Experimental evaluation of bulk charcoal pad configuration on evaporative cooling effectiveness

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Abstract: The purpose of the study was to evaluate the performance of bulk charcoal pad configuration, experimentally. For this, a number of experiments have been conducted in a wind tunnel in order to evaluate the pressure drop, cooling efficiency and specific water consumption as a function of air velocity, water flow rate and pad configuration. The test were carried out at six levels of air velocity (0.12, 0.51, 0.82, 1.05, 1.10 and 1.14 m s-1), three water flow rates (2.2, 3.2 and 5.2 l min-1) and three pad configurations: single layer pad (SLP), double layers pad (DLP) and triple layers pad (TLP) made out of small and large size charcoal particle of equivalent diameter 30 mm and 50 mm respectively. It was found that pressure drop range of small size charcoal pads is 2.67 to 240.00 Pa while that of pads made out of large size charcoal are much lower with the range of 2.00 to 173.33 Pa, depending on the pad configuration, air velocity and water flow rate. The cooling efficiencies of the small size charcoal pads vary from 56.71% to 96.10% while the cooling efficiencies of large size charcoal pads are 45.41% to 90.06%, depending on the pad configuration, air velocity and the water flow rate. Generally, DLP and TLP configuration with larger wet surface area provide high cooling efficiencies and high pressure drops, though it obviously leads to increase in water consumption. DLP and TLP configurations at low air velocity are therefore recommended for practical applications.

Keywords: charcoal, pad configuration, wind tunnel, evaporative cooling, pressure drop, cooling efficiency, specific water consumption

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1 Introduction

Evaporative cooling is a simple cooling technique that has been used for centuries to provide low-air temperatures and high relative humidity for cooling produce (Thompson and Kasmire, 1981). Rising energy cost, together with scant water resources in most areas of intensive production, urge the use of evaporative cooling systems that are economical and highly water and energy efficient (Franco et al. 2011). Two basic types of evaporative cooling are commonly used: direct and indirect evaporation cooling. Published data concerning both are enormous (Duan et al., 2012; Xuan et al., 2012). The present study focuses on the direct evaporative cooling principle which is the oldest and most widespread form of evaporative air conditioning (Heidarinejad et al., 2009).

Direct evaporative cooling systems are based on the evaporation of water in the air stream; with evaporative cooling pads. The wetted-medium could be porous wetted pads consisting of fibers or cellulose papers (Franco et al., 2010; Koca et al., 1991). According to He et al. (2015a) and Koca et al. (1991), the wetted material behavior can be classed as aspen pad and rigid media. Aspen pad behavior is difficult to achieve particularly in rural Africa and rigid media is mostly imported. To reduce investment cost and promote sustainable engineering systems,

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research on alternative and locally available cheap materials with reasonable thermal performance, comparable or better than rigid media is necessary. A number of researchers have evaluated locally available materials as alternative pad media (Jain and Hindoliya, 2011; Adebisi et al., 2009; Gunhan et al., 2007; Al-Sulaiman, 2002; Liao et al., 1998). However, pad sagging, pad clogging, pad scaling, pad deterioration and mold formation, are big problems thus limiting their useful life and general use.

Several characteristics are used to rate a pad (Koca et al., 1991). Among these characteristics include pressure drop and efficiency which are affected by the pad design, thickness, pad configuration, air velocity and water flow rate (Fanco et al., 2010; Rawangkul et al., 2008; Gunhan et al., 2007; Koca et al., 1991). Pressure drop versus air velocity is essential for selecting a fan and pad area for a particular application while efficiency is the most important physical performance factor. The more efficient a pad at a given air velocity, the more cooling it will provide (Koca et al., 1991). Evaporative cooling pad’s water consumption is another essential parameter, especially due to the scarcity of this resource. It enables engineers to determine the size for the pump and water storage design (Franco et al., 2012; Franco et al., 2010). Franco et al. (2010) reported that the amount of water evaporated from a pad is related to the outside air temperature and relative humidity, as well as pad’s structural characteristics and air velocity through the pad.

According to Gunhan et al. (2007), a pad material should have a porous structure that can hold water, light in weight, durable for repeated wetting and drying, inexpensive and locally available. Moreover, it should allow easy construction into required shape and size (Liao et al., 1998). Based on these attributes, we selected locally available and inexpensive material, charcoal of different sizes to test as pad media. Despite the widespread studies conducted in the past on evaporative cooling, there are no experimental investigations on cooling performance of wetted charcoal pad configurations which is useful for system engineering design. The key issue is the trade-off between the wetted medium cooling and the extra pressure drop, both of which are a strong function of the wetted media (pad) configuration. Hence, the performances of charcoal pads made out of small and large size particles are evaluated experimentally and the effect of air velocity, water flow rate and pad configuration on the pressure drop, cooling efficiency and water consumption examined. An additional objective is aimed at identifying suitable wetted pad configuration that provides high cooling efficiency and low pressure drop.

