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Experimental study on improving operating conditions of wet cooling towers using various rib numbers of packing

Pooriya Shahali [a], *Mehdi Rahmati* [b,c], *Seyed Rashid Alavi* [b,c,*], *Ahmad Sedaghat* [b]

[a] *Mechanical Engineering Department, University of Shahrekord, Shahrekord 88186-34141, Iran*
[b] *Department of Mechanical Engineering, Isfahan University of Technology, Isfahan 84156-83111, Iran*
[c] *Isfahan Mathematics House, Isfahan 81698-51177, Iran*

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ABSTRACT

There are different mass and heat transfer mechanisms between water and air flows inside wet cooling towers (WCTs) so that it is a very difficult task to manage or optimize their operations. In this experimental work, the WCT performance is parametrically investigated in order to understand effects of water flow rate, inlet water temperature, type and arrangement of packing, and mass flow rate of air. Three different types of PVC packings (7, 9 and 18 ribs) are studied in this article separately to investigate influences of rib numbers. Furthermore, operation of the WCT is investigated by changing the inlet water temperature, rib numbers of packing, and flow rate of air and water. Ultimately, a guideline is proposed to reach optimum operating conditions of WCTs by virtue of mathematical equations derived from regression analysis of the measured data.

Étude expérimentale de l’amélioration des conditions de fonctionnement de tours de refroidissement humides en faisant varier le nombre de nervure de clayettes

Mots clés : Tour de refroidissement humide ; Transfert de chaleur et de masse ; Clayettes ; Efficacité ; Analyse de régression ; Conditions de fonctionnement optimales

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[*] *Corresponding author.* Department of Mechanical Engineering, Isfahan University of Technology, Isfahan 84156-83111, Iran. Tel.: +983133912667; Fax: +983133912628.

E-mail address: r.alavi@me.iut.ac.ir (S.R. Alavi).

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Nomenclature

$C_{p,a}$	specific heat capacity of air $[kJ\cdot kg^{-1}\cdot K^{-1}]$
$C_{p,w}$	specific heat capacity of water $[kJ\cdot kg^{-1}\cdot K^{-1}]$
$\dot{m}_w$	mass flow rate of water $[kg\cdot s^{-1}]$
$\dot{m}_a$	mass flow rate of air $[kg\cdot s^{-1}]$
N	rib numbers of packing
n	size of the actual output (or regressed output)
Q_L	cooling capacity of air [W]
Q_V	cooling capacity by evaporation [W]
Q_K	cooling capacity by convection [W]
Q	cooling capacity [W]
q_w	flow rate of water $[Lit\cdot h^{-1}]$
r	latent heat of evaporation $[kJ\cdot kg^{-1}\cdot K^{-1}]$
T_{w1}	temperature of inlet water [°C]
T_{w2}	temperature of exit water [°C]
t_{db1}	dry-bulb temperature of inlet air [°C]
t_{db2}	dry-bulb temperature of exit air [°C]
t_{wb1}	wet-bulb temperature of inlet air [°C]
t_{wb2}	wet-bulb temperature of exit air [°C]
ω_1	inlet absolute humidity $[kg_w\cdot kg_a^{-1}]$
ω_2	outlet absolute humidity $[kg_w\cdot kg_a^{-1}]$

1. Introduction

Power plants, large air-conditioning systems and some industrial systems generate enormous amounts of waste thermal energy that should be transferred. Cooling towers (CTs) are devices responsible for dissipating waste thermal energy to the ambient environment. CTs operate based on mass and thermal energy transfer from high temperature water to coolant air. In general, industrial cooling towers are divided into two major types (dry or wet) based on the heat transfer mechanism between the warm water and coolant air flow. In dry cooling towers (DCTs), radiators installed on the bottom are employed for conveying high temperature water in order to reject heat from warm water to the airflow.

In wet cooling towers (WCTs), water flows over the packing and consequently a direct interface between the warm water and coolant air flow occurs. So, an insensible heat transfer (through evaporation) is also considered in WCTs in addition to the sensible heat transfer, which is the only heat transfer mechanism in the DCTs. From an economic point of view, it is more common to use WCTs in hot weather regions due to their better performance rather than DCTs. Thus, DCTs are utilized in low water areas that suffer from lack of water.

Many factors such as packing types, inlet water temperature, mass flow rate of air and volume flow rate of water affect operation of WCTs. Therefore, performance of WCTs could be improved by obtaining optimum values of these parameters. For this sake, a large number of research efforts have been devoted to thermal performance of WCTs through experimental and theoretical analyses of the mass and thermal energy transfer mechanisms. Goshayshi and Missenden (2000) researched mass transfer coefficient of different packings experimentally. They showed that the packing coefficient for mass transfer is dependent on pitch and distance of packings. Facão and Oliveira (2000) presented the thermal performance of WCTs for the purpose of chilling. They determined mass and thermal energy transfer coefficients experimentally. Fisenko et al. (2002, 2004) presented correlations for natural and forced draft in order to obtain performance of CTs. They optimized the performance of CTs under changing atmospheric conditions. There exist other works that relates mass and thermal energy transfer processes to WCTs by some correlations such as the model developed by Kloppers and Kröger (2005). Stabat and Marchio (2004) employed mass and thermal energy balance and heat transfer laws to present a model based on the Lewis factor for the sake of predicting water and energy usage in various operations. Kloppers and Kroger (2005) investigated the effect of the Lewis number on thermal energy transfer performance of natural and forced draft WCTs. Smrekar et al. (2006) showed that the efficiency of natural draft CT could be increased through optimization of the thermal energy transfer across the cooling tower. They analyzed the water transportation mechanisms across the cooling tower and subsequently suggested correlations in order to find an optimum ratio of water to air flow rates. The experimental study of ceramic tile packing and its influence on the CTs performance was first carried out by Elsarrag (2006). In consequence, a model was developed according to correlations for the sake of predicting the outlet water and air temperature conditions. Lemouari et al. (2007) conducted experiments on heat transfer performance of a cooling tower with various parametric studies, which yielded a similar model to that of Gharagheizi et al. (2007). Lemouari et al. (2009) studied experimentally the mass and heat transportation between air and water flow rates, which have indirect contact with a packed cooling tower. They suggested modification of the generalized mass and heat transfer coefficients through involving the influence of water and air transportation. Sarker et al. (2009) studied other features of cooling tower such as cooling capacity, efficiency and pressure losses. Their apparatus was based on using bare and finned tubes. They observed that the thermal efficiency was improved by using the finned tube because of higher pressure losses compared with the bare tube. Furthermore, a cooling tower model was numerically investigated by Heidarinejad et al. (2009) and was validated by the literature's experimental data. Through a case study, it was demonstrated that it is important to include the rain zones and spray in analyses for the sake of improving accuracy in design. Heyns and Kröger (2010) investigated the heat and fluid flow characteristics of evaporation coolers. They developed correlations for heat transfer coefficient in water film, mass transport between water and air, and pressure losses on air transport. Their measured results showed that the thermal energy coefficient for layer of water was dependent on mass flow rate of air and water and temperature of spraying water. In addition, the mass transfer of water and air were correlated to spray velocities of water and air. Yoo et al. (2010) obtained correlations for mass and heat transfer based on their measured data. They used these correlations to determine the latent heat transfer. Zheng et al. (2012) investigated oval tubes in order to find out the possibility of utilization in WCTs and subsequently proposed correlations for optimum WCTs with oval tubes. Papaefthimiou et al. (2012) investigated weather conditions on the thermal