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Experimental study on the performance of a mechanical cooling tower fitted with different types of water distribution systems and drift eliminators

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HIGHLIGHTS

► A variation in the water distribution system can increase cooling tower's thermal performance up to 40%.
► The presence of eliminators do not necessarily worsen the cooling tower's performance.
► The correlations predict the thermal performance of the cooling tower well (error < 0.95%).

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ABSTRACT

Water drift emitted from cooling towers is objectionable for several reasons, mainly due to human health hazards. Generation and control of drift depends mostly on the couple of elements water distribution system and drift eliminator. The configuration of these two components not only affects drift but also the cooling tower thermal performance. However, no references regarding the effect of the water distribution system on the cooling tower characteristic have been found in the reviewed bibliography. This paper presents an experimental investigation of the thermal performances of a forced draft counter-flow wet cooling tower fitted with a gravity type water distribution system (GWDS) for six drift eliminators and when no drift eliminator was fitted. The interaction between distribution system and drift eliminators is analyzed. Heat and mass transfer processes taken place in the cooling tower have found to be affected by the mass transfer coefficient and the exchange mass-heat area per unit of cooling tower volume. The comparison between the obtained results and those found in the literature indicates that the pressure water distribution systems type (PWDS) achieve better performances than the GWDS. Maximum averaged differences of 38.66% in terms of cooling tower performance have been obtained between the two water systems. The data registered in the experimental set-up were employed to obtain correlations of the tower characteristic. The outlet water temperature predicted by these correlations was compared with the experimentally registered values, obtaining a maximum averaged difference of ±1.61% for the water-to-air mass flow ratio correlation and ±0.95% for the water and air mass flow ratios.

1. Introduction

Cooling towers are evaporative heat transfer devices in which atmospheric air cools warm water, with direct contact between the water and the air by evaporating part of the water. Chilled water falls into the tower basin while the removed heat leaves the device as warm air. They are commonly used to dissipate heat from power plants, water-cooled refrigeration, air conditioning and industrial processes. The principle of operation of cooling towers requires spraying or distributing water over a heat transfer surface (packing) across or through which a stream of air is passing. As a result, water droplets are incorporated in the air stream and, depending on the velocity of the air, will be taken away from the unit. This is known as drift and it is independent of water lost by evaporation.

Although cooling tower drift is objectionable for several reasons (Lewis [1],) such as ensuing corrosion problems on equipment, piping and structural steel, accumulated salts on downwind vegetation or ice formation during winter months (Pedersen et al. [2]), undoubtedly the most hazardous problem concerning human health

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Nomenclature

A_V	surface area of water droplets per unit volume of tower, (m^2/m^3)
c	constant for the ASHRAE correlation
C_{pm}	specific heat at constant pressure of moist air, (J/kg_a K)
C_{pw}	specific heat at constant pressure of water, (J/kg_w K)
G	mass flow rate of dry air, (kg_a/s)
GWDS	gravity water distribution system
h	enthalpy of moist air, (kJ/kg_a)
h_C	heat transfer coefficient of air, (W/m^2 K)
h_D	mass transfer coefficient, (kg/m^2 s)
h_f	specific enthalpy of saturated liquid water, (J/kg_w)
$h_{f,w}$	specific enthalpy of water evaluated at t_w, (J/kg_w)
$h_{fg,w}$	change of phase enthalpy ($h_{fg,w} = h_{g,w} - h_{f,w}$), ($kJ/kg_w$)
h_g	specific enthalpy of saturated water-vapour, (J/kg_w)
$h_{g,w}$	specific enthalpy of saturated water-vapour at t_w, (J/kg_w)
h_g^0	specific enthalpy of saturated water-vapour evaluated at 0 °C, (J/kg_w)
$h_{s,w}$	specific enthalpy of saturated moist air evaluated at t_w, (J/kg_a)
L	mass flow rate of water, (kg_w/s)
Le	Lewis number
m	constant for the ASHRAE correlation
$\dot{m}_a$	mass flow rate of dry air, (kg_a/s)
$\dot{m}_w$	mass flow rate of water, (kg_w/s)
n	constant for the ASHRAE correlation
NTU	number of transfer units
PWDS	pressure water distribution system
t	dry-bulb temperature of moist air, (°C)
t_w	water temperature, (°C)
TC	tower characteristic
V	volume of tower, (m^3)
W	humidity ratio of moist air, (kg_w/kg_a)
$W_{s,w}$	humidity ratio of saturated moist air evaluated at t_w, (kg_w/kg_a)