2 Materials and methods

2.1 Wetted media

The wetted media used in this study is bulk charcoal obtained from a local market in Witzenhausen, Germany. The species of the wood used to produce the charcoal is a pine variety. The charcoal was sorted into two size fraction: small and large. For each size fraction, the equivalent diameter was calculated as average of the three main dimensions (length (L), width (W) and height (H)) of a sample consisting of 150-200 particles. The calculated equivalent diameters are 30 mm and 50 mm for small and large sizes charcoal, respectively. Each size fraction of the charcoal material was filled separately into galvanized steel frames to create an evaporative cartridge. The front and the back faces of the cartridges were covered with a wire mesh. The frontal area of these cartridges was 500 mm by 424 mm (H × W) and the thickness was 100 mm.

2.2 Wind tunnel system

To determine the performance of a low-cost evaporative cooling pad (charcoal), an open-circuit wind tunnel was designed and fabricated in the Agricultural Engineering Department workshop, University of Kassel, Witzenhausen, Germany. The schematic of the wind tunnel is depicted in Figure 1. The apparatus consisted of an inlet induct, butterfly valve, centrifugal in-line duct fan, test section and an air exit section. The entrance to the apparatus consisted of a round galvanized steel air duct with diameter of 150 mm and a length of 850 mm. At 300 mm downstream from the duct inlet, a honeycomb flow straightener with tube diameter of 5 mm and tube length of 50 mm was installed to remove any tangential velocity components (Román and Hensel, 2014). The butterfly valve was installed 202 mm upstream of the fan in order to reduce the airflow to the desired test condition. The test section is a hollow rectangular duct made out of 19 mm thickness MR grade plywood and insulated with 40 mm thick styropor material to minimize heat loss to the surroundings. The dimensions of the test section were 1800 mm×500 mm×525 mm.

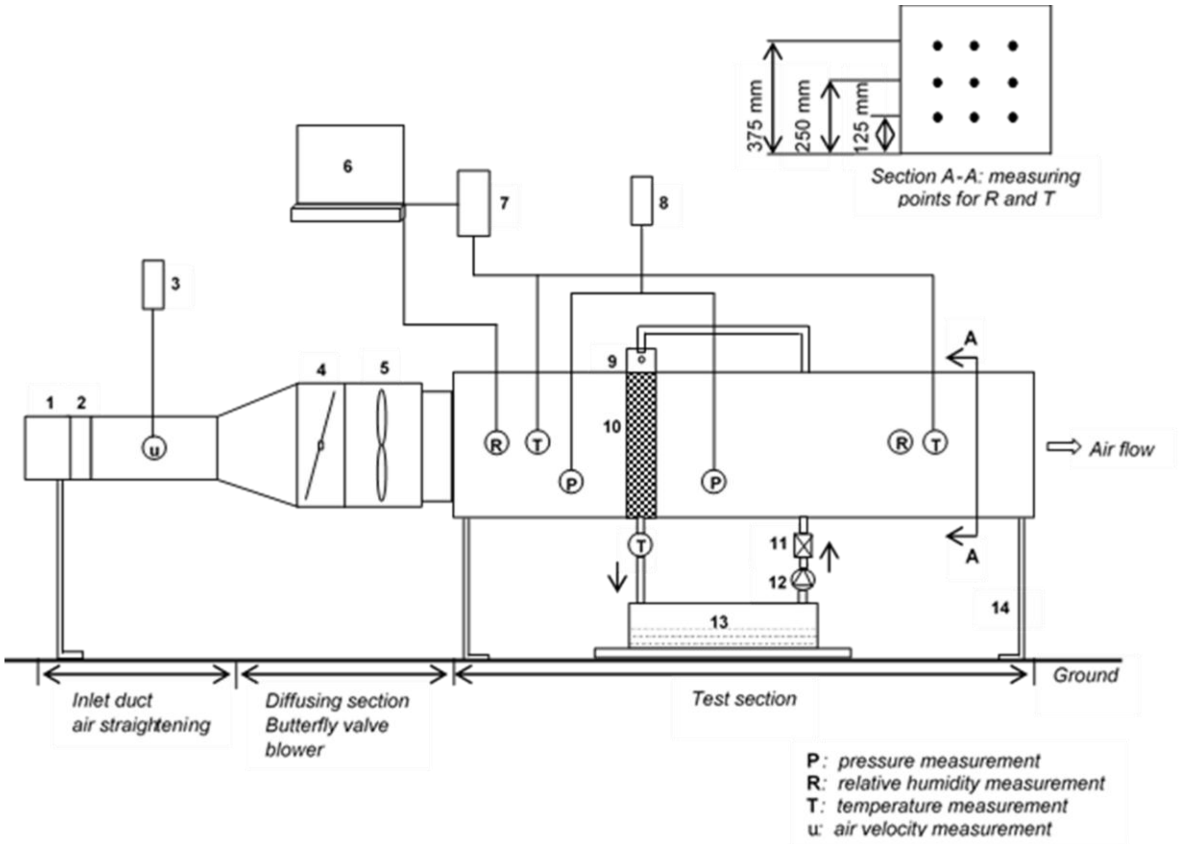


Figure 1 Schematic of the wind tunnel incorporated with a single layer pad (not drawn to scale).

