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Experimental study of a counter flow regenerative evaporative cooler with finned channels

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ABSTRACT

A regenerative evaporative cooler has been fabricated and tested for the performance evaluation. The regenerative evaporative cooler is a kind of the indirect evaporative cooler comprised of multiple pairs of dry and wet channels. The air flowing through the dry channels is cooled without any change in the humidity and at the outlet of the dry channel a part of air is redirected to the wet channel where the evaporative cooling takes place. The regenerative evaporative cooler fabricated in this study consists of the multiple pairs of finned channels in counter flow arrangement. The fins and heat transfer plates were made of aluminum and brazed for good thermal connection. Thin porous layer coating was applied to the internal surface of the wet channel to improve surface wettability. The regenerative evaporative cooler was placed in a climate chamber and tested at various operation condition. The cooling performance is found greatly influenced by the evaporative water flow rate. To improve the cooling performance, the evaporative water flow rate needs to be minimized as far as the even distribution of the evaporative water is secured. At the inlet condition of 32 °C and 50% RH, the outlet temperature was measured at 22 °C which is well below the inlet wet-bulb temperature of 23.7 °C.

1. Introduction

Regenerative evaporative cooler (REC) is a type of an indirect evaporative cooler as shown in Fig. 1(a). The flow paths of dry and wet air of REC are shown on psychrometric chart in Fig. 1(b). A portion of the air flown out of the dry channel is redirected into the wet channel which is humidified inducing water evaporation and cools down the wet channel to result in the heat absorption from the dry channel.

The REC has several advantages which correspond with the current trends. The REC is energy efficient since it does not require compressor which is most energy consuming component in the vapor compression refrigeration. Additionally, it is environmentally friendly because the REC employs only water as working fluid. The other merits of the REC include that it can lower the intake air temperature below the wet bulb temperature to the dew point temperature without any increase in the humidity.

A representative configuration for regenerative evaporative cooler comprising dry and wet air passages was proposed as early as 1976 by Maisotsenko and his colleagues in Soviet patent SU No. 979796. The principle and process of the regenerative evaporative cooling were reported in Maisotsenko et al. [1]. Recently his group reviewed the technical fundamentals of REC and presented the performance comparison with a vapor compression system [2]. More recently, an extensive review was conducted by Duan et al. [3] on the background, history, current status, concept, principle, performance evaluation, system configuration, market prospect and future research focuses of regenerative evaporative cooling technology.

One of the earliest practicable configuration of the regenerative evaporative cooler was presented by Pescod [4]. He proposed a simple design method for the regenerative evaporative cooler (REC) using parallel plastic plates with pin protrusions to enhance the heat and mass transfer coefficients. Maclaine-cross and Banks [5] presented an approximate heat and mass transfer model for the analysis of the indirect evaporative coolers. They approximated the saturation line as a linear function of temperature in the operating range and the cooling performance of the evaporative cooler was estimated by analogy to dry surface heat exchangers. They compared their model with finite difference solution and showed they are in good agreement.

Hsu et al. [6] investigated three basic types of wet-surface heat exchangers: unidirectional flow, counter flow and two closed-loop flow configurations with extraction utilizing finite-difference numerical scheme. It is found that the counter flow closed-loop flow configuration has the highest effectiveness so it is the preferred geometry.

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Nomenclature

A	heat transfer area, m^2
c	specific heat, kJ/kg °C
D	dew point, °C
h	heat transfer coefficient, W/m^2 °C
i	enthalpy, kJ/kg dry air
i_{fg}	latent heat of evaporation, kJ/kg
L	streamwise length of cooler, m
m	dimensionless flow rate of evaporative water
$\dot{m}$	mass flow rate, kg/s
N	number of transfer units
Q	heat transfer rate, kW
r_{ex}	extraction ratio
T	temperature, °C
$\dot{V}$	volume flow rate, CMM, m^3/min
w	humidity ratio, kg/kg dry air
x	streamwise coordinate of the dry channel, m

Greek letters

ε	effectiveness
ϕ	relative humidity

Superscript

$*$	dimensionless length

Subscript

a	moist air
d	dry channel
e	evaporative water
in	inlet
out	outlet
s	supply
w	wet channel

Erens and Dreyer [7] discussed modeling of a cross-flow parallel plate REC and conducted numerical analysis. They found the optimum fraction of cooled primary side air passed through the wet side is a function of plate spacing. For a REC with plates spaced 3 mm apart, the optimum extraction ratio is 36%.

