Energy Conversion and Management 126 (2016) 526–536

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Numerical and experimental investigation of a novel configuration of indirect evaporative cooler with internal baffles

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ARTICLE INFO

Article history:
Received 15 April 2016
Received in revised form 20 July 2016
Accepted 15 August 2016
Available online 24 August 2016

Keywords:
Indirect evaporative cooler
Internal baffles
Experimental
Theoretical model
Wet bulb effectiveness
Dew point effectiveness

ABSTRACT

In this study, five configurations for a novel indirect evaporative cooler with internal baffles in the dry air channel (Type A, Type B, Type C, Type D and Type E) were proposed to determine a better configuration of indirect evaporative cooler. The discretization of the governing equations of mass and heat transfer by using the finite difference method and solved by method of iterative in MATLAB. The numerical results of these simulations are validated by present experimental data and published experimental data, which resulted great agreement between numerical results and experimental data. Results show that under these five configurations, for change the inlet air conditions, the outlet cooling air temperature decreases with increases the number of baffles, the percentage decreases about 15.1%, 18.9%, 20% and 20.5% for Type B, Type C, Type D and Type E compared to Type A respectively, whereas the average wet bulb effectiveness of Type B, Type C, Type D and Type E are around 33.3%, 40.3%, 42.3% and 43% higher than that of the Type A respectively. For change the inlet air velocity from 1.5 to 5.5 m/s, the outlet cooling air temperature varies over ranges of 21.3–27.3 °C, 18.4–23.3 °C, 18.2–22.75 °C, 18–22.6 °C and 17.9–22.5 °C for Type A, Type B, Type C, Type D and Type E respectively. The results showed that a novel configuration of indirect evaporative cooler with internal baffles is a better configuration to investigate the condition of thermal comfort.

1. Introduction

The use of the evaporative cooling system to reduce the temperature of the air is a good option in cooling applications. Evaporative cooling system is one contrasting option to conventional vapor compression for applications of air conditioning. Also, the evaporative cooling system utilized as a low energy consuming device for different applications of air conditioning and cooling in agricultural, industrial and buildings in dry and hot locales. Two main groups of the evaporative cooling system are; indirect evaporative cooling system and direct evaporative cooling system. Different uses of evaporative cooling have been broadly concentrated on and utilized for modern and private segments, for example, humidifier, evaporative cooler and cooling tower [1–6]. The evaporative cooling system required electrical power for the air blower and water pump. Therefore, the saving in the electrical power approximately 66% compared to the conventional vapor compression system [1–4].

Ren and Yang [7] proposed a one-dimensional model for description of the heat and mass transfer in the indirect evaporative model with counter/parallel stream arrangements. Their explanatory results demonstrated great concurrence with the numerical results of their model. Hettiarachchi et al. [8] introduced the impact of the Longitudinal Heat Conduction on the transfer wall for the indirect evaporative model with cross stream arrangement. They assumed the temperature distribution over the water film and the walls are same. This model was the main model which considered the impact of the Longitudinal Heat Conduction on the transfer wall for the indirect evaporative model with cross stream arrangement. Heidarinejad and Bozorgmehr [9] proposed a heat and mass transfer model for indirect/direct evaporative model. Their model utilized a few presumptions, for example, the exchanger divider and water layer has the same temperature. Their model indicated great assignation with the experimental data. Heidarinejad et al. [10] experimentally studied the behavior of a two-stage indirect/direct evaporative cooler. They showed that for using a two-stage indirect/direct evaporative cooler the effectiveness changes in a range 108–111% while for using a single stage indirect evaporative cooler the effectiveness changes in a range of 55–61%.

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http://dx.doi.org/10.1016/j.enconman.2016.08.028
0196-8904/

Nomenclature

A	wall area (m^2)
c_p	heat capacity (kJ/kg °C)
C_F; C_w	fluid to air and water to air heat capacity ratios, respectively
D_H	channel hydraulic diameter (m)
H	the coefficient of heat transfer (W/m^2 °C)
h_c	the coefficient of convective heat transfer (kW/m^2 °C)
h_{fg}^o	water evaporation heat at (0 °C) kJ/kg
h_v	water vapor specific enthalpy at water film temperature (kJ/kg)
K	thermal conductivity (W/m K)
K_m	the coefficient of convective mass transfer (kg/m^2 s)
L	channel length (m)
Le	Lewis factor
M	the rate of mass flow (kg/s)
NTU	number of heat transfer units
Nu	Nusselt Number
P	pressure (Pa)
RH	Relative Humidity (%)
Re	Reynolds Number
s_d	distance between baffle (m)
s_h	baffle height (m)
s_p	the gap between the plate (m)
T	wall thickness (m)
T	temperature (°C)
U	coefficient of overall heat transfer (kW/m^2 °C)
V	velocity (m/s)
W	channel width (m)
x	coordinate along channel length (m)
y	coordinate along channel width (m)