(1 = inlet duct, 2 = airflow straightener, 3 = hot wire anemometer, 4 = butterfly valve, 5 = in-line duct centrifugal fan, 6 = computer, 7 = data logger, 8 = digital differential pressure meter, 9 = water distributor, 10 = wetted medium, 11 = flowmeter, 12 = water pump, 13 = water tank, 14 = supports).

For the purpose of this study, specific test frames were designed to incorporate different layers of the wetted-medium (Figure 1). These frames consisted of a galvanized metal structure with water distribution system incorporated into the top. This system has been used by other researchers (Barzegar et al., 2012; Franco et al., 2010). The distribution pan with perforations at the bottom was located at the top of the media to feed the water to the media more uniformly by gravity. Water was fed to the distribution pan through the distribution pipes, which were constructed of a 20 mm diameter PVC pipe with 2 mm holes, 25 mm apart. Water from the distribution pan was dripped down by gravity to wet the media uniformly. In the lower part of the frames, a water collection system allowed water to drain by gravity into a water tank, before being ceaselessly recycled by a 14 Watts, 12 V DC pump (SP20/20, Solarproject, UK). Water flow at the entrance was controlled by varying the voltage of the pump by a DC power regulator and readings from the flowmeter (GARDENA water smart flowmeter, GARDENA GmbH, Germany) with an average range of 2 to 30 l min^{-1} and an accuracy of ±5%.

2.3 Wetted-medium configuration

Three different configurations of the wetted-medium in the wind tunnel were analyzed regarding their capacity for climate conditioning. These were termed as single layer pad (SLP), double layers pad (DLP) and triple layers pad (TLP) configuration. Figure 2 shows a perspective of the experimental set-up with pads incorporated at the test section. The wet surface of a single layer pad was 0.212 m^2 and it was identical for the three pad configuration. The distance between the pad layers (Figure 2b and c) was 0.3 m.

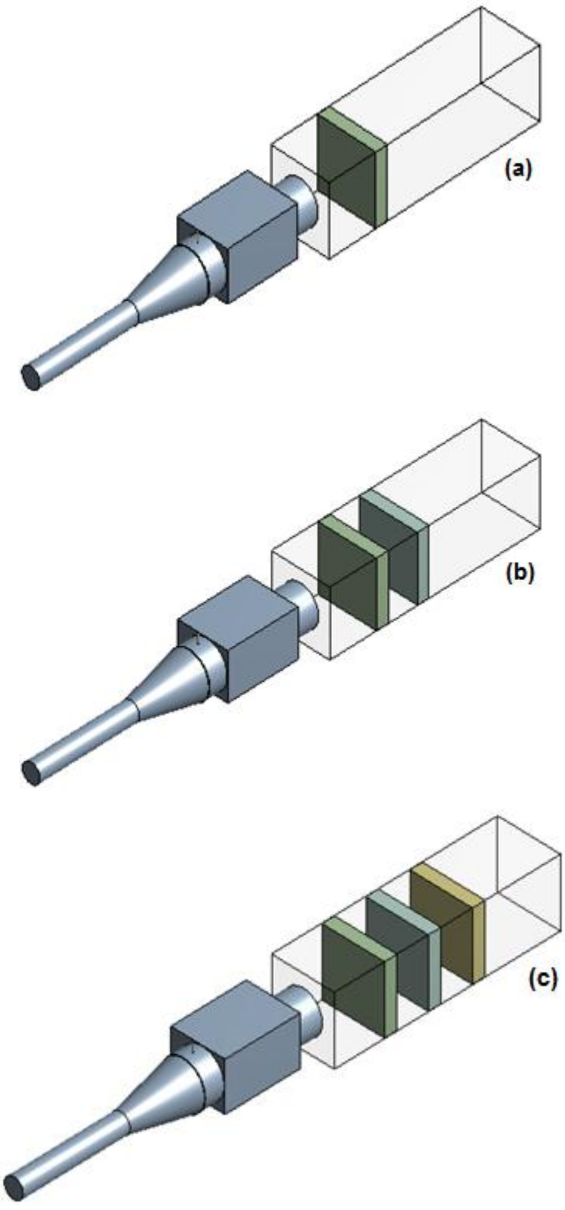


Figure 2 A perspective of the experimental set-up of the pad configurations:

(a) single layer pad (SLP); (b) double layers pad (DLP); (c) triple layers pad (TLP).

