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Performance evaluation of water collection systems for a hybrid dephlegmator

Jacques du Plessis, Hanno C.R. Reuter *

Department of Mechanical Engineering, Stellenbosch University, Private Bag X1, Matieland 7602, South Africa

HIGHLIGHTS

- A water collection system is investigated to determine its collection effectiveness, drainage capability and pressure drop.
- Modifications are made that increase the collection effectiveness from 92% to 100%.
- Parametric CFD models are used to determine the loss coefficients for the trough and various basin systems designs.
- Empirical relations are proposed using the parametric CFD models.
- A comparison shows that the trough system generally has the lowest loss coefficient and pumping head requirements.

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ABSTRACT

Trough and basin water collection systems are used in wet-cooling towers and evaporative air-cooled heat exchangers to collect cooling or deluge water below the fill or heat exchanger bundle at the air inlet. Trough systems typically collect water in overlapping parallel troughs while allowing air to pass upwards between the troughs, whereas basin systems collect the water in a basin and the air enters laterally above the basin edge. The novel hybrid (dry/wet) dephlegmator (HDWD) requires a deluge water collection system supported high above the ground. A trough system is therefore considered the best option for this application. Apart from patents, limited information is found on the design and air-side loss coefficients of such systems and how they compare to equivalent basin systems. An existing trough collection system is therefore investigated experimentally to determine its collection effectiveness and drainage capability and to measure pressure drop characteristics. Modifications are made that increase the collection effectiveness from 92% to 100%. Parametric CFD models are developed and used to determine the loss coefficients for the trough and various basin system designs and empirical relations are proposed. A comparison shows that the trough system generally has the lowest loss coefficient and pumping head requirements.

1. Introduction

In this paper, the water collection, drainage and pressure drop characteristics of an existing and modified collection trough design are determined experimentally to verify improvements in performance. A validated parametric CFD model is developed and used to investigate the effects of various geometric parameters on the air-side loss coefficient. An empirical relation is proposed for design purposes that fits the numerical data. CFD models are also developed for different single and cascaded basin designs to obtain air-side loss coefficient data and empirical correlations, which are ultimately used to compare the proposed trough system with various basin systems.

Water collection systems are designed process specifically to collect drops or streams of water falling under gravity through air that passes either in counter-, cross- or cross-counterflow to it, as typically required at the air inlets of wet-cooling towers and evaporative cooling systems. Water trough systems (Fig. 1a) allow air to pass upwards through them while collecting the free-falling water in overlapping parallel troughs. In the more commonly used water basin systems (Fig. 1b), the water is collected in a basin and the air enters the cooling tower or deluged heat exchanger through lateral air inlets above the basin. The geometry and design of the above mentioned water collection systems result in different air-side flow patterns and loss coefficients and water pumping head requirements which need to be optimized.

The hybrid (dry/wet) dephlegmator (HDWD) is an air-cooled steam condenser that uses dry and wet cooling to enhance power

* Corresponding author.

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Nomenclature

A	area (m^2)
B	buoyancy, breadth (m)
D	diameter (m)
E	energy (J)
F	force (N)
G	mass velocity (kg/m^2 s)
g	gravitational acceleration (m/s^2)
H	height (m)
K	loss coefficient (–)
L	length (m)
m	mass flow rate (kg/s)
N	rotational speed (rpm)
P	power, pressure (W, N/m^2)
R	radius (m)
S	slope (m/m)
T	temperature (K)
t	temperature (°C)
V	volume (m^3)
v	velocity (m/s)
W	width (m)
x	co-ordinate, spacing (m, m)
y	co-ordinate (m)

Subscripts

a	air
b	basin
bl	blades
c	casing
ch	channel
ct	cooling tower
d	drag, drop, dynamic
db	delugeable bundle
dp	deflector plate
f	frontal, fan
ft	finned tube
h	hub, hydraulic
he	heat exchanger
m	mechanical
i	initial, inlet
p	primary, pump
pr	projected
rz	rain-zone
s	secondary, shroud, static
t	total
tr	trough
w	water

List of abbreviations

CFD	computational fluid dynamics
DPM	discrete phase model
EACHEs	evaporative air-cooled heat exchangers
HDWD	hybrid for (dry/wet) dephlegmator
NDWCT	natural draft wet-cooling towers
SU	Stellenbosch University
VSD	variable speed drive
WCTs	wet-cooling towers

plant performance [1]. As can be seen in Fig. 1, wet cooling is achieved by means of a second stage horizontal delugeable bare tube air-cooled heat exchanger (wet/dry) bundle connected to the steam outlet of a finned tube (dry) bundle. Since these units are located high above the ground and air enters the heat exchangers in parallel from below, a trough water collection system is considered to be the most suitable option for this type of system.

Limited literature is available on the performance characteristics of trough systems even though a number of patents have been registered [3,4] and [8]. Performance data are therefore needed for collection system design purposes and calculation of the air-side flow losses.

In the following sections, the experimental work and CFD models used to develop novel collection trough and basin system design and empirical loss coefficient relations are presented and discussed.

2. Experimental work

This section presents the experimental work done to measure the water collection effectiveness, water draining capabilities and air-side flow losses of an existing and modified trough design, depicted in Fig. 2.

2.1. Drop impingement tests

Drop impingement tests are conducted to observe if all the water impinging on the trough is collected in the channel.

2.1.1. Experimental apparatus

The experimental setup is shown in Fig. 3. A stream of single water drops, produced by a drop generator, is allowed to impinge on the top edge, inclined plane and lower edge (Fig. 2) of a single water trough, which is recorded with a high speed digital camera at a rate of 150 frames per second. The drop diameters and trajectories are measured directly from the photo images, as done by Terblanche [12]. Tests are conducted on the original trough design and various modified troughs.

2.1.2. Results

It was seen that water drops impinging on the top edge of the trough are cut into two parts, where one part falls onto the inclined

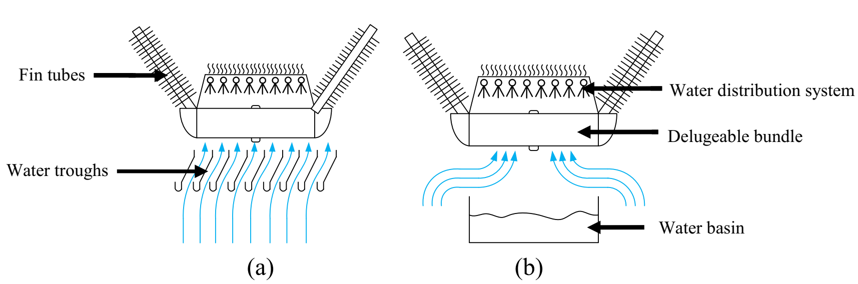

Fig. 1. (a) Troughs with vertical flow. (b) Basin with lateral flow.