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Evaluation of Pads and Geometrical Shapes for Constructing Evaporative Cooling System

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Abstract

Investigations were carried out into local materials as cooling pads, and shapes for constructing evaporative coolers. Materials investigated include jute, latex foam, charcoal and wood shavings. Shapes of cooling systems considered were of hexagonal and square cross-sections. Some physical properties of pad materials that could affect the effectiveness of the evaporative coolers were also determined. Results of "No – load" tests carried out on the coolers indicated that the effectiveness of the cooling pads was in the following decreasing order of magnitude - Jute, latex foam, charcoal and wood shavings. The hexagonal shape cooler was found to be more efficient than the square shape. The average cooling or saturation efficiency for hexagonal cooler was 93.5% (jute), 91.4% (latex foam), 91.3% (charcoal) and 91.9% (wood shavings). The maximum temperatures observed were 6.4 (jute pad), 4.9 (latex foam pad), 5.2 (charcoal pad) and 3.6 degree Celsius. The results of this study will assist researchers in their selection of pad materials in the study of evaporative cooling systems.

Keywords: evaporative coolers, pad materials, shape, saturation efficiency, temperature drop

1. Introduction

Most of the research publications on evaporative cooling are from the temperate regions of the world whose climatic conditions are quite different from those of tropical countries. Harris (1987) recorded that the wet-bulb temperature prevailing in an area is one of the important limitations in evaporative cooler performance. It is only in localities where reasonable low wet-bulb temperature (21°C and below) occurs intermittently with high dry -bulb temperature (32°C and above) for extended period of time that evaporative cooling was successful.

Manufacturers have tried many pad materials including fabrics, excelsiors of pine, fir, cotton wood, cedar, red wood, spruce and other woods; plain and etched glass fibres; copper, bronze and galvanized screening; vermicultie, perlite and expanded paper and woven plastic (Watt, 1986). Aspen excelsior pads have been the primary material for evaporative cooling systems (Hanan et al., 1978). The excelsior is made by shredding aspen wood *(propulus tremuloides)* which is made into mats by enclosing it in cloth netting. The mats were then placed in a framework forming a solid pad area. Heins (1974) reported that 30 cm thick CEL-dek (Trade Name) paper pads provided 6 percent more cooling efficiency than the standard aspen pad. The newer kool-cel (Trade Name) is only 10 cm thick and can be adapted easily to aspen pad installations.

Reece and Deaton (1971) reported that performance of broiler males improved in two tests when the ambient air temperature was reduced using evaporative cooling, to 29.4°C from highs of 35 and 37 degree Celsius. Timmons et al. (1980) reported that evaporative cooling of the pad system offered the greatest cooling potential but was more expensive than the foggers. Hanan et al. (1978) reported that the pad and fan method of cooling green houses revolutionized the industry. Many other researchers have experimented on different pad materials such as successive layers of corrugated paper (Koca et al., 1991), natural fibers- jute, palm, luffa (Al- Sulaiman, 2002), corrugated cellulose (Lertsatitthanakorn et al., 2006), pumice stones- coarse and fine (Gunhan et al., 2007), jute, hessian and cotton waste (Olosunde et al., 2009), rice straw and palm leaf fibers (Darwesh et al., 2009), Celdek R 7060-15, Munters AB, Kista, Sweden (Dagtekin et al., 2009), clay (Ndukwu, 2011), straw, CELdek, sliced wood (Ahmed et al., 2011), metal pad, cellulose pad, organic pad (CELdek), inorganic pad (GLASdek), PVC pad, porous ceramic pad, wood wool pad (Xuan et al., 2012).

In view of the good prospect of evaporative cooling systems, Manuwa (1989) investigated the possibility of using local materials as cooling pads comparing two shapes of evaporative coolers.

This study was therefore undertaken to investigate and evaluate the effectiveness of potential cooling pads (using locally available materials) and shapes for constructing evaporative cooling systems.

2. Materials and Methods

2.1 Place of Study

A study was carried out in the month of July and August, 1989 at the department of Agricultural Engineering, faculty of Technology, University of Ibadan, Nigeria (127.12N 3.52E). Table 1 shows mean daily minimum and maximum temperatures in Ibadan for a period of three years prior to the study.