2.4 Test procedure and instrumentation

For the purpose of this study, measurements of air velocity and flow of water through the porous medium are required, as well as temperature and humidity of the airflow before and after crossing the wetted-medium to determine the saturation efficiency of the media and the volume of water evaporated. Measurement of the air pressure drop through the porous medium (dry and wet) of the tested cooling pad configurations (SLP, DLP and TLP) is also essential.

For testing of the evaporative pads, control of the test room environmental conditions is necessary. Therefore, in order to keep the room dry-bulb temperature at approximately 31 ℃±2 ℃ and relative humidity of 45%±3.2%, which represent long-term averages of dry season months in Northern Ghana, a 2000 W fan heater was placed at the inlet of the system. Measurements were carried out 200 mm downstream from the fan outlet. Static pressure drop across a given pad configuration was measured with a digital differential pressure meter (Testo 510, Testo AG, Germany) with an accuracy of ±1.5%. The pressure meter was connected by a flexible rubber hose to pressure taps located on the surface of the wind tunnel. One pressure tap was located 350 mm downstream from the fan outlet and the remaining taps 650, 950, and 1250 mm upstream respectively. The average air velocity was measured with a hot wire anemometer (PL-135HAN, Voltcraft, Germany) with a working range of 0.1 to 25 m s^{-1} and accuracy of ±1% full scale. The probe of the hot wire anemometer was placed at the duct center and 400 mm downstream of the flow straightener (Figure 1). To determine the air velocity in the wind tunnel from a single measurement point, the guideline of VDI/VDE 2640 part 3 (1983) was used and described by Román and Hensel (2014).

The wet-bulb temperature near the inlet duct of the wind tunnel was recorded manually using a digital hygrometer (model HT-86, Shenzhen Handsome Technology Co., Ltd., China) with accuracy of ±0.8 ℃. The temperature and relative humidity of the inlet and outlet air was measured with digital temperature and capacitive humidity data loggers (Testo 174H, testo AG, Germany) with accuracy of ±0.5 ℃ and ±3%, respectively. For the air inlet conditions, one data logger was located 300 mm upstream from the first pad to be tested. The inserted length of the data logger was 250 mm from the tunnel floor. Nine data loggers were placed at 1700 mm downstream from the fan outlet to measure the outlet dry-bulb temperature and relative humidity. The data loggers were located in groups of three and were mounted across the width of the test section. The inserted length of each group were 125, 250 and 375 mm from the tunnel floor respectively to form a measuring grid (see Figure 1, section A-A).

Water flow rates tested were: 0 (dry), 2.2, 3.2, 5.2 and 7.2 l min^{-1}. However, on analyzing the other parameters in the wind tunnel, it was observed that the air stream passing the wetted-medium (for all pad configuration investigated) causes an emergence of water entrainment off the medium at flows of 7.2 l min^{-1}. Therefore, only four flow variables were tested: dry (only for the pressure drop), 2.2, 3.2 and 5.2 l min^{-1}. The air velocity through a given experimental set-up was regulated by throttling the fan at predetermined series and taking measurements with a hot wire anemometer. The range of average air velocity for the test was set between 0.12 and 1.14 m s^{-1}. At the beginning of each test, water flow was fixed. The evaporative cooling pads were wetted before testing begins to ensure saturation (Barzegar et al., 2012; Liao and Chiu, 2002). The initial air velocity 0.12 m s^{-1} was maintained for 30 min, and then increased to 0.51, 0.82, 1.05, 1.10 and 1.14 m s^{-1} respectively during the test. For each air velocity, at least 10 min waiting period was maintained to ensure equilibrium between the wetted media and the new air and water conditions. All tests were performed in triplicate.

The Testo 174H data loggers were programmed via computer interface. At each velocity, data points were recorded at equilibrium condition by all data loggers at 5 min intervals except pressure drop measurement and the average values were used in data analysis.

2.5 System performance analysis

The cooling efficiency of evaporative air cooling is measured by the saturation effectiveness or the evaporative saturation efficiency (ANSI/ASHRAE Standard 133-2001). It is determined as the ratio between the drop in air temperature after passing through the pad and the maximum possible drop under conditions of air saturation using the following Equation 1:

$$\eta_{\text{cool}} = \frac{T_1 - T_2}{T_1 - T_{wb}} \times 100 \qquad (1)$$

Where, T_1 is the dry-bulb temperature of the incoming air (℃), T_2 is the dry-bulb temperature of the outgoing air (℃), T_{wb} is the thermodynamic temperature of the wet-bulb at the entrance and η_{cool} is the efficiency. The value of the efficiency depends on the air velocity through the wetted-medium, and the water air ratio (Franco et al., 2010).

