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Experimental evaluation of the performances of cellulosic pads made out of Kraft and NSSC corrugated papers as evaporative media

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ABSTRACT

The purpose of this study was to evaluate the performances of cellulosic pads made out of Kraft and NSSC corrugated papers in three flute sizes, experimentally. A number of experiments have been done in a wind tunnel in order to evaluate the cooling efficiency and water consumption as a function of air velocity. The tests were carried out at three levels of air velocity (1.8, 2.25, and 2.67 ms^{-1}) for three flute sizes of Kraft and NSSC corrugated papers (2.5, 3.5, and 4.5 mm). Analysis of the results indicated that cooling efficiency improves with decrease of air velocity and flute size of corrugated papers; however, water consumption increases with the increase of air velocity. The results were compared with each other and it was shown that the cellulosic pad made out of Kraft paper with 2.5 mm flute size has the highest performance (92%) at 1.8 ms^{-1} air velocity in comparison with the other cellulosic pads.

1. Introduction

Providing comfortable indoor climate for occupants in a building is a very important subject in air conditioning systems. For this reason, people employ several devices that provide thermal comfort throughout the year. Evaporative cooling process is one of the inexpensive techniques used to improve human comfort conditions during hot season since ancient time [1]. Evaporative coolers have been widely used in many arid areas of the world such as southwestern United States, Australia, and western Asia [2].

The key mechanism in an evaporative cooling process is based on heat and mass transfer between air and water when they contact together [3]. Air can be cooled by passing through the wetted surface and loses a certain amount of sensible heat so increases an equal amount of latent heat of water vapor [4]. As a result of this process, the relative humidity and water vapor content of the air increase [5].

Researchers used different methods to increase the cooling efficiency of evaporative coolers in recent years. These methods include changes of air velocity, mass flow rate of feed water, dry bulb temperature, static pressure drop, pad thickness, genus and geometric structure of pad, quality of feed water, and modification of evaporative cooling structure, etc. Pescod [6] proposed new type of evaporative cooler that utilizes a thin plastic as the surface for the evaporative cooling. It has been found that using this type of evaporative cooler, temperature drop of 10 °C can be achieved. Koca et al. [7] have developed a procedure for testing evaporative cooling pads. Their results show that pad performance is affected by pad angle, pad thickness, face air velocity, and static pressure drop across the pad and can be expressed in terms of evaporative cooling efficiency and static pressure drop. Taha et al. [8] designed and tested special type of evaporative cooler. The cooler consisted of galvanized zinc sheet in a rectangular shape. Charcoal granules were used as an outer wetted layer which produced cooling effect by evaporation. They found that by using this cooler, the ambient temperature is reduced by 10–13 °C. Liao et al. [9] investigated the effects of air velocity and pad thickness on efficiency and pressure drop of evaporative cooling pads. Two kinds of pads such as coir fiber and non-woven fabric perforated pads were used in their experimental work. They have shown that coir pads have high efficiencies (>85%) for all thicknesses. Dzivama et al. [10] suggested that stem sponge is a superior pad material in comparison with the ground sponge, jute fiber, and charcoal. Liao and Chiu [2] investigated the effects of fine and coarse fabric PVC sponge on performance of evaporative cooling pads. Their results have shown that the efficiencies of coarse fabric PVC sponge are higher than fine fabric PVC sponge. Dai and Sumathy [4] studied cross-flow direct evaporative cooler in which the wet durable honeycomb paper

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Table 1
Physical properties of used resin and glue.

Glue	
Polymeric base	Caoutchouc
Solvent	Aromatic
Basic weight (gm^{-3})	0.84
Viscosity (cP)	25–35
Bonding strength ($N\ cm^{-2}$)	15–20
Resin	
Appearance	Milky white liquid
Type	Cross linkable
Emulsifying system	Anionic
Viscosity (cP)	200–500
pH(as packed)	5–6
T_g (°C)	+30
Mechanical stability	Good