Table 1. Mean daily minimum and maximum temperatures at project site, in Ibadan (1986-1988)

MONTH	1986		1987		1988	
	MDMIT °C	MDMAT °C	MDMIT °C	MDMAT °C	MDMIT °C	MDMAT °C
Jan	21.1	32.9	23.4	33.7	21.3	33.8
Feb	23.5	34	24.3	35.7	24.7	35.8
Mar	23.2	33.4	24.1	34.9	24.9	35.1
Apr	23.3	33.2	25.3	36.3	24.2	34.2
May	22.2	32.2	23.9	34.4	24	32.2
June	21.8	30.4	23.3	30.8	22.5	32.7
July	20.8	27	23.1	30.2	22.2	32.1
Aug	20.6	28	23.1	29.6	21.8	33.3
Sept	21.6	28.6	22.9	29.8	22	33.2
Oct	22.3	29.7	23.3	29.2	22.7	34.1
Nov	22.3	31.1	23.7	33.8	23.6	35.3
Dec	19.2	32.3	23.9	32.8	22.5	36.5

MDMIT = Mean Daily Minimum Temperature, °C

MDMAT = Mean Daily Maximum Temperature, °C

Source: Climate office, Geography Department, University of Ibadan, Ibadan

2.2 Materials

2.2.1 Shed

A flat roofed shed (3.5 m x 3.5 m x 1.8 m high) was constructed under which the coolers were installed for experimentation. Sturdy trees, bamboo poles, leaves, palm fronds were used in the construction. Its function, among others, was to reduce the effect of sensible heat that could be gained from solar radiation.

2.2.2 Evaporative Coolers

The two coolers have equal capacity of 2.21×10^5 cubic centimeters. Each side of the hexagonal section cooler was 29.5 cm while the height was 98.0 cm. However, the square cross-section cooler has each side measured 47.5 cm and 98.0 height like the hexagonal cross-section cooler. Wood was used in constructing the frame, mild steel sheet for the containers and perforated galvanized pipes for dripping water on the cooling pads. The coolers were painted white .to minimize the effect of solar radiation absorption on the coolers' surfaces. Details of the coolers designs and fabrication are presented in Manuwa (1989).

2.2.3 Pad-holders

Pad-holders were constructed for the coolers so that they were not limited to cloth-like pads that would only wrap round the cooler. The pad-holders therefore make the coolers more versatile and effective. They were constructed with wood and covered with 2 mm-mesh wire netting and designed to have a pad thickness of 2.5 cm. Full details and description of the pad holders are found in Manuwa (1989).

2.2.4 Pad Materials

The pad materials investigated include:

1) Latex foam, used in the form of 15 mm cubes;

2) Jute material, prepared from jute bags;

3) Charcoal (wood) prepared and used in the form of 15 mm cubes;

4) Wood shavings from African cordia (*cordia millenii)* sieved with a laboratory test sieve of 850 micro-metre aperture sizes.

2.3 Methods

It was necessary to determine some physical properties of the pad materials used in this study since the properties would definitely have effects on the effectiveness and operational characteristics of the coolers. The properties, investigated were moisture content, bulk density, and water holding capacity. In determining these properties, three replications were made in each case.

2.3.1 Moisture Content

The pad materials (Charcoal and wood shavings) were observed for moisture content determination. For charcoal, three samples each of mass 12 gm were used. The samples were put inside aluminum drying dishes before they were placed inside the oven. Drying was done for twenty four hours at which time the weights remained constant with further drying. Drying temperature was 100°C. The same apparatus and method was used for wood shavings. Three samples of equal masses (15 gm) were oven-dried for twenty four hours at 100°C drying temperature.

2.3.2 Water Holding Capacity

By definition, it is the ratio of the mass of water held at saturation to the initial mass of the material. Samples of latex foam and jute materials which readily became saturated when soaked were piled up to allow excess water drip off before the determination of water holding capacity. Samples of charcoal and wood shavings were however soaked in water for 24 hours before the determination of their water holding capacities.