The specific water consumption (C_w) of the pads (kg h^{-1} m^{-2} ℃$^{-1}$) is expressed as the mass flow of evaporated water (m_e) per unit of the wetted-medium frontal area (A_{mfr}) (i.e., the air flow area) and the maximum thermal difference possible given the conditions of air entering the wetted-medium (Franco et al., 2010).

$$C_w = \frac{m_e}{(T_1 - T_2)A_{mfr}} \qquad (2)$$

Where the mass flow of evaporated water (m_e) is obtained by applying the water vapour balance:

$$m_e = m_{v2} - m_{v1} \qquad (3)$$

m_{v1} and m_{v2} are the flows of vapor at the entrance and exit of the wetted-medium, respectively in kg h^{-1}. Dividing Equation 3 by the flow of dry air (m_a) in kg h^{-1} which is constant between the entrance and the exit of the wetted-medium (Franco et al., 2012) gives:

$$m_e = m_a(W_2 - W_1) \qquad (4)$$

Where W_1 and W_2 are the absolute humidity of the air at the entrance and exit of the pad, respectively (kg$_w$ kg$_a^{-1}$) and $m_a = \rho_a Q_a$, in which ρ_a is the air density (kg m^{-3}) and Q_a is the air flow through the pad (m^3 h^{-1}). Substituting expression (1) in Equation 2, the water consumption of the pads depends on the air velocity through it, the saturation efficiency and the air conditions on entering the pad (Franco et al., 2012; Franco et al., 2010):

$$C_w = \frac{m_e}{\eta_{cool}(T_1 - T_{wb})A_{mfr}} \qquad (5)$$

2.6 Statistical analysis

Duncan test and analysis of variance were carried out to determine the level of significance and the combined effect of pad configuration, water flow rate and air velocity on the cooling efficiency of the pad media.

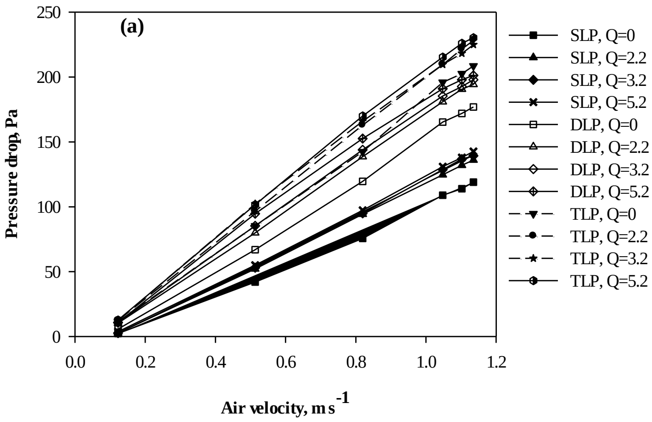
3 Results and discussion

3.1 Pressure drop across the media

Figures 3a and b depict the effect of inlet air velocity, water flow rate and pad configuration on the pressure drop along the length of the evaporative cooler. A comparison of Figure 3a with b shows, in general, that the pressure drop across pads made of small size charcoal is larger than that across pads made of large size charcoal at the same pad configuration and water flow rate. The pressure drop increases with the increase in air velocity (Figure 3a and b); this is in accordance with the literature (Franco et al., 2010; Gunhan et al., 2007; Liao et al., 1998; Koca et al., 1991).

For all pad configurations, the higher the water flow applied, the greater the pressure drop for a given air velocity. The lower pressure drop in all pad configurations (Figure 3a and b) occurs in the dry conditions and it increases with a higher water flow rate. According to El-Dessouky et al. (1996), the increase in water flow increases the films of the water retained on the surface of the media and thus decreases the volume for the airflow in the media, and as a result increases the pressure drop. The water flow effect on the pressure drop is however small in the test range (Figure 3) and there is no significant difference ($P > 0.01$) between water flows tested for the two pad media at the studied pad configurations. The result in this study is similar to the results of the study done by Franco et al. (2010), Gunhan et al. (2007), Koca et al. (1991).

Essentially, a greater pressure drop is obtained with TLP configuration compared to DLP and SLP configurations (Figure 3a and b). Statistically, the difference between the investigated pad configurations is significantly different ($P < 0.01$) at the same air velocity and water flow rate. For instance, at 0.12 m s^{-1} air velocity and water flow of 5.2 l min^{-1} for small size charcoal pad, the pressure drop increased from 3.67 to 10.67 Pa (+191%) when SLP was changed to DLP configuration while it changed from 3.67 to 12.33 Pa (+236%) when SLP was changed to TLP configuration. In the case of large size charcoal pad, pressure drop increased from 2.66 to 3.33 Pa (+25%) for SLP and DLP and from 2.66 to 5.34 Pa (+101%) respectively, at similar test condition. Similar trends were observed for tests at other air velocity and water flow conditions.



