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Further investigation on the performance of a shower cooling tower

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Abstract

This study was prompted by the need to design towers for applications in which, due to salt deposition on the packing and subsequent blockage, the use of tower packing is not practical. In the previous model we presented [Qi Xiaoni, Liu Zhenyan, Li Dandan. Performance characteristics of a shower cooling tower. Energy Convers Manage 2007;48(1):193–203.], three critical assumptions were made to reduce the complexity and computational time, which can also reduce the models' accuracy. Accurate modelling of the operating process is a determining factor both for designing the shower cooling tower (SCT) and for optimising its operation. In this paper, we derive a new model without applying the three assumptions. According to the condition of the outlet air, the governing equations consider two cases, including the supersaturated and unsaturated states. This model is used to predict the performance of a full scale SCT located in China with different conditions for validation. The differences in the heat and mass transfer analyses of the two models are described at different atmospheric conditions.

Keywords: Shower cooling tower; Critical assumptionss; Heat and mass transfer model; Performance

1. Introduction

Cooling towers remain widely used in industry and air conditioning for cooling circulating water [2–4]. The conventional tower packed with fill or packing material has a great surface area, as shown in Fig. 1a. In the conventional cooling tower, fill acts as the medium of heat and mass transfer, by means of which the air entrains thermal energy by absorbing heat and humidity. A common fill material is wood or fiberglass slats over which the water slowly drips. The purpose of the fills is to distribute the water current and provide a great surface area for contact between the air and the water. However, the fills are subject to fouling during operation, which reduces the tower's efficiency with time. Fouling of cooling tower fills is one of the most important factors affecting its thermal performance, which reduces the cooling tower's efficiency and capability. On the other hand, the existence of the fills increases the draught drag extremely, which is the main part of the power consumption. So, the general disadvantages of the conventional cooling tower include: lower temperature drop, higher power consumption, noise of motor, fills easily blocked, electric fan easily damaged, unstable cooling effect, difficulty of replacing or cleaning the fills and so on.

In view of the disadvantages of the conventional packed cooling tower (PCT), some scholars [5–7] developed a new type of shower cooling tower (SCT) in which fills are eliminated entirely and small water droplets replace the fill as the mode of mass transfer. This is a breakthrough for the cooling tower. The SCT broke the design way of the conventional cooling tower by doing away with the fills of the original countercurrent type of cooling tower and ameliorating the spray distribution of water. In SCTs, the circulating water is separated into small droplets in the spray distribution water zone and the drenching zone in which normal heat transfer can be accomplished without fill and the circulating water can be cooled to the anticipated temperature.

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Nomenclature

A	area (m^2)
c	specific heat (kJ/(kg °C)]
C_d	drag coefficient on droplet (dimensionless)
g	gravitational acceleration (m/s^2)
d	equivalent diameter (m)
h_c	heat transfer coefficient (W/m^2 K)
h_d	mass transfer coefficient (kg/m^2 s)
i_v	specific vaporization heat of water (kJ/kg)
m	mass or mass flow rate (kg)
i	specific enthalpy (kJ/kg)
Le_f	Lewis factor
Nu	Nusselt number
Pr	Prantdl number
Re	Reynolds number
Sc	Schmidt number
Sh	Sherwood number
t	time (s)
T	temperature (°C)
u	velocity (m/s)
U	internal energy (J)
w	humidity ratio of moist air evaluated at T_a (kg/kg)
z	vertical coordinate (m)

Symbols

λ	thermal conductivity coefficient (W/mK)
μ	dynamic viscosity coefficient (Pa/s)
ρ	density (kg/m^3)

Subscripts

a	air
c	convection
d	droplet
e	evaporation
p	constant pressure
s	saturated
ss	supersaturated
v	vapor
w	water
1	inlet
2	outlet

In the conventional cooling tower, due to salt deposition on the packing and subsequent air flow block, the thermal performance of the tower declines after a period of time. Eliminating the fill makes the tower fully empty, which is of far reaching significance in circulating water with high temperature, high turbidity [5]. Application of PCTs to industry is not practical due to salt deposition on the packing and subsequent blockage.

Studies of SCTs have been reported sporadically over the years: B. Givoni developed a kind of SCT used for cooling buildings in 1995 [6,7], which consists of an open shaft with showers at the top and a collecting pond at the bottom. A pond at the bottom of the shaft collects the sprayed water for recirculation by a small pump. He introduced the system and performed a test to analyze its thermal performance. His students tested and compared the performance of this system in three very different climates in another paper. However, they did not give any theoretical analysis to assist the system. In China, the SCT attracts many investigators' attention and is becoming a research hotspot these years. From the current research situation, SCTs are mainly studied through experimental research. So, there are few papers presenting a detailed analysis of a SCT. In the last year, we analyzed the performance characteristics of a SCT and derived a mathematical model (designated as Model 1 herein) for a SCT that is based on one dimensional heat and mass balance equations [1]. The theory of heat and mass transfer exchange at the water droplet level is utilized,

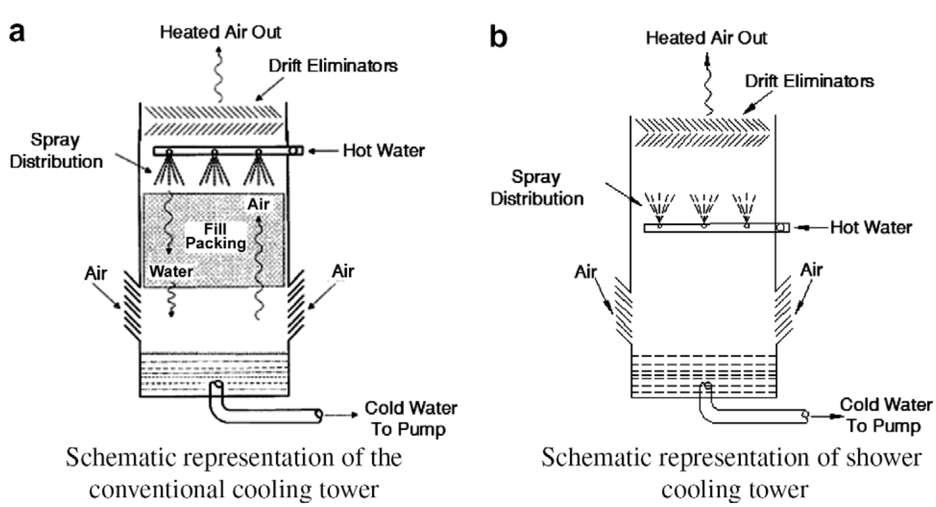

Fig. 1. (a) Schematic representation of the conventional cooling tower and (b) schematic representation of shower cooling tower.