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Thermal performances investigation of a wet cooling tower

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Abstract

This paper presents an experimental investigation of the thermal performances of a forced draft counter flow wet cooling tower filled with an "VGA" (Vertical Grid Apparatus) type packing. The packing is 0.42 m high and consists of four (04) galvanised sheets having a zigzag form, between which are disposed three (03) metallic vertical grids in parallel with a cross sectional test area of 0.0222 m^2 (0.15 m × 0.148 m). This study investigates the effect of the air and water flow rates on the cooling water range as well as the tower characteristic, for different inlet water temperatures. Two operating regimes were observed during the air water contact, a pellicular regime (PR) and a bubble and dispersion regime (BDR). These two regimes can determine the best way to promote the heat transfer. The BDR regime seems to be more efficient than the pellicular regime, as it enables to cool larger water flow rates. The comparison between the obtained results and those found in the literature for other types of packing indicates that this type possesses very interesting thermal performances.

Keywords: Wet; Cooling; Tower; Packing; Flow; Thermal; Characteristics

1. Introduction

Usually industrial processes produce large quantities of heat which must be permanently removed in order to maintain standard operating parameters. Cooling towers filled with packing are widely used to dissipate large heat loads from these processes, such as power generation units, chemical and petrochemical plants and refrigeration and air-conditioning systems, to the atmosphere. Their principle is based on heat and mass transfer using direct contact between ambient air and hot water through some types of packing. Indeed, the type of packing used in cooling tower has an important role in the tower as it controls the heat and mass transfer processes between water and air. Several researchers have investigated this subject through experimental analysis of the heat and mass transfer processes in these equipments.

Simpson and Sherwood [1] studied the performances of forced draft cooling towers with a 1.05 m packing height consisted of wood slats. Kelly and Swenson [2] studied the heat transfer and pressure drop characteristics of splash grid type cooling tower packing. The authors correlated the tower characteristic with the water/air mass flow ratio and mentioned that the factors affecting the value of the tower characteristic were found to be the water-to-air ratio, the packed height, the deck geometry and, to a very small extent, the hot water temperature. They also mentioned that the tower characteristic at a given water-to-air ratio was found to be independent of wet bulb temperature and air loading, within the limits of air loading used in commercial cooling towers. Barile et al. [3] studied the performances of a turbulent bed cooling tower. They [3] correlated the tower characteristic with the water/air mass flow ratio.

El-Dessouky [4] studied the thermal and hydraulic performances of a three-phase fluidized bed cooling tower.

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Nomenclature

a	contact area air–water, m^2	V	volume of the exchange core, m^3
G	air mass flow rate, kg/h	G'	air mass flux, kg/m^2 h
L	water mass flow rate, kg/h	L'	water mass flux, kg/m^2 h
T_1	inlet water temperature (°C)	T_2	outlet water temperature (°C)
t_1	inlet air temperature (°C)	t_2	outlet air temperature (°C)
R	cooling water temperature range (°C)	KaV/L	tower characteristic (dimensionless)

He used spongy rubber balls 12.7 mm in diameter and with a density of 375 kg/m^3 as a packing, and developed a correlation between the tower characteristic, hot water inlet temperature, static bed height, and the water/air mass flux ratio. Bedekar et al. [5] studied experimentally the performance of a counter flow packed bed mechanical cooling tower, using a film type packing. Their results were presented in terms of tower characteristics, water outlet temperature and efficiency as functions of the water to air flow rate ratio, L/G. They concluded that the tower performance decrease with an increase in the L/G ratio, however they did not suggest any correlation in their work. Goshayshi and Missenden [6] also studied experimentally the mass transfer and the pressure drop characteristics of many types of corrugated packing, including smooth and rough surface corrugated packing in atmospheric cooling towers. Their experiments were conducted in a $0.15\ m \times 0.15\ m$ counter flow sectional test area with 1.60 m packing height. From their experimental data, a correlation between the packing mass transfer coefficient and the pressure drop was proposed. Milosavljevic and Heikkila [7] carried out experimental measurements on two pilot-scale cooling towers in order to analyze the performance of different cooling tower filling materials. They tested seven types of counter flow film type fills and correlated their pressure drop data as well as the volumetric heat transfer coefficient with the water and air flow rates. More recently, Kloppers and Kröger [8] studied the loss coefficient for wet cooling tower fills. They tested trickle, splash and film type fills in a counter flow wet cooling tower with a cross sectional test area of $1.5\ m \times 1.5\ m$. They [8] proposed a new form of empirical equation that correlates fill loss coefficient as a function of the air and water mass flow rates. There exist several other mathematical models which can correlate heat and mass transfer processes occurring in wet cooling towers, such as the models proposed and discussed by Khan et al. [9] and Kloppers and Kröger [10].

The main objective of this study is to investigate the thermal performances of a forced draft counter flow wet cooling tower filled with an "V.G.A." type packing. This type of packing which was first proposed for the mass transfer processes between gas and liquid [11] has not been used in cooling water systems using direct contact between water and air. Recently, Lemouari [12] and Lemouari and Boumaza [13,14] used this packing in an evaporative cooling system to study its thermal and hydraulic performances. Therefore, this study presents an experimental investigation of the thermal performances of cooling towers filled with the "V.G.A." type packing. This packing consists of vertical grids disposed between walls in the form of zigzag. The principle of its performance is as follows: the gas (air) enters by the bottom of the tower and arrives by the top of that while crossing several times the vertical grids, whereas the liquid (water) is introduced at the top of the tower and flows along the vertical grids.

The obtained results which relate mainly the tower characteristic as well as the cooling water range temperature (35 °C and 50 °C) with the air and water flow rates seem to be in agreement with those shown in the literature. This suggests the validation of these results.

2. Experimental apparatus and procedure

The experimental apparatus used in this study is illustrated in Fig. 1. It consists mainly of a cooling tower (1) which represents the main device used in this test, a cold water basin (2), a storage tank (3) which contains two electric heaters (12), a water pump (4), a flow meter device (5), a by-pass pipe (6), a water distributor (7), a fan (8), an air distribution chamber (9), a water-drops separator (10), a thermostat (11). Auxiliaries items are also used such as temperatures and pressures measuring devices (13), (14) as well as system for the regulation of water levels (15) in the feed basin. The cooling tower [12] has a parallel form of dimensions $206\ mm \times 148\ mm \times 550\ mm$, and is made of Plexiglas. It is filled with the "VGA" type packing having a cross-sectional area of $150\ mm \times 148\ mm$, height of 420 mm and consists of four (04) galvanised zigzag form sheets, between which are disposed three (03) metallic vertical grids in parallel. The distance between each two grids is 50 mm (width of the cell). The water distributor [12] is made of copper tubes of 10/12 and 6/8 mm diameters, respectively. Fine droplets sweeping the width of the zigzag starting from the top of the tower are introduced through this distributor. The considered measurements which were taken consist of the temperatures increase (dry and wet) of the air at the entry and exit of the tower, as well as the inlet and outlet water temperatures.

The experimental procedure is as follows:

– Initiating the circulation of a water flow, and lighting the electrical heaters at the same time.