2.3.3 Bulk Density

Bulk densities were determined by filling a standard 40 liter container with each pad material when poured from a fixed height of 50 cm above and into a stationary container, striking off the top level and weighing on top of a loading balance of sensitivity ±l gm. For the jute material, jute bag was cut into small pieces before they were dropped from the fixed height into the container to fill it.

2.4 Test Procedure

The cooler and accessories were assembled and set up under the shed to determine the effectiveness of the materials and the efficiencies of the coolers. Before the commencement of the test each morning, the valves were opened wide to get the pads properly saturated within a short time. Subsequently, the-valves were opened slightly to maintain the pads in a saturated state by water drips.

2.4.1 Temperature and Relative Humidity Measurement

Temperature changes in and around the coolers including that of the re-circulated water were measured and recorded hourly. Three sensitive mercury-in-glass thermometers and three whirling hygrometers were used. The thermometers measure dry-bulb temperatures while the whirling hygrometers measured both dry-bulb and wet-bulb temperatures. The instruments were positioned at each point that temperature was required and read when the mercury level became stable. However, the whirling hygrometer was whirled each time before the reading was taken. From the dry-bulb and wet-bulb temperatures that were observed, wet-bulb depressions were determined and the corresponding relative humilities were read from standard hygrometric tables. The relative humidity values determined were those of the ambient environment, the coolers' inner space at hourly intervals.

The performance of the cooling pads and hence the cooling system was based on the saturation or cooling efficiency. The saturation efficiency was calculated using the model reported by Haris (1987):

$$\eta_{sat} = \frac{T_{db} - T_{exit}}{T_{db} - T_{wb}} \times 100\% \quad (1)$$

Where,

T_{exit} = dry bulb temperature of air exiting pad

T_{db} = dry bulb temperature of air entering pad

T_{wb} = wet bulb temperature of air entering pad

2.4.2 Air Speed and Coolers' Relative Positions

An anemometer was used to measure air speed every three hours during the study. The following pad face air velocities were recorded: 0.69-1.25 m/s for latex foam pad tests; 0.35-1.125 m/s for wood shavings pad tests; 0.51-1.37 m/s for jute pad tests and 0.98- 1.45 m/s for charcoal pad tests. The coolers were placed under the shed in such a way that there was no obstruction of one cooler by the other, that is, the air which was entering one cooler was not intercepted by the other cooler. To achieve this preliminary investigation of the prevailing wind direction was carried out and noted. This was found to be from South-west towards North-west. Consequently, the coolers were positioned on a straight line: the hexagonal cooler to the South of the square cross-section cooler.

2.4.3 Re-circulating Water

The same quantity of water (50 litres) was used to commence the experiment each day and so the level was marked in both tanks. 'Make up' water was added as required (usually the last thing during the day). This was done to avoid unnecessary heat being added to the system, since water temperature at ambient condition was always higher than the re-circulating water temperature. Water in the bottom tank or Sump' was usually siphoned into another container by a one-meter, 10 mm diameter robber hose. The water was then returned to the top tank for recirculation.

2.4.4 Pad Thickness

To maintain pad thickness and thus prevent sagging and bulging of the pads and pad holders respectively, wire strands from such netting mat used in the pad holders were used to bind at specific intervals the pairs of netting together and thus maintain the predetermined thickness of the pads.

2.4.5 Comparing Shapes and Pad Materials

For each pad materials (Latex foam, wood shavings and jute), the hexagonal and square shapes were compared as experimental observations were taken. The criterion used was the drop in the ambient temperature produced by the coolers and consequent increase in relative humidity inside the coolers. For each pad installed, tests were carried out on the coolers for at least four days continuously. The charts plotted in this paper were means of average values obtained from the replicates. The effectiveness of the cooling pads was also established during the tests.

3. Results and Discussion

3.1 Physical Properties of Pad Materials

The summary of some physical properties of cooling pads materials is given in Table 2. Jute and latex foam had no moisture in them initially. The initial moisture in wood shavings and charcoal however was not available for cooling since the materials were "dry" on the surface.

