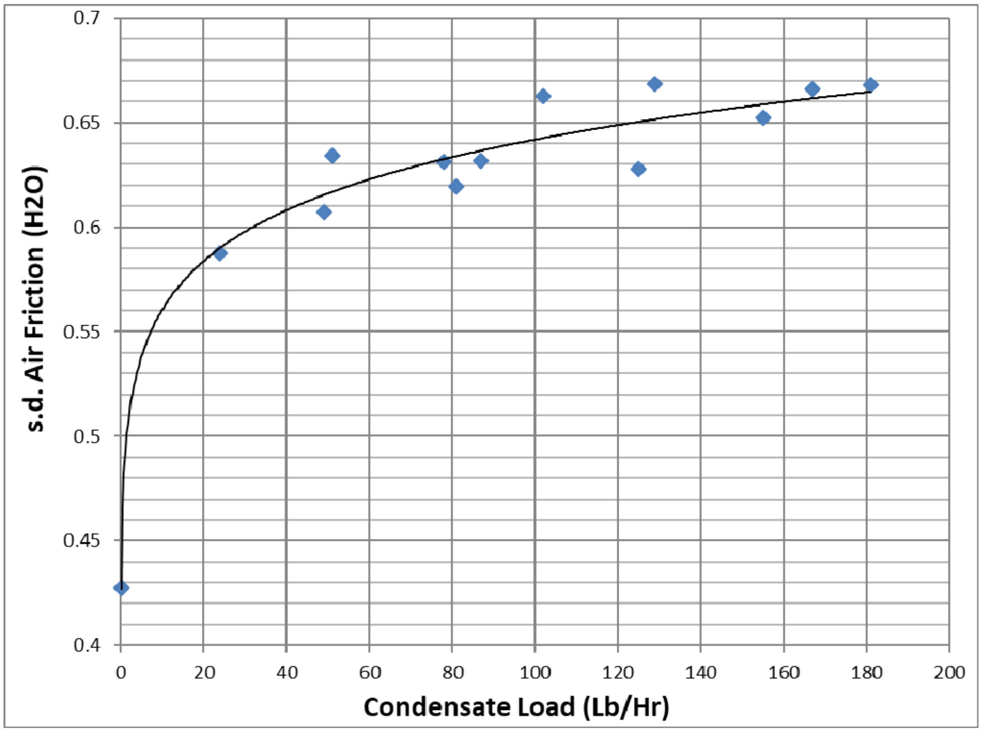

Figure 3 Condensate rate impact on air friction for heat exchanger #1

3.2 Test Results for Heat Exchanger #2

Heat exchanger #2 was a 4-row coil with a flat fin surface. The tube OD was 3/8 in (9.52 mm). The fin density was 10 FPI (394 FPM). Figure 4 shows the air friction test results under 3 different face velocities. All of these tests were conducted under wet-surface conditions. The results show that the higher the face velocity, the higher the air friction. The impact of condensate rate on the air friction was much smaller than that of heat exchanger #1. At a face velocity of 250 FPM (1.27 m/s), the air friction only changed 0.01 inH2O (2.5 Pa) at very low condensate rate all the way to a very high condensate rate. When the condensate rate was greater than 50 Lb/hr, the air friction remained constant, with no measurable increase. At a face velocity of 440 FPM (2.24 m/s), the change was only 0.022 inH2O (5.5 Pa) for a condensate rate between 9 and 85 Lb/hr (1.13 to 10.71 g/s).

3.3 Test Results for Heat Exchanger #3

Heat exchanger #3 was a 6-row coil with a raised lanced fin surface. The tube size was 5 mm OD. The fin density was 12 FPI (473 FPM). Figure 4 shows the air friction test results under 3 different face velocities. All these tests were performed under wet-surface conditions. The results show that the higher the face velocity, the higher the air friction. The condensate rate ranges from 10 to 100 Lb/hr (1.26 to 12.60 g/s). When the face velocity was around 200 FPM (1.02 m/s), the air friction changed from 0.175 to 0.249 inH2O (43.6 to 62.0 Pa). The highest air friction was 42% higher than the lowest air friction. The air friction under dry surface conditions at the same face velocity was only 0.076 inH2O (18.9 Pa). When the face velocity was around 300 FPM (1.52 m/s), the air friction changed from 0.326 to 0.488 inH2O (81.2 to 121.6 Pa). The highest air friction was 50% higher than the lowest air friction. When the face velocity was around 400 FPM (2.03 m/s), the air friction changed from 0.508 to 0.773 inH2O (126.5 to 192.5 Pa). The highest air friction was 52% higher than the lowest air friction. When the condensate rate reached 80 Lb/hr (10.08 g/s) or above, the air friction seemed to remain the same.

