International Journal of Thermal Sciences 90 (2015) 70–78

Contents lists available at ScienceDirect

International Journal of Thermal Sciences

journal homepage: www.elsevier.com/locate/ijts

Water spray for pre-cooling of inlet air for Natural Draft Dry Cooling Towers – Experimental study

Abdullah Alkhedhair*, Zhiqiang Guan, Ingo Jahn, Hal Gurgenci, Suoying He

Queensland Geothermal Energy Centre of Excellence, School of Mechanical and Mining Engineering, The University of Queensland, Brisbane 4072, Australia

ARTICLE INFO

Article history:
Received 28 July 2014
Received in revised form
24 November 2014
Accepted 24 November 2014
Available online

Keywords:
Natural draft
Spray
Pre-cooling
Evaporation
Droplet
Spray efficiency

ABSTRACT

This paper deals with an experimental investigation of inlet air pre-cooling with water sprays aimed to enhance the performance of Natural Draft Dry Cooling Towers during high ambient temperature periods. An open-circuit wind tunnel with a test section of 1×1 m^2 cross section and length of 5.2 m was employed to represent an inlet flow area section in a Natural Draft Cooling Tower. Experimental measurements of droplet evaporation and air cooling are presented. Nine high pressure, hollow cone nozzles were tested at various droplet sizes, air velocities (1, 2, 3 m/s), and injection rates under different ambient conditions. The water spray was characterized using a Phase Doppler Particle Analyser (PDPA). The effects of drop size distribution and air velocity on droplet evaporation, cooling effectiveness, and coverage area were investigated. The data shows clear trends of cooling enhancement with low air velocity or small droplet size distribution. It was found that the spray cooling efficiency, to a large extent, is dependent on spray coverage area. The experimental findings will benefit optimizing spray cooling performance in Natural Draft Dry Cooling Towers and nozzle arrangement.

1. Introduction

This paper presents results of a study on the effect of droplet size and air velocity on performance of inlet air spraying to enhance the performance of natural draft dry cooling towers (NDDCTs). This knowledge is crucial for designing effective spray cooling systems for NDDCTs. Due to a number of reasons, which include water consumption restrictions, environmental regulations and flexibility of plant site selection [1,2], air-cooled condensers in general, and NDDCTs in particular, are becoming the preferred choice for many power plants despite their higher capital costs and the reduced performance at high ambient air temperatures. The performance of dry cooling towers can be enhanced on hot days by various techniques [3,4], including water sprays.

In water spray cooling, water is sprayed into the inlet air in order to reduce the inlet air temperature by evaporative cooling. Cooler air means cooler condensers. This increases the overall cycle efficiency and helps the plant recover some of the performance reduction caused by hot ambient temperatures. An effective water spray design needs to avoid non-uniform cooling distribution and incomplete evaporation of droplets. These issues can be avoided and an optimum design can be achieved only if the spray cooling mechanisms under these conditions are well understood. Although a considerable amount of literature has been published about spray cooling in different applications, mainly gas turbine fogging and air conditioning, no study exists on analysing spray cooling under conditions typical of NDDCTs. Applications of spray cooling in gas turbine fogging and air conditioning generally have different operating conditions from those for natural draft cooling towers.

Over the past decades, spray cooling has become more popular due to its simplicity, low capital cost, and ease of operation and maintenance [5]. Furthermore, the air stream motion is not affected by the presence of droplets, as the pressure drop caused by the sprays is insignificant [6]. Spray nozzles are used to distribute water into the inlet air and to provide a large water–air contact surface by producing small droplets as can be seen in Fig. 1.

The knowledge of the optimum droplet size is crucial for designing spray cooling systems. According to Wells [7], spray droplet size distribution is a major parameter that impacts droplet movement and evaporation efficiency. Spray cooling performance is also strongly influenced by air velocity [8]. Some of the other important parameters are: (a) cone angle, (b) injection rate, (c) droplet velocity, (d) injection direction, (e) meteorological condition [8–11].