Table 2. Some Physical Properties of Experimental Pad materials

Pad materials	Moisture content	Bulk density	Water holding capacity
	% (db)	Kg/m^3	kg/kg
Jute	0	89.8	2.1
Latex foam	0	7.7	15.1
Charcoal	10.3	267.3	0.5
Wood shavings	12.3	35.8	2.5

The significance of the bulk density lies in the fact that the weight of a material is directly proportional to its density. Therefore, for a given size of cooler, lighter bulk weight would be handled the lesser the bulk density of the cooling pad. Olosunde et al. (2009) used jute pad that was less dense (82.81 kg/kg) than the type used in this study (89.80 kg/kg) also whose water holding capacity was lower (1.762 kg/kg) than the type in this study (2.1 kg/kg) .

According to Watt (1986) drip cooler effectiveness depends largely upon pads that had maximum clean wet surface with a minimum air flow resistance. This requires pad materials having surfaces that spread water rapidly by capillary action and through which air passes. This observation was confirmed in this study. Although not measured quantitatively, it was observed that jute pad offered the least resistance to air flow due to tiny holes it contained. The continuous strands of woven threads in it enabled water to spread rapidly. It was observed from the water holding capacity of the pad materials that a quantity of water equal to at least one half the mass of the cooling pad must be held by the material for it to cool the passing air. Latex foam would have been the best pad but for the fact that air only passes through the openings among the 'cubes' and not actually through the pores where most of the water are being held.

3.2 Variation of Temperature inside and outside the Evaporative Cooling Systems

Figure 1 shows the variation of dry-bulb temperature versus time inside and outside the coolers. The daily temperature readings within each cooler depend on ambient conditions. There was significant difference ($p < 0.05$) in each case between the temperature observed inside the coolers and the ambient temperature. Maximum temperature inside and outside the coolers was observed at about 13.00 hours for all the tests (Figure 1). This trend was also reported by other researchers (Dagtekin et al., 2009; Ahmed et al., 2011).