Stoitchkov and Dimitov [8] improved Maclaine-cross and Banks method which uses a linear approximate model and presented a simple procedure to estimate the cooling performance of a cross-flow parallel plate evaporative cooler. Their correction offered reliable and fast procedure for wet surface heat exchangers.

Jain [9] developed a prototype regenerative cooler using standard readily available components such as a fin-tube heat exchanger and a cooling tower. In the prototype, the air was cooled in the fin-tube heat exchanger by the cooled water flowing inside the tubes. The cooled water was fed from the cooling tower in which the water was cooled evaporatively by recirculating a part of the cooled process air.

Caliskan et al. [10] evaluated three novel air coolers based on M-Cycle in various aspects. Energy analysis is performed to achieve wet bulb effectiveness, cooling capacity, Coefficient of Performance (COP) and Primary Energy Ratio (PER) of the systems. Exergy efficiency and sustainability are obtained with exergy analysis under six various dead state temperatures. Furthermore, environmental assessments are obtained using GHG emission rates of the systems.

Most of previous work including above-mentioned studies regarding regenerative evaporative cooler employed crossflow type plate heat exchanger. This is attributed to the ease of conversion from the commercialized air-to-air crossflow plate heat exchanger to the regenerative evaporative cooler. However, the crossflow plate heat exchanger has the demerit of large size. In order to achieve the practical use of regenerative cooler, the size is an important factor as well as the cooling performance.

Recently, a few works are found regarding the counter flow indirect evaporative cooler. Zhao et al. [11] numerically investigated a novel counter flow heat and mass exchanger used in the indirect evaporative cooler. They showed that the effectiveness of the cooler is largely affected by the dimensions of the airflow passages, air velocity and working to intake air ratio and less dependent on the temperature of the evaporation water.

Riangvilaikul and Kumar [12] carried out the experimental study of the counter flow REC for various inlet conditions. They constructed a REC consisting of 4 dry channels and 5 wet channels separated by polymer sheets. The dew point effectiveness of the REC ranged from 0.58 to 0.84 for various inlet conditions. The result was also compared with previous studies showing higher effectiveness of the counter flow type REC than cross flow. Riangvilaikul and Kumar [13] also performed a numerical study for the same REC and showed good agreement with the experimental data. They analyzed the effect of various parameters on the effectiveness of the REC such as inlet air conditions, air velocity, channel gap, channel length, extraction ratio. The important finding is that the dew point effectiveness is mainly influenced by the inlet air temperature and humidity.

The field test of the counter flow indirect evaporative cooler was also conducted by Bruno [14]. The cooler is installed in a commercial and residential application. The dew point effectiveness of the cooler was 0.65 for the commercial application and 0.75 for the residential application. Furthermore, it is analyzed that the indirect

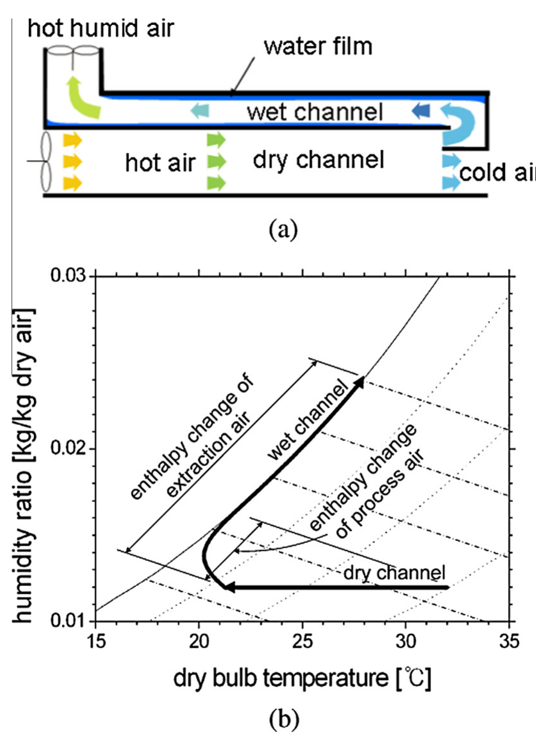

Fig. 1. Principle of regenerative evaporative cooling (a) schematic of regenerative evaporative cooler (b) flow paths of dry and wet air on psychrometric chart.