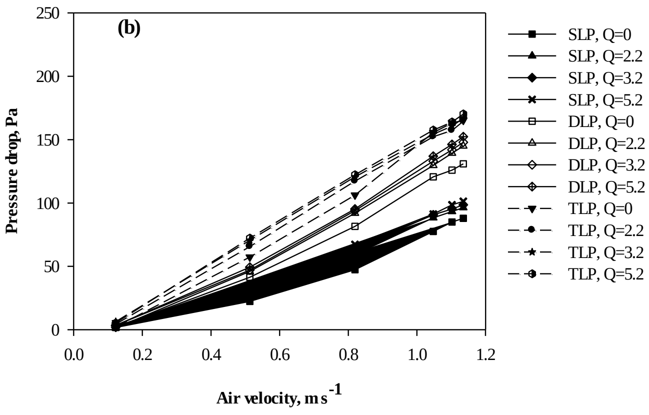


Figure 3 Pressure drop across three pad configurations at four water flow rates (water flow rate Q is in l min^{-1}) for (a) small size charcoal; (b) large size charcoal.

3.2 Cooling efficiency

Figure 4a and b shows the cooling efficiency at different air velocities through the three pad configurations made of small and large size charcoal particles and for all the water flow rates applied. Comparing Figure 4a with b, one can find that, in general, the cooling efficiency for pads made of small size charcoal particles is higher than that for pads made of large size charcoal at the same pad configuration and the corresponding proportional water flow rate. The results indicate that when the velocity of the air circulated through the cooling pad configurations increases, the cooling efficiency decreases marginally. The results compare to that of Gunhan et al. (2007) closely. With the increase in air velocity, the duration of air-water contact is reduced, and therefore, there is inadequate time for the air to transfer heat and mass with the water, lowering the cooling efficiency.

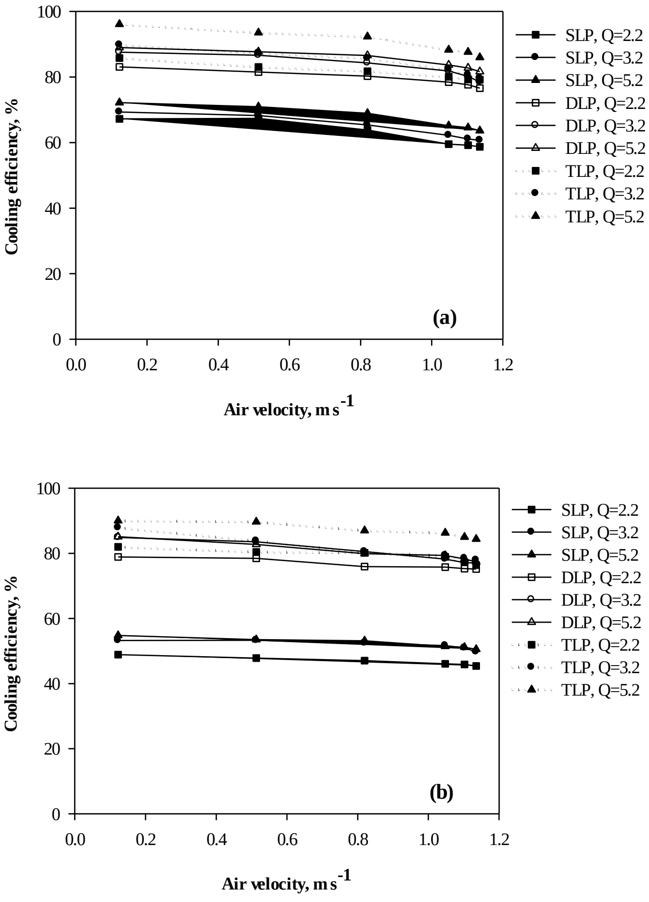


Figure 4 Effect of air velocity and pad configuration on cooling efficiency at different water flow rates (water flow rate Q is in l min^{-1}): (a) small size charcoal pad; (b) large size charcoal pad.

Figure 4a and b also shows the effect of pad configuration on the cooling efficiency for all water flow rates. According to the analysis of variance, the effect of pad configuration on cooling efficiency is significant at 99% probability level. The results of Duncan tests are given in Table 1. As a general characteristic, we can say that using SLP configuration allows limited surface area for adiabatic cooling. On the other hand, DLP and TLP configuration exposes larger wet surface area, respectively, thus allowing air to pick up moisture and cool. This type of pad configuration results in cooling efficiency of 76.60% to 89.0% for DLP and 79.21% to 96.10% for TLP for small size charcoal pads and 73.72% to 85.14% for DLP and 73.42% to 90.06% for TLP for large size charcoal pad.

Table 1 Effect of pad configuration on the evaporative cooling efficiency

Pad configuration	Evaporative cooling efficiency,%	
	Small size	Large size
SLP*	63.55^a	50.49^a
DLP*	82.82^b	79.00^b
TLP*	85.59^c	82.56^c

*Values followed by different letter in the same column are significantly different according to Duncan's test at P < 0.01.