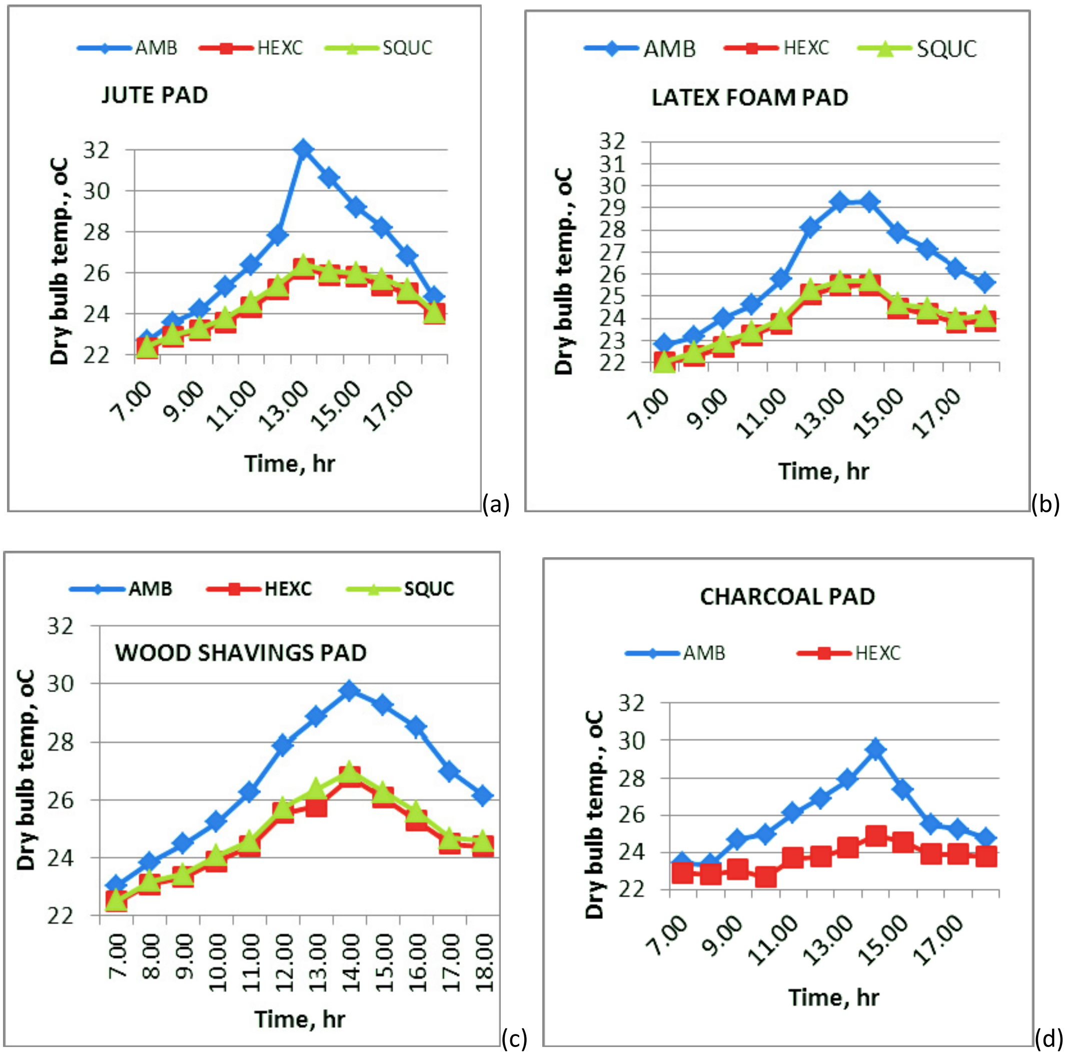

Figure 1. Hourly variation of dry bulb temperature inside and outside the coolers with different pad materials (a) jute, (b) latex foam, (c) wood shavings, (d) charcoal

The lowering of the dry-bulb temperature which was clearly observable in the curves is a measure of the effectiveness of the cooling pads.

3.3 Variation of Relative Humidity (RH) inside and outside the Evaporative Cooling Systems

Figure 2 shows the variation of relative humidity versus time inside and outside the coolers. The curves also compared shapes showing that hexagonal cross sectional shape cooler produced higher value RH at a particular point in time. In all the curves, the hexagonal cooler produced higher relative humidity values inside the coolers with time. The reduction in the variation of relative humidity over time inside the cooler compared to ambient conditions was an indication of the effectiveness of the cooler in maintaining high uniform relative humidity. The marked increase in relative humidity over the ambient values is an evidence of the suitability of the pad materials as potential cooling pads. Minimum relative humidity values inside and outside the coolers were observed at about 13.00 hours for all the tests as shown (Figure 2). Maximum relative humidity observed inside the coolers ranged from 91 to 98%. This agrees with the report (Xuan et al., 2012) that 100% relative humidity was not achievable in direct evaporative cooling systems because 100% saturation is impossible due to two reasons. Firstly, most of the pads are loosely packed, and the process air can easily escape between the pads without sufficient contact with the water. Secondly, the contact time between air and water is not long enough which results that heat and mass transfer is insufficient.

