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Sensitivity Analysis of Evaporative Condensers Performance Using an Experimental Approach

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Abstract

The evaporative condensers operate at lower condensing temperatures with respect to dry condensing units and involve reduced water consumption if compared with water cooled condensers. A test rig to investigate the evaporative condenser at small scale has been designed and built up. The condensing refrigerant has been simulated by electrical heaters and an air handling unit provides air with dry bulb temperature and relative humidity set by the user. All the parameters affecting the evaporative condenser performance can be monitored and adjusted, in order to carry out either an extensive experimental campaign or a sensitivity analysis. The results, as expected, clearly show that the heat released to air increases with the outer surface temperature of electrical heaters and decreases with relative humidity. An increase of 37.5% of the air flow rate (at constant sprayed water) leads to a maximum reduction of the heat transfer rate of 50%. Different tubes arrangements have been compared, showing as a decrease of the transversal pitch involves worse performance.

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Keywords: Evaporative condensers, Experimental tests, Heat rejection, Test bench, Sensitivity analysis

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1. Introduction

The evaporative cooling is an energy saving technology widely used both in the industrial refrigeration and in residential air conditioning systems. Savings are based on a heat transfer increase occurring when water is sprayed on heat transfer surfaces of a condensing unit and a reduced temperature difference between air and refrigerant is reached; this leads to operate refrigeration cycles at lower condensing temperatures and at higher COP values. The evaporative cooling is a well-established technology; nonetheless, the involved physical phenomena are not easy to be modelled so that the topic represents an important field of research widely explored. Parker and Treybal [1] carried

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out an experimental campaign on evaporative coolers and derived empirical relationships for heat and mass transfer coefficients.

Nomenclature

d	outer diameter [m]
$\dot{G}$	volumetric flow rate [m^{3}h^{-1}] for air, [l·min^{-1}] for water
h	specific enthalpy [kJ·kg$_{\mathrm{da}}$$^{-1}$]
$\dot{m}$	mass flow rate [kg·s^{-1}]
P_l	longitudinal pitch [m]
P_t	transversal pitch [m]
$\dot{Q}$	heat transfer rate [kW]
RH	relative humidity [%]
T	temperature [°C]
v	velocity [m·s^{-1}]
x	specific humidity of moist air [kg·kg$_{\mathrm{da}}$$^{-1}$]
Greek symbols	
ρ	density [kg·m^{-3}]
Subscripts	
air	moist air
da	dry air
db	dry bulb
in	air conditions before the interaction with electrical heaters
max	maximum
mean	average
out	air conditions after the interaction with electrical heaters
setpoint	conditions at the outlet of the air handling unit
wall	outer surface of electric heaters

Mizushina et al. [2] obtained empirical relationships for heat and mass transfer coefficients corresponding to different tube diameters. Kreid et al. [3] and Korenic [4] studied the influence of fins on evaporative coolers and condensers performance. Bykov et al. [5] focused on the water temperature and air enthalpy variations with the elevation above the water basin. Webb [6] proposed a mathematical model for cooling towers, evaporative coolers and condensers, while Erens and Dreyer [7] carried out numerical analyses on both the devices. Zalewsky and Gryglaszewski [8] developed a mathematical model for counter-current evaporative condensers validated by experimental data. Ettouney et al. [9] experimentally compared the performance of evaporative condensers and dry condensing units. Qureshi and Zubair [10] modeled evaporative coolers and condensers and focused on the effect of fouling by introducing [11] a characteristic factor. Qureshi and Zubair [12] carried out an experimental campaign on evaporative coolers and condensers showing that the process fluid flow rate is the most affecting parameter for the former, while the condensing temperature and relative humidity are the relevant factors for the latter. Hajidavaloo and Eghtedari [13] found that the substitution of a dry condensing unit with an evaporative condenser in a conditioning system leads to a decrease of 20% of the power consumption and to an increase of 50% of the COP. Jahangeer et al. [14] used finite differences technique to model a single straight tube of evaporative condenser and explored the heat transfer coefficients. Tissot et al. [15] investigated on the advantages of evaporative cooling and noticed that the maximum increase of the COP is of 29%. Islam et al. [16] proposed a validated model of an air conditioning system operating with an evaporative condenser. Fiorentino and Starace [17] carried out 2D numerical activities of the falling film evaporation on horizontal tubes and studied different types of flows depending on tubes arrangement and water-to-air flow ratio. Junior and Smith-Schneider [18] carried out an experimental campaign on a small scale evaporative condenser. They collected 40 samples and obtained a predicting function of the heat transfer rate with the condensing temperature, air dry and wet bulb temperatures, water and air flow rates, water temperature. Liu et al. [19] analyzed the performance of an