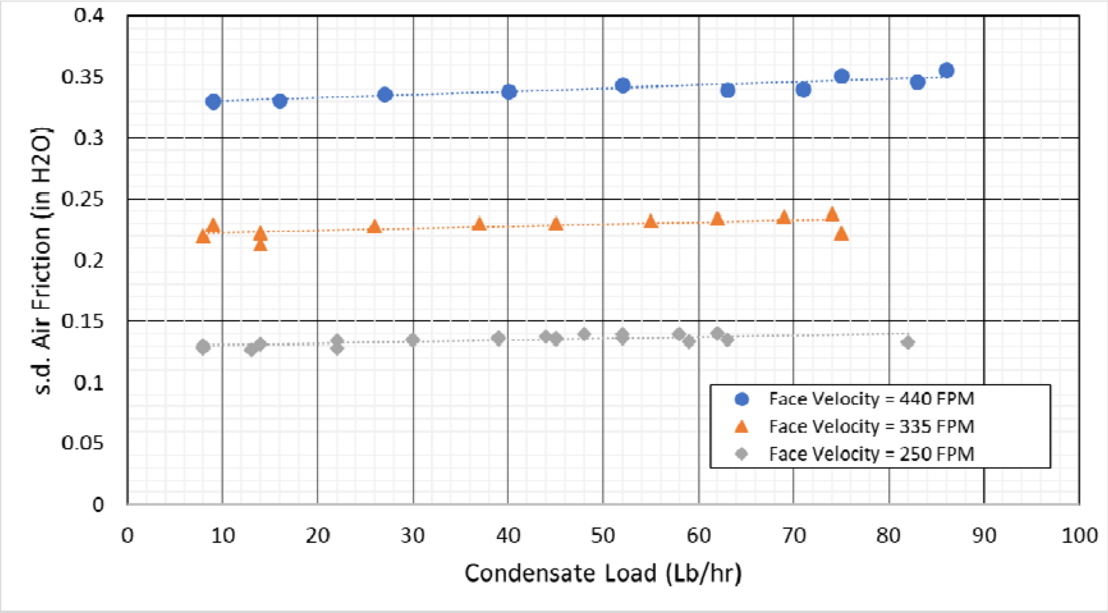

Figure 4 Condensate rate impact on air friction at different face velocity for heat exchanger #2

4. CONCLUSIONS

1. Three different finned-tube heat exchangers were tested under wet-surface conditions. The face velocity was a major factor on the air friction on both dry-surface and wet-surface conditions. The higher face velocity led to higher air friction for the tested heat exchangers.
2. Compared to the air friction at dry-surface conditions, the air friction at wet-surface conditions was much higher, even with a very low condensate rate.
3. The influence of condensate rate on the air friction was identified from all three tested heat exchangers. The higher condensate rate generally caused the higher air friction.
4. The impact of condensate rate on the air friction was greater at the higher face velocity than that at the lower face velocity.
5. The air friction under wet-surface conditions seems have a maximum value. When the condensate rate reaches a certain number, the air friction will no longer increase further.

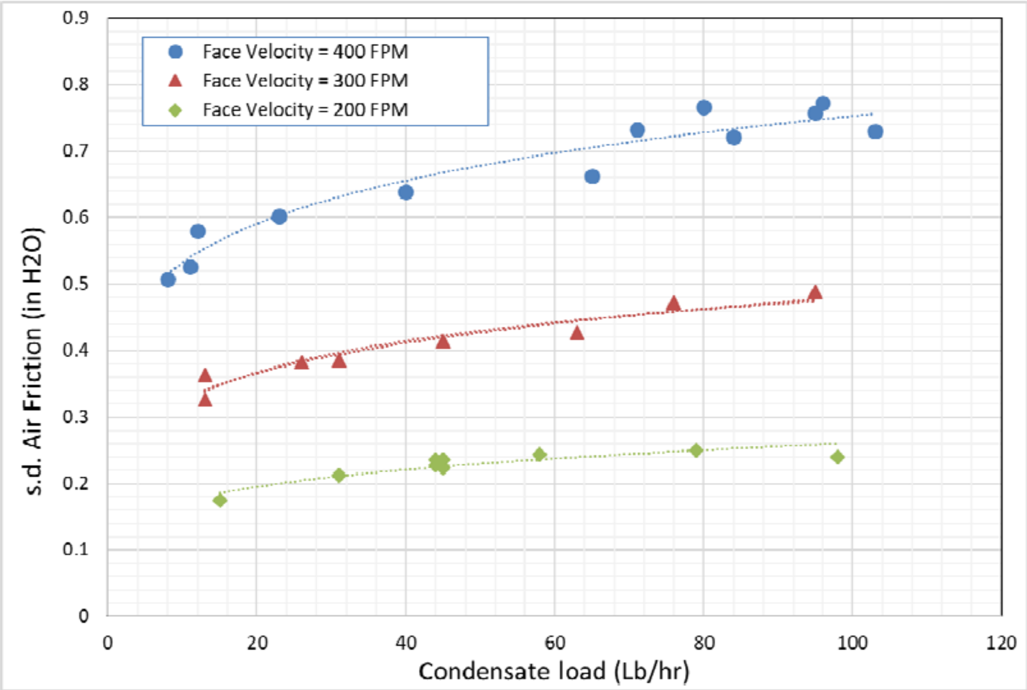

Figure 5 Condensate rate impact on air friction at different face velocity for heat exchanger #3

NOMENCLATURE

FH	Fin height	(ft)
FL	Fin length	(ft)
FV	Face velocity	(ft/min at standard condition)
SCFM	Air flow rate	(cubic feet per min at standard condition)
t	Temperature	F
Q	Heat transfer capacity	BTUH

Subscript

1	inlet
2	outlet
db	dry-bulb
wb	wet-bulb
s	sensible
t	total
w	wall

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