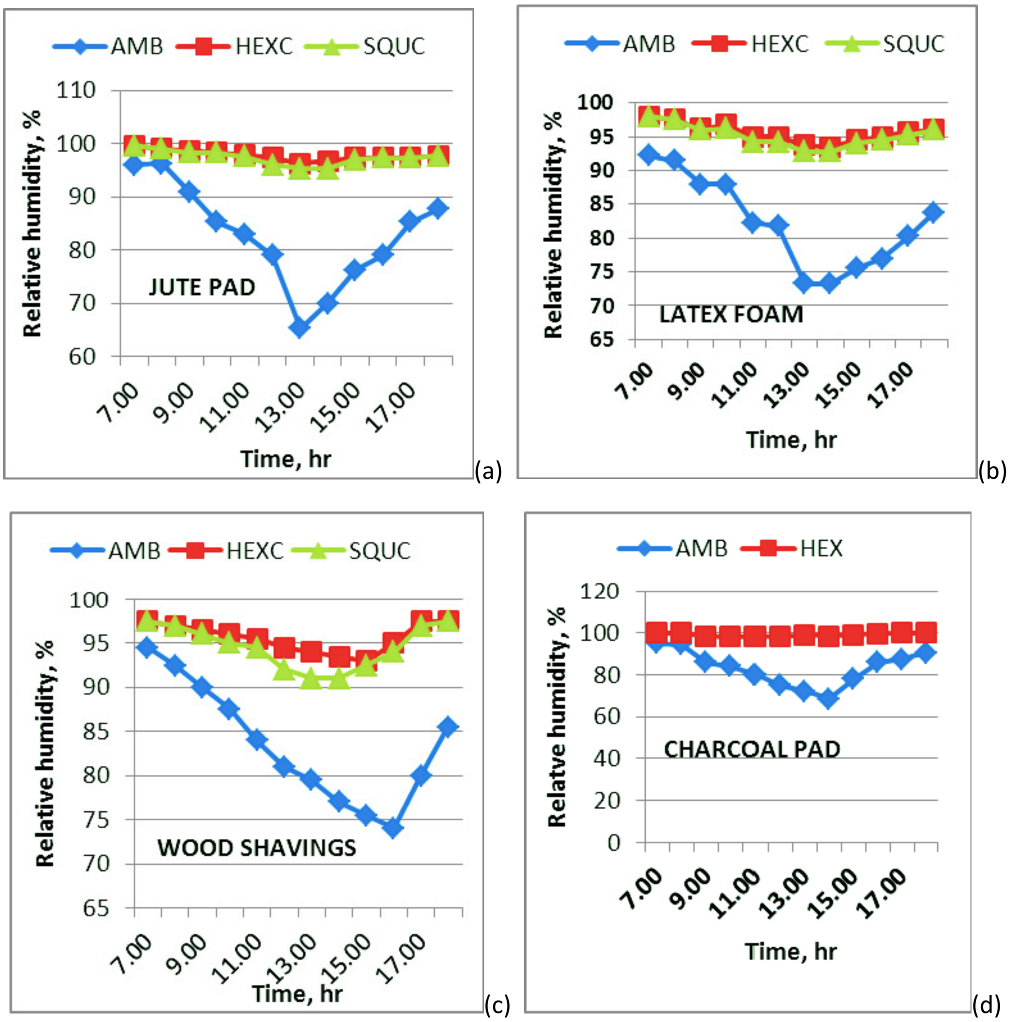

Figure 2. Hourly variation of relative humidity inside and outside the coolers with different pad materials (a) jute, (b) latex foam, (c) wood shavings, (d) charcoal

3.4 Variation of Temperature Drop inside the Evaporative Cooling Systems

Temperature drop was observed to increase from small values in the early morning (8.00) to a peak about (13.00) and then dropped towards evening (18.00) (Figure 3). This trend is directly related to the variation of ambient dry-bulb temperature with time. Moreover, these curves enable comparisons of the effectiveness of the cooling pads. In decreasing order of magnitude, they are: jute > latex foam > charcoal > wood shavings.

The maximum and minimum temperatures inside the coolers with the different cooling pads are shown and compared in Table 3. It would be noted that charcoal was not used on the square cross-section cooler. There was no significant difference ($p < 0.05$) in the maximum or minimum temperature drop between the hexagonal- and square cross- section coolers with the same pad material. However, there was significant difference ($p < 0.05$) between temperature drops produced by the different pads on the same cooler.