Greek letters

ε_{dew}	dew point effectiveness
ε_{wb}	wet-bulb effectiveness
λ	thermal conductivity ratio
μ	coefficient dynamic viscosity (Pa s)
ρ	density (kg/m^3)
σ	surface wettability

Subscripts

asw	moist air in equilibrium with a water surface
ca	cooling air
i	Inlet
o	Out
pl	Wall
v	water vapor
wa	working air
w	water film

Heidarinejad et al. [11] numerically studied the behavior of a ground- coupled circuit -assisted hybrid a direct evaporative cooling system. They showed that the mix of ground coupled circuit and the direct evaporative cooling system is competent so as to give comfort conditions while direct evaporative cooling system alone did not. They suggested that this novel system is a naturally spotless and vitality effective system, which can be utilized as a different option for the conventional vapor compression systems. Khalajzadeh et al. [12] numerically studied the behavior of a novel integrated system consists of an indirect evaporative cooler and a ground heat exchanger. In their numerical study, the ground heat exchanger used as the pre-cooling unit before the indirect evaporative cooler to cool the inlet air to the indirect evaporative cooler. They showed that this novel system is a naturally spotless and vitality effective system, and could easily provide thermal comfort conditions. Woods and Kozubal [13] studied the behavior of the hybrid air conditioning consists of a liquid desiccant dehumidifier and an indirect evaporative cooler.

Buker et al. [14] experimentally studied the behavior of a solar energy driven liquid desiccant coupled evaporative cooling system. They demonstrated that their proposed system was proficient to give around 5.2 kW of cooling, 3 kW of heating and 10.3 MW h/year power generations. Pandelidis and Anisimov [15] presented heat and mass transfer model in different eight types of the M-Cycle exchangers. Their numerical study showed that the performance of the heat and mass exchangers strongly depends on the inlet air conditions. Younis et al. [16] created prescient numerical models of the conditioned space with a specific end goal to study the performance of displacement ventilation system combined with new evaporative cooled ceiling. They demonstrated that the energy saving for the displacement ventilation system combined with a new evaporative cooled ceiling about 36.2% compared with the displacement ventilation system combined with chilled ceiling system. Heidarinejad and Moshari [17] created a new numerical model to study the behavior of a cross-flow indirect evaporative cooling system taking into account the impact of gravity-driven water temperature variation and wall heat conduction along the exchanger plate. They demonstrated that at the same inlet air conditions the effectiveness of a two-stage indirect/direct evaporative cooling system is 50% higher than that of a one-stage indirect evaporative cooling system.

With regard to the above-mentioned researchers, there has been no attention on the various design of indirect evaporative cooler. The aims of the present study is to present five novel configurations of indirect evaporative cooler, whereas one configuration (Type A) is the indirect evaporative cooler without internal baffles in dry air channel, while the other four configurations (Type B, Type C, Type D and Type E) are indirect evaporative cooler with internal baffles in dry air channel with various baffles pitch. In this study, a theoretical model of the heat and mass transfer has been developed to evaluation the performance of the novel configuration of an indirect evaporative cooler with internal baffles in the dry air channel. The system effectiveness and the outlet cooling air conditions predicted by the model are validated by the current experimental work and experimental data by Riangvilaikul and Kumar [18]. The validated model can, therefore, be utilized to optimize and investigate the system effectiveness operating under various inlet air conditions. Also, the effects of different operating conditions (inlet air temperature, inlet air humidity ratio, inlet air velocity and working to cooling air ratio) have been investigated.

2. Description of the novel configuration

The novel configuration of an indirect evaporative cooler is a regenerative evaporative cooler, where a part of inlet air stream is extracted at the end of dry air channel and then circulates to the wet air channel (working air) and the remaining air stream represents the cooling air supply to the cooling space. Five configura-