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Performance Assessment of a Counter Flow Cooling Tower – Unique Approach

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Abstract

Cooling tower is one of the most suitable system for evaporative cooling of hot water in comparison with other types of evaporative cooling systems. In the present study, a finite difference model is developed for predicting the characteristics of coupled heat and mass transfer processes occurring in a counter flow forced draft cooling tower. This model consists of thermal effectiveness, height of the tower and moisture effectiveness as variable parameters, and provides a correlation for heat and mass transfer coefficients in order to obtain the desired performance parameters. The predicted results for evaporative cooling process are in good agreement with the experimentally measured data. The mathematical model developed in this study can be used as a tool for predicting the cooling tower performance characteristics.

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*Keywords:*Cooling tower, heat transfer coefficients, mass transfer coeffieicents, moisture wffectiveness, thermal effectiveness, evaporation loss

1. Introduction

Cooling towers are widely used in the thermally driven cooling systems, such as oil refineries, thermal power plants, water cooled condenser based air conditioning systems, petrochemical and other chemical industries for rejecting the waste heat. There are several types of cooling towers in which the forced draft counter flow cooling tower is most commonly used in small scale industries. Also, this type of cooling tower is widely used in laboratories for demonstration purpose. Cooling tower works on the principle of evaporative cooling where ambient air is humidified

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and hot water is cooled due to heat and mass transfer interactions between them. The driving potential for heat transfer is temperature difference between the ambient air and the water whereas for mass transfer is their vapour pressure difference. The complicity of heat and mass transfer have been studied way back from 1925. Merkel [1] was the first person who described the heat and mass transfer process for an evaporative cooling by proposing a mathematical model. Several researchers have emphasized on various analytical models for coupled heat and mas transfer processes using ε-NTU models [7-11] and finite difference models [2-6, 12, 13]. Zivi et al. [2] extended the analysis of Merkel to cross flow cooling towers. In Merkel's method evaporation loss has been neglected. Therefore, Zivi et al. [2] proposed a new mathematical model and studied the performance of cross flow cooling tower by considering evaporation loss. It has been observed that by ignoring evaporation loss introduces an error in the Merkel results which is not conservative and may reach 12% depending on the design conditions. Nottage [3] and Yadigaroglu and Pastor [4] modified and analyzed the Merkel model for greater accuracy. Threlkeld [5] analyzed the cooling tower, taking into consideration the water loss due to evaporation and the actual Lewis number, unlike the assumptions made in Merkel's model.

Nomenclature

c_p	specific heat at constant pressure (kJ/kg-K)
$\dot{m}$	flow rate (kg/s)
G	mass flux or flow rate per unit cross-sectional area (kg/ m^2-s)
a_t	specific surface area per unit volume (m^2/ m^3)
T	temperature (°C)
z	height of the tower (m)
h	enthalpy (kJ/kg)
Greek letters	
ξ	effectiveness
λ	evaporation loss (kg/m^2-s) or (kg/s)
δ	latent heat of vaporization (kJ/kg)
ω	air specific humidity ratio (kg$_v$ /kg$_{da}$)
$\propto_m$	mass transfer coefficient (kg/m^2-s)
$\propto_h$	heat transfer coefficient (W/m^2-K)
Subscripts	
a	air
e	equilibrium
v	water vapour
w	water
i	inlet
o	outlet
T	thermal
m	moisture

Poppe model was developed in the early 1970s [6] and does not make any simplified assumptions made by Merkel. The main difference between the Merkel and Poppe models were discussed by Kloppers and Kroge [7]. The objectives of their investigation were to include the ε-NTU method and compare Merkel, Poppe and ε-NTU models. They concluded that for estimating the water outlet temperature of the cooling tower either Merkel or ε-NTU method could be used but for the estimation of heat transfer rate, prediction through Poppe approach was accurate. Jaber and Webb were proposed [8] a modified definition of effectiveness based on an analogy between counter flow heat exchangers and counter flow cooling towers. This effectiveness model simplifies the complicated calculations which are encountered in Merkel and Poppe method and reduces the computational time. Cheng-Qin et al. [9] reformulated the simple effectiveness-NTU model to take into consideration the effect of non-linearity's of humidity ratio, the enthalpy of air in equilibrium and the water losses by evaporation. Khan and Zubair [10, 11] considered the effects of Lewis