---

* Corresponding author. Tel.: +61 411217779.
E-mail address: a-khoder@hotmail.com (A. Alkhedhair).

http://dx.doi.org/10.1016/j.ijthermalsci.2014.11.029
1290-0729/

Nomenclature

A	area (m^2)
D_{32}	sauter mean diameter (μm)
D_{v90}	90% of water volume made up of droplets of this size and smaller (μm)
$\dot{m}_a$	air flow rate (kg/s)
$\dot{m}_w$	water flow rate (kg/s)
RH	relative humidity (%)
V_a	air velocity (m/s)
V_d	water velocity magnitude (m/s)
$T_{db,o}$	average outlet air temperature (°C)
$T_{db,ao}$	average outlet temperature at the cooled area (°C)
P_w	water pressure (MPa)
w	humidity ratio (kg/kg of dry air)
η	spray cooling efficiency

Subscripts

a	air
w	water
i	inlet
o	outlet
db	dry-bulb
wb	wet-bulb
c	cooling
m	modified

A limited number of numerical and experimental studies were carried out on spray cooling performance [1,12,13]. In particular, a numerical investigation conducted by Tissot [11] on a small channel has shown that sprays with small droplet size distributions may result in a reverse effect on the global spray cooling efficiency due to the compromise effect of momentum exchange and evaporation rate. In an earlier numerical study [5], modelling the spray cooling performance in a test channel approximating the inlet flow in an NDDCT, the present authors showed that the global cooling performance relies mainly on droplet size distribution and air velocity. There also is a trade-off between droplet size and air velocity and the resulting spray dispersion due to momentum exchange. Based on the numerical results on the previous paper [5], a wind tunnel test rig approximating the NDDCT inlet flow conditions was built and utilised for this study.

The droplet evaporation and the resulting cooling of the air were investigated experimentally for a range of inlet air conditions and a number of spray nozzles and water flow rates. The following sections report on the results of this investigation. Droplet evaporation rates and cooling effectiveness are quantified in terms of air temperature and humidity. The effects of drop size distribution and air velocity on droplet evaporation and cooling effectiveness are discussed. A modified cooling efficiency is introduced to distinguish the effect of spray dispersion on the cooling effectiveness.

2. Materials and methods

2.1. Test section

An open-circuit wind tunnel located at the University of Queensland (Gatton Campus) was employed as an approximation to the inlet flow environment in an Natural Draft Cooling Tower. The wind tunnel setup and associated instruments utilized in this experiment are illustrated in Fig. 2. The tunnel overall length is 10 m with test section dimensions of 1 m height, 1 m width, and 5.2 m in length. The experimental rig mainly consists of an air system, a water system, a test section and measurement systems. During the experiment, air is drawn into the tunnel through a variable speed centrifugal blower fan (2) then passes through a diffuser with four perforated metal plate screens (5). A subsequent honeycomb (6) (19 mm diameter and 50 mm width) and four woven nylon screens (7) eliminate flow eddies and provide a uniform air velocity profile to the working section. One nozzle (8) is installed in the centre of the working section and directed horizontally in a co-current direction (air and water moving in the same direction) at a height of 0.6 m and 0.55 m downstream from the contraction cone to avoid non-uniformities in the air flow. Fallen water is drained into two sumps placed at the middle and end of the working section (10). The test section side walls are made of transparent acrylic to allow visualization of the water spray as well as giving access to the PDPA system and the photographing system (21, 22). Moreover, the test section side walls are removable to allow nozzle replacement.

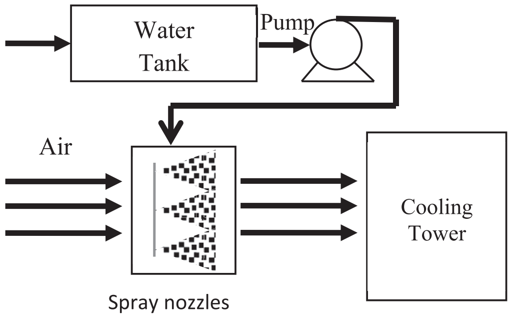

Fig. 1. Schematic diagram of inlet air cooling by spray.

2.2. Air system

Air entering the wind tunnel is drawn directly from the atmosphere. The air is provided via a variable speed centrifugal blower fan powered by a 75 kW electric motor. The electric motor is equipped with a digital frequency controller to accurately control motor speed in the range 15–1650 rpm. In order to supply the controlled inlet air for the tunnel at desired level of temperature and humidity, a 24 kW air heater (20) upstream of the fan inlet was employed. The temperature is controlled to avoid fluctuation due to seasonal changes. The air heater (20) is capable of providing a 6 °C increase at 3 m/s air velocity. The heater size was one of the limitations on the experiment as some of the desired inlet conditions couldn't be obtained with high air flow rates. The heater is connected to a controller, which controls the temperature to ±0.5 °C.

2.3. Water system

The water supply system consists of three joined water tanks (18), a high pressure water pump (15), a recirculation pump (11), the spray nozzle (8) and associated high pressure piping. During the experiment, tap water is pumped from the main water tank to the spray nozzles through the high pressure piping using a variable speed, high pressure water pump. The flow rate delivered to the nozzle is controlled by a bypass valve (13), where excess water is