constituted as the packing material. They found that the lowest temperature ever achieved and the system performance can be further improved by optimizing the operation parameters such as the mass flow rates of feed water and process air as well as the different dimensions of the honeycombed paper. AL-Sulaiman [11] has evaluated the performance of three natural fibers, palm (stem), jute and luffa. The results indicated that luffa has an overall advantage over the other fibers. Anyanwu [12] reported design, construction, and measured performance of a porous evaporative cooler for preservation of fruits and vegetables. The results have shown that the cooler storage chamber temperature varies over 0.1–12 °C from ambient air temperature. Beshkani and Hosseini [13] have modeled mathematically the performance of rigid media equipped with corrugated papers as a wetted medium. Results were compared with those of channel flow and showed that corrugating one side of the channel at high velocity can improve efficiency by 40%. Gunhan et al. [14] have used pumice stone, volcanic tuff, and greenhouse shading net as alternative pad materials. According to the results, volcanic tuff pads are good alternative to the CELdeck pads at 0.6 m/s air velocity. Rawangkul et al. [15] investigated the performance of two small coconut coir pads with different configurations and compared with commercial rigid media paper pad. They found that the cooling efficiency of the manufactured coconut coir evaporative cooling pad is fairly good (about 50%) and close to that of commercial paper pad (about 47%). Wu et al. [1] discussed the effects of the air frontal velocity and pad thickness on the cooling efficiency of a direct evaporative cooler. An optimum frontal velocity of 2.5 m/s was recommended to decide the frontal area of pad module in the given air flow. Khond [16] evaluated the performance analysis of desert cooler by using stainless steel wire mesh pad, coconut coir pad, khus pad, and wood wool pad. These pads were compared in terms of cooling efficiency, water consumption rate, and air velocity. Water consumption values were 0.24, 0.134, 0.21, 0.066 l/min for wood wool pad, coconut coir, khus pad, and stainless steel, respectively. Air velocity for coconut coir, stainless steel wire mesh pad, wood wool pad, and khus pad were 5.2, 4.5, 4, 3.4 m/s, respectively. Maximum and minimum cooling efficiencies were found in wood wool pad and stainless steel wire mesh pad, respectively. Ahmad et al. [17] evaluated the performance of three types of evaporative cooling pad for greenhouse (celdek pads, straw pads, and sliced wood pads). Their results showed that sliced wood pads and straw pads had the highest and lowest performance, respectively. Mali et al. [18] compared pressure drop, humidity variation, the amount of evaporated water, and effectiveness of two types of commercial cellulosic pads (5090 and 7090). Their results show that with the increase of inlet air velocity and pad thickness, overall pressure drop and amount of evaporated water increase. Effectiveness and humidity variation decrease with the increase of air velocity.

In this paper, the performances of various cellulosic pads made out of two common corrugated paper types namely Kraft and NSSC made in Iran are evaluated experimentally and the effects of air velocity and flute size of corrugated papers on the cooling efficiency, pressure drop, and water consumption are investigated. In fact, for manufacturing of paperboard in Iran, Kraft and NSSC papers are often used since they have shown good mechanical properties in manufacturing of corrugated papers.

2. Materials and methods

2.1. Materials

Kraft and NSSC papers were received from Mazandaran wood and paper factory in Iran and then corrugated with three flute sizes (A: 4.5, B: 2.5, and C: 3.5 mm). For manufacturing of Kraft paper, the combination of hardwood-softwood chips and $NaOH–Na_2S$ liquor are cooked under high temperature and pressure, but for manufacturing of NSSC paper, the combination of hardwood chips and Na_2So_3 liquor are cooked under high temperature and pressure. Suitable resin and Glue were selected to improve wet strength of the sheets and bonding them with each other. Some physical properties of these materials are given in Table 1.

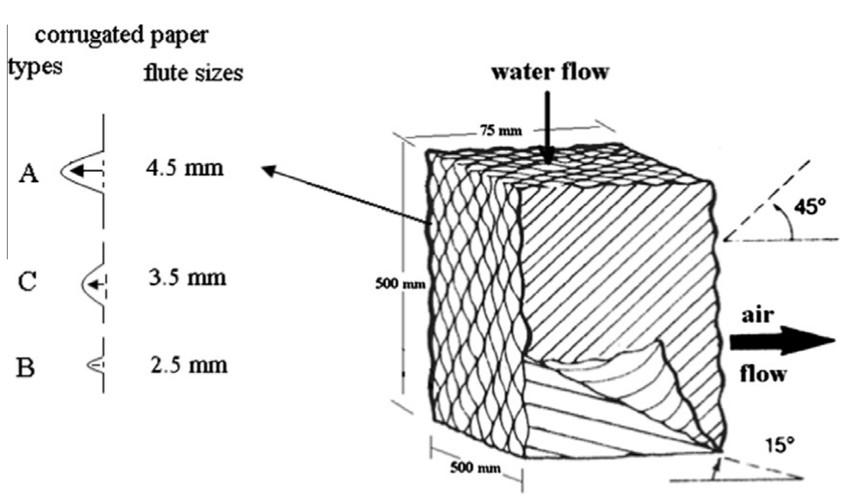

Fig. 1. Schematic of cellulosic pad and corrugated paper types and flute sizes.