Considering the water flow, and according to the test results obtained, the cooling efficiency increased marginally in most instances when water flow applied to the various pad configurations varies from 2.2 to 5.2 l min^{-1}. This is demonstrated in Figure 5a and b for air velocities of 0.12 and 1.14 m s^{-1} except TLP configuration made of large size charcoal at 1.14 m s^{-1}. Statistically, the results of the test indicated that there is no significant effect at 99% probability level of water flow rate in the present study on the cooling efficiency at the same pad configuration and the corresponding air velocities. Some earlier studies indicated that cooling efficiency is increased with the increase of water flow rate until the pad is sufficiently moist (Dzivama et al., 1999; Mekonnen, 1996). However, in the present study, the design of the water distribution system (section 2.2) allowed water to be evenly distributed at the chosen water flow rates, thus all pads were fully saturated. The results are supported by past studies (He et al., 2015b; Franco et al., 2010; Gunhan et al., 2007). He et al. (2015a) reported that a further increase in water flow rates than what is practically required for saturation decreases the cooling efficiency as the excess water may block the pore spaces of the medium. The results of the effect of water flow on cooling efficiency are particularly of great importance, since we can reduce water flow supplied to a given pad configuration by providing flow rates that will fully wet the media while the cooling performance remain unchanged. This makes it possible to reduce the designing pump power for wetting media and use less water (He et al., 2015b), thus satisfying an ongoing comprehensive research project that aimed to quantify the potential of using direct photovoltaic powered water pump for evaporative cooling purposes.

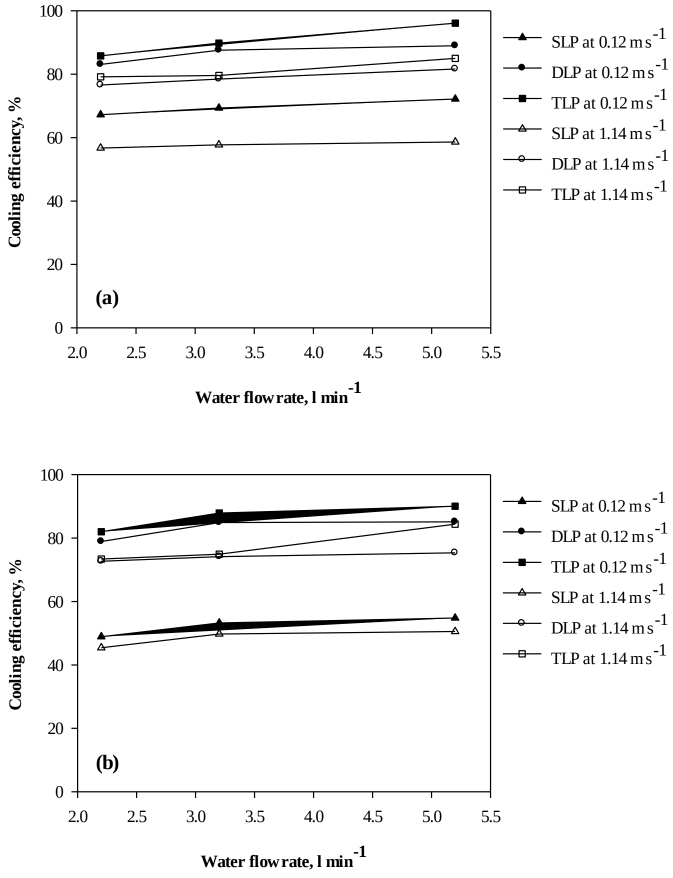
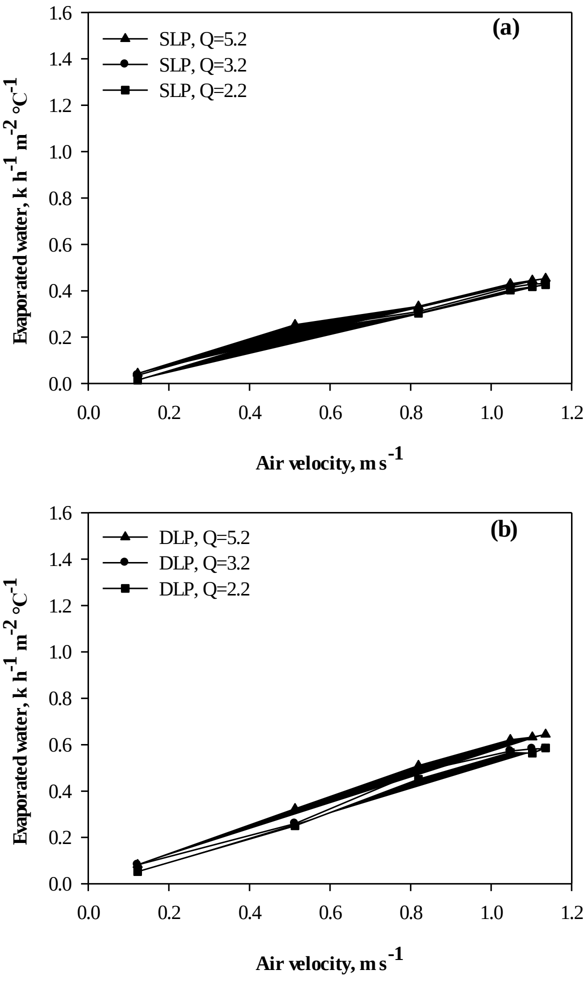