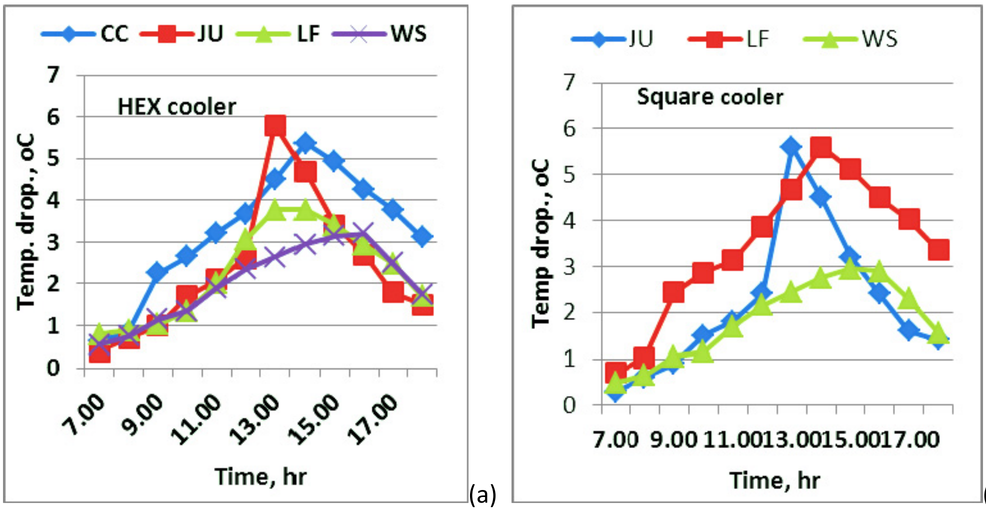

Figure 3. Hourly variation of temperature drop inside the coolers with different pad materials (a) hexagonal cooler, (b) square cooler

Table 3. Effectiveness data of evaporative coolers

Pad materials	Temperature drop ^oC		Mean saturation efficiency(η_{sat}) %
	Maximum	Minimum	
Jute	6.4	5.8	93.5
	6.2	5.6	84.1
Latex	4.9	3.8	91.4
foam	4.8	3.6	81.8
Charcoal	5.2	4.6	91.3
Wood	3.6	3.2	91.9
shavings	3.4	3	83.2

Top entry, hexagonal cooler; Bottom entry, square cooler

3.5 Cooling Efficiency of the Evaporative Cooling System

Many researchers (Al- Sulaiman, 2002); Lertsatitthanakorn et al., 2006; Dagtekin et al., 2009; Ahmed et al., 2011; Xuan et al., 2012*)* have estimated cooling (saturation) efficiency of direct evaporative cooling system using equation (1). Mean saturation efficiencies of the coolers with the pads tested in this study are shown in Table 3. Results show jute pad produced highest cooling efficiency (93.5%) with hexagonal cooler and (84.1%) with square cross section cooler. This is comparable with values in literature. Al-Sulaiman (2002) reported cooling efficiency of 62.1% with jute pad, 55.1, 49.5 and 38.9% with luffa, Aspen wood excelsior and palm fibers, respectively. Olosunde et al. (2009) reported 86.2% cooling efficiency for jute pad. Gunhan et al. (2007) reported a range of cooling efficiency for five different pads under different conditions: CELdek (46.1 to 78.5%); Volcanic tuff (68.0 to 77.9%); Fine pumice stones (77.7 to 90.6%), coarse pumice stones (56.1 to 72.1%); shading net (25.2 to 32.8%). In comparison, the pads in this study seem to have better performance with regards to cooling efficiencies. Also, Darwesh et al. (2009) reported cooling efficiency (63.34 to 76.51%) with rice straw and (59.38 to 65.4%) palm leaf fibers under similar conditions of pad thickness and temperature. From the above reports, the pads tested in this study have good prospect to be considered and further investigated as potential cooling pads.

3.6 Significance of Shape

It was observed in all tests that the hexagonal cross-section cooler was more efficient than the square cross- section cooler (Table 3). This could be attributed to the former having greater projected area than the latter, so that for the same cooler capacity and wind direction, more air would pass through the cooling pads on the hexagonal cross-section cooler than the square cross-section cooler. The results of the performance criteria (temperature drop, cooling efficiency, and increase in relative humidity) show significantly higher ($p < 0.05$) values for hexagonal cooler.

4. Conclusions

From the results of this study presented above, the following conclusions can be drawn.

1) Hexagonal cross section cooler are more efficient than square cross section cooler in terms of the saturation efficiency, maximum temperature drop and increased RH values.

2) The maximum mean temperature drops obtained during this study were 6.4 and 6.2^{o}C for hexagonal and square cooler, respectively. Similarly the maximum mean saturation efficiencies were 93.5 and 84.1% for hexagonal and square cooler, respectively.

3) Some local pad materials (jute, latex foam, charcoal and wood shavings) and shapes (hexagonal XS and square XS) were studied for the purpose of constructing evaporative cooling systems.

4) The effectiveness of the pads in decreasing order of magnitude is: jute > latex foam > charcoal > wood shavings.

5) The performance of these pads compare favorably with those reported by other researchers elsewhere.

6) More tests are required especially ‘load tests’ to ascertain the effectiveness of the coolers.

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