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Modeling and optimization of dew-point evaporative coolers based on a developed GMDH-type neural network

Hamoon Jafarian, Hoseyn Sayyaadi *, Farschad Torabi

Faculty of Mechanical Engineering-Energy Division, K.N. Toosi University of Technology, P.O. Box: 19395-1999, No. 15-19, Pardis St., Mollasadra Ave., Vanak Sq., Tehran 1999 143344, Iran

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ABSTRACT

A precise model of a counter-flow indirect dew-point evaporative cooler was developed using the group method of data handling-type neural network while the network was trained by extracted data from a validated numerical model. After validating the model, it was employed in a multi-objective optimization problem that implements the non-dominated sorting genetic algorithm-II method. The system was optimized in diverse climatic conditions. In this regard, Yazd, Masjed-Soleiman and Ahvaz were chosen as representatives of cities with hot, hot semi-humid and hot-humid climates in Iran. In each city, optimum values of channel length, channel gap, inlet air velocity and return to intake air ratio were found so that these decision variables maximize the average coefficient of performance and minimize the specific area of the cooler, simultaneously. The results indicated that the developed model can predict the supply air temperature accurately with less than 1 °C error and due to its quick calculation process it is possible to optimize the design based on hourly climate data without any needs to very fast processors. Moreover, using the optimization, the coefficient of performance and specific area for the system designed to be used in Yazd were improved 36.3% and 30.9%, respectively. This figure at Masjed-Soleiman and Ahvaz was 16% and 7.92% improvement in the specific area at the cost of 2.63% and 2.19% reduction in the coefficient of performance, respectively. These improvements allowed the system to reach its full potential and making dew-point evaporative coolers as a suitable cooling system in diverse climatic conditions.

1. Introduction

Nowadays, providing thermal comfort is a necessity for human life. To achieve this purpose, heating ventilation and air conditioning (HVAC) systems consume about 15% of the total electricity produced [1]. Mechanical vapor compression refrigeration is the current dominant technology in the air conditioning market which has a very high electricity consumption. To reduce the electricity usage, researchers have been searching for new and effective technologies. Evaporative coolers are one of the promising technologies in HVAC industry due to their simple structure, low capital cost and high coefficient of performance (COP). Nevertheless, the high humidity of the supplied air and low cooling potential of conventional direct evaporative cooling systems were the main disadvantages of this system that hindered the extension. However, in recent decades, very important breakthroughs were achieved in this field [2,3]. First, the problem of high-humid supply air was solved using indirect evaporative coolers (IECs) and afterward, the new novel thermodynamic cycle (M cycle) was proposed, which increased the cooling capacity by making it possible to reach the supply temperature to the dew-point temperature [4]. Among different suggested configurations of dew point coolers [5–7], the flat plate dew-point counter-flow IEC has shown promising results [8–10]; therefore, it was investigated further in the present paper.

A flat plate dew-point cooler is a stack of paired channels. A pair of channel consists of a supply air channel (dry channel) and exhaust-air's channel (wet channel) that are allocated side by side and separated by a thin plastic wall as shown in Fig. 1. Fig. 2 shows the two airstreams states on the psychrometric chart as they pass through channels. The ambient air enters the supply channel at state 1 and is cooled off by the counter-flow air stream into the exhaust channel. At the end of supply channel, state 2, a fraction of cooled dry air siphons off into the exhaust channel, and the rest is used for air conditioning. In the exhaust channel, water film covers the walls and evaporates into the exhaust air stream. The water evaporation cools the exhaust air that is responsible for cooling the supply air stream. Air at state 2 has a lower wet bulb temperature in comparison to state 1; therefore, it has a higher cooling potential. Hence, using the air in state 2 as an input to the wet channel

* Corresponding author.
E-mail addresses: sayyaadi@kntu.ac.ir, hoseynsayyaadi@gmail.com (H. Sayyaadi).