Subscripts

a	dry air
m	moist air
w	water
1	inlet
2	outlet

is the emission of chemicals or microorganisms to the atmosphere. Regarding microorganisms, the most well-known pathogens are the multiple species of bacteria collectively known as legionella. These bacteria tend to thrive at the range of water temperatures frequently found in these cooling systems. Hence, workers or other people near a cooling tower may be exposed to drift, may inhale aerosols containing the legionella bacteria, and may become infected. Numerous legionella outbreaks have been linked to cooling towers (Bentham and Broadbent [3] and Isozumi et al. [4]).

Generation and control of drift depends mostly on the couple of elements water distribution system and drift eliminator. In order to minimize cooling tower drift, baffles known as drift eliminators, which work by changing the direction of the airflow as it passes through them, are located at the cooling tower exit surface. As a result, droplets are collected by inertial impact. The drift eliminator's performance can be quantified mainly by two factors: the droplet collection efficiency and the pressure drop across the eliminator. Chan and Golay [5] developed a numerical technique to design a drift eliminator for a particular cooling tower by setting a pressure drop limit, and then choosing the geometry that provides the best collection efficiency. Zamora and Kaiser [6] calculated the pressure drop and the collection efficiency for several drift eliminator geometries. They proposed correlations for the collection efficiency as a function of an inertial parameter for the geometries studied.

For the purpose of spreading warm water, which needs to be cooled within the cooling tower packing, a component identified as a water distribution system is set in cooling towers. According to Mohiuddin and Kant [7], two different types of water distribution systems, splash and film flow systems, can be found in general use. Splash systems break up the water into small particles in order to expose as much water surface as possible to the air whereas film flow systems distribute the liquid as a thin film (without the formation of droplets) on the packing located underneath. Water distribution systems' operation can be quantified by the pressure drop across the device and the size of the droplets achieved. The higher the pressure drop across the water distribution system is, the smaller the size of water droplets spreading over the packing, and therefore more pumping work is required. Meanwhile, the size of the droplets achieved by the system will affect the cooling tower performance and cooling tower drift.

The configuration of these two components not only affects drift but also the cooling tower thermal performance. The accepted concept of cooling tower performance is the tower characteristic (TC), usually determined by the water-to-air mass flow ratios (L/G). Many studies assessing the influence of some cooling tower constructive elements can be found in the literature. Regarding the packing, Thomas and Houston [8] and Lowe and Christie [9] developed heat and mass transfer correlations with air and water mass flow rates as independent variables by using cooling towers fitted with different types of packing. Kelly and Swenson [10] studied the heat transfer and pressure drop characteristics of a splash grid type of cooling tower packing. These authors correlated the TC with the water-to-air mass flow ratio and concluded that the factors affecting the TC value were found to be the water-to-air ratio, the packed height, the deck geometry and, to a very small extent, the inlet water temperature. Goshayshi and Missenden [11] experimentally studied the mass transfer and the

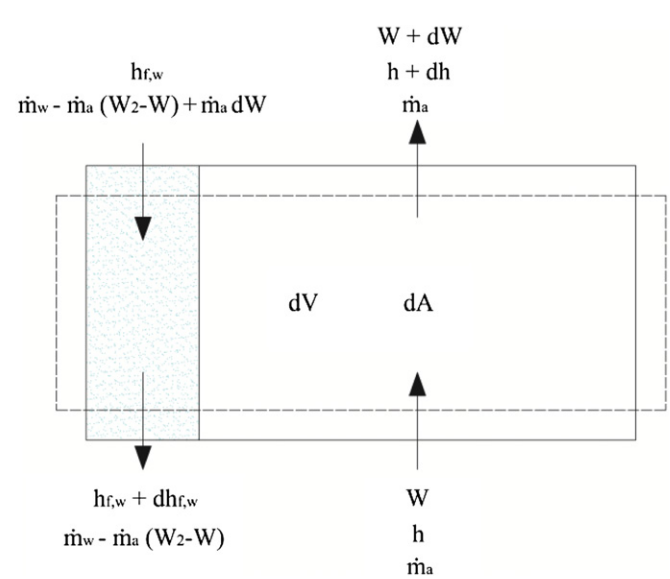

Fig. 1. Schematic diagram of counter-flow cooling tower.