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Condensate retention on a louver-fin-and-tube air cooling coil

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Abstract

This paper presents a study of condensate retention on a louver-fin-and-tube air cooling coil, which is commonly used in air conditioning (A/C) systems. Compared to previously related work focusing on the influence of condensate retention on the heat and mass transfer between air and a cooling coil, the present study emphasizes the impacts of operating parameters on condensate retention on a cooling coil. A new method to describe the steady-state condensation has been suggested and a new mathematical model to represent the force balance of retained condensate developed. The mass of condensate retained has been measured experimentally under various operating conditions of a direct expansion (DX) air cooling and dehumidification system. The influences of air dry-bulb temperature, moisture content and Reynolds Number on condensate retention are discussed. The model developed relates the mass of condensate retained to condensing rate, and is successful in predicting the trends of condensate retention under normal operating conditions for air cooling applications.

Keywords: Air conditioning; Heat exchanger; Air cooler; Finned tube; Louver; Experiment; Modeling; Condensation; Vapour; Water

Retention du condensat sur un refroidisseur d'air du type tube aileté

Mots clés : Conditionnement d'air ; Échangeur de chaleur ; Refroidisseur d'air ; Tube aileté ; Persienne ; Expérimentation ; Modélisation ; Condensation ; Vapeur ; Eau

1. Introduction

The key component in an air handling unit is an air cooling and dehumidifying coil, whether it is chilled water based or direct expansion (DX) based. Since the resistance of heat transfer between a cooling media and air lies mainly on the air side of a cooling coil, louver-fins are commonly used in the air side of the coil to enhance air side heat transfer. Normally simultaneous air cooling and dehumidification takes place in an air cooling coil [1], when coil surface temperature is below the dew point of the air passing through the coil and water condenses on fin surfaces. Condensate can block inter-louver gaps and spoil the flow-directing ability of the louvers, reducing heat transfer. Furthermore, for an on-off controlled DX based air conditioning unit, the condensate that is retained on the surface of its cooling coil

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Nomenclature

a	acceleration ($m\,s^{-2}$)
A_c	cross-sectional area (m^2)
A_k	wetted area of coil along the air flow direction (m^2)
D_h	hydraulic diameter (m)
F_d	drag force due to the air flow (N)
F_g	gravitational force (N)
F_s	surface tension force (N)
g	gravitational acceleration ($m\,s^{-2}$)
H	height of control volume (m)
k	coil depth along the air flow direction (m)
L	length of control volume (m)
m_a	mass flow rate of air ($kg\,s^{-1}$)
m_{co}	condensing rate ($kg\,s^{-1}$)
M_d	mass of condensate drained off (kg)
$M_{re\text{-}e}$	mass of condensate re-evaporated (kg)
M_s	mass of condensate retained at steady-state condition (kg)
P	wetted perimeter of cross-section (m)
Q	air volumetric flow rate ($m^3\,s^{-1}$)
Re_D	Reynolds Number based on hydraulic diameter
t	time (s)
T_d	air dry-bulb temperature (°C)
T_w	air wet-bulb temperature (°C)
V_a	air velocity ($m\,s^{-1}$)
V_c	velocity of control volume mass ($m\,s^{-1}$)
V_s	suction velocity ($m\,s^{-1}$)
W	width of control volume (m)

Greek letters

ν	kinematic viscosity of air flow ($m^2\,s^{-1}$)
θ	correlational coefficient ($N\,kg^{-1}$)
ρ_c	mass density of control volume ($kg\,m^{-3}$)
ω	air moisture content ($kg\,kg^{-1}$)

Subscripts

U	upstream of a cooling coil
D	downstream of a cooling coil

during its on-period may flow along with the recirculation air and re-evaporate when the DX unit is operating at its off-period. Thus, indoor humidity may be raised to a level affecting human comfort. Condensate retained also provides a medium for biological activity to proceed, causing odors and other environmental problems. Therefore, it is important to understand the nature of condensate retention on the air side of a finned air cooling coil during its cooling and dehumidifying operation.

Combined sensible and latent heat transfer in air cooling applications has attracted a great deal of related research. However, few studies have focused on understanding and characterizing the condensate retained itself. The effects of system operating conditions, surface wettability, the coil geometry on the mode of retention and the quantity and location of condensate retained are not yet fully understood.

Nusselt [2] has been usually credited with carrying out the first theoretical investigation on film condensation. A vertical plate exposed to a condensable vapor at its saturation temperature was considered. The plate temperature was uniformly below the saturation temperature of the vapor. The velocity through the condensate layer was determined by noting that the shear stresses at the plate surface must be equal to the weight of the condensed fluid.

Guillory [3] conducted experiments on the dehumidification of air flowing between parallel plates. It was suggested that, when a finned heat exchanger was operating at a given Reynolds Number, a fixed quantity of condensate can be supported on plate surfaces. Therefore, condensing rate may be represented by the rate at which it runs off from the surface, with the actual quantity of condensate retained on the surfaces at any given time being relatively constant.

The experimental and theoretical studies reported in the early literature usually assumed that the only type of condensation occurring on air cooling coil fins was film condensation. However, a number of studies have indicated that there are cases where dropwise condensation has occurred.

Tuve and Mckeeman [4] noticed a difference in the heat transfer performance of air cooling coils at a given operating condition. It was suggested that the difference may be due to the changing of dropwise condensation to film condensation on cooling coil fins.

By inspecting the surface of a parallel plate heat exchanger after each experiment, Helmer [5] was able to identify the type of water droplet formed on the surface of the exchanger. There was no water film layer found on the wall. However, there was no yet conclusion that dropwise condensation was the dominant mode of condensation.

It is known that dropwise condensation would occur when a condensing surface has been treated with a suitable surface promoter such as fatty acid or when the surface has been plated with a noble metal such as gold. The function of a promoter is to reduce the surface tension of a vapor–solid surface, while not reducing proportionately the tension of a liquid–solid or a liquid–vapor interface [6].

Results of the visualization study by McQuiston [7] showed that dropwise condensation was formed on aluminum, constantan and copper surfaces. The air stream did not appear to affect water droplets, which however, appeared to be under the influence of gravity and surface tension only, and the condensing rate was affected by neither the mass transfer rate nor Reynolds Number. On the other hand, McQuiston [8,9] tested three different surface conditions for the same heat exchanger: dry, wet with film condensation,