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Nomenclature

A	area (m^2)
$A_{specific}$	specific area ($m^2\,W^{-1}$)
b	half channel gap (m)
C	cooling capacity (W)
cd	crowding distance for one objective
CD	total crowding distance
c_p	specific heat capacity ($J\,kg^{-1}\,K^{-1}$)
COP	coefficient of performance
D	diffusivity ($m^2\,s^{-1}$)
DI	distance from ideal point
e_c	selection pressure criteria
g	coefficients or weights
h_{fg}	latent heat of evaporation ($J\,kg^{-1}$)
I	number of inputs
k	heat conductivity ($W\,m^{-1}\,K^{-1}$)
L	channel length (m)
$\acute{m}$	mass flow rate ($kg\,s^{-1}$)
MSE	mean square error
n	number of inputs for each neuron
N	total number of inputs
Num_{obj}	number of objectives
Num_{Ip}	initial population
Num_{data}	number of data
$Num_{neurons}$	maximum possible number of neurons in each layer
Num_{ps}	number of solutions on Pareto front
Obj	objective
Obj^n	non-dimensionalized objective
P	pressure (Pa)
q''	heat flux ($W\,m^{-2}$)
$\dot{Q}$	heat rate (W)
r	return to intake air ratio
R	coefficient of correlation
$RMSE$	root of mean square error
T	temperature (K)
u	velocity in x direction ($m\,s^{-1}$)
v	velocity in y direction ($m\,s^{-1}$)
$\dot{V}$	volumetric flow rate ($m^3\,s^{-1}$)
w	channel width (m)
W	electric consumption (W)
x, y	coordinates (m)
Y	real output
$\hat{Y}$	model estimation of output

Greek symbols

α	selection pressure
δ	thickness (m)
μ	dynamic viscosity (Pa s)
η	efficiency, effectiveness
ρ	density ($kg\,m^{-3}$)
ω	humidity ratio ($kg\,kg^{-1}$)

Subscripts

amb	ambient
ave	average
b	base
const	constant power consumers
dp	dew point
e	exhaust channel
f	fan
i	inlet
j	solution index
k	objective index
l	Pareto front solution index
min	minimum
max	maximum
o	outlet
opt	optimum
pl	plate (wall)
s	supply channel
t	total
w	wick

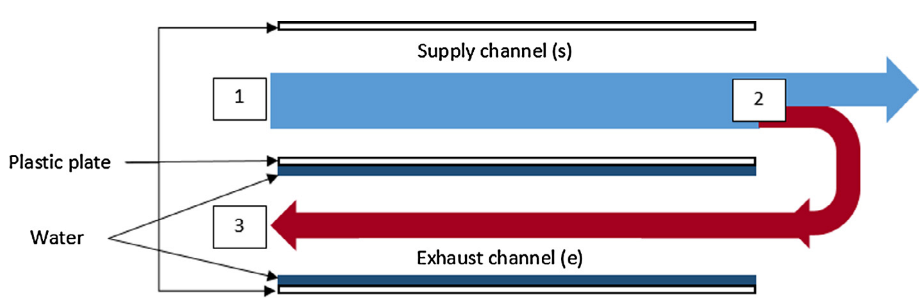

Fig. 1. Schematic top view of a channel pair in a dew-point indirect evaporative cooling system.

is the difference between a dew point evaporative cooler and a conventional IEC.

To reach the best performance of any system, it is required to optimize affecting the design and operating parameters. Therefore, optimization is a necessity for using the real potential of any system. It means that in order to have a higher potential for usage of M-cycles, those should be optimized in a sophisticated optimization approach.

To optimize the system, first, a precise model is required. In this regard, numerical models could be employed. Using a numerical model, it is possible to evaluate the performance of the system under different circumstances. However, the accuracy of the model should be validated by experimental data; afterward, numerical model might be extended to cases that experimental data are not available. Numerical modeling of these coolers was attended by researchers. The key parameter in numerical modeling of the system is the boundary condition on the separating wall of channel pairs; many have considered the boundary condition as constant temperature and calculated constant heat and mass transfer coefficients based on classical heat and mass transfer concepts [9,11–15].

Woods et al. [16] investigated numerical modeling of a dew-point cooler as the second stage of a DEVAP system; The separating