Figure 5 Effect of water flow rate on the evaporative cooling efficiency of (a) small size media and (b) large size media for the three pad configuration tested at two air velocities

3.3 Water evaporation rate from the pads

Figures 6 and 7 report the calculated water evaporation rate of the two media sizes studied at different air velocities and water flows, expressed in kg of water evaporated per hour per m^2 per degree ℃ of temperature reduction (Equation 5). As the air velocity increases, the rate of evaporation increases. At a given air velocity and water flow, the water evaporation rate of pad made of small size charcoal is higher than its counterpart ($P < 0.01$). For instance, at air velocity of 0.52 m s^{-1} and water flow of 3.2 l min^{-1}, the amount of water evaporated for small size charcoal pads was approximately 0.2280, 0.2594 and 0.5983 kg h^{-1} m^{-2} ℃$^{-1}$ per square meter of pad area for SLP, DLP and TLP respectively, while in the case of pads made of large size charcoal these values were 0.1611, 0.2103, and 0.5186 kg h^{-1} m^{-2} ℃$^{-1}$ per square meter of pad area for SLP, DLP and TLP respectively. Similar trends can also be observed at the other working conditions investigated.



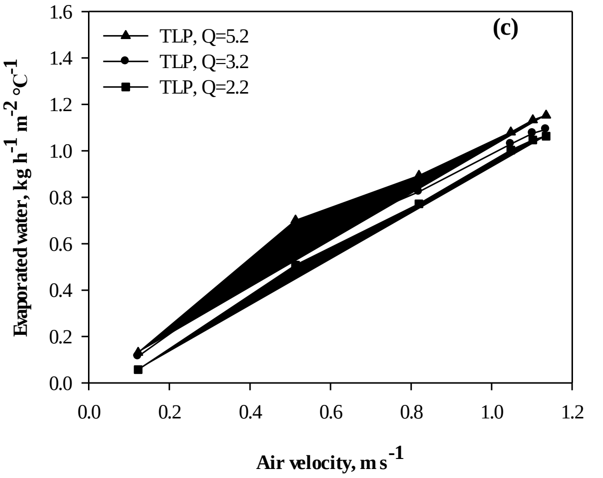
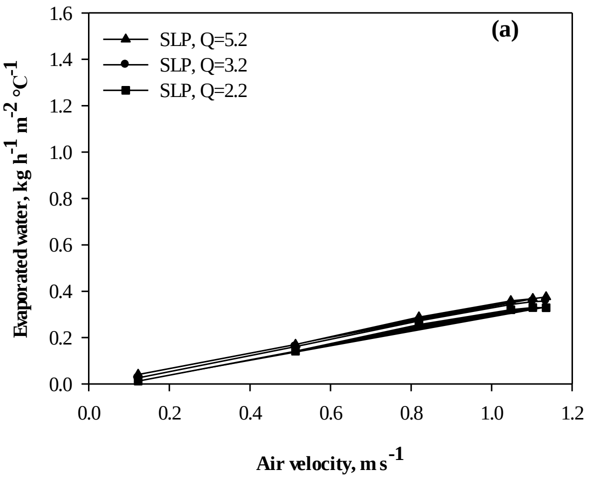
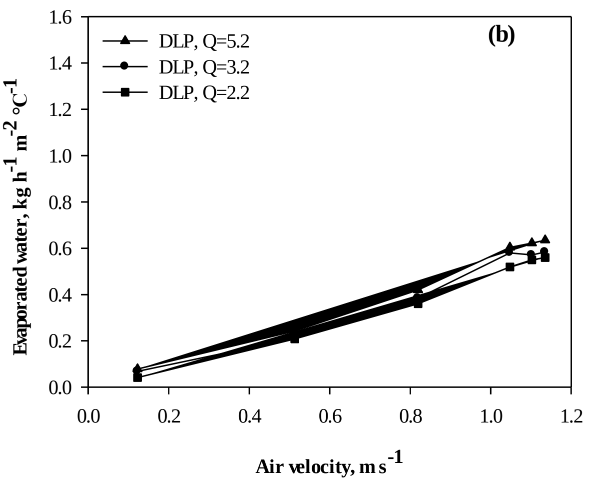


Figure 6 Effect of air velocity through small size charcoal pad configuration on specific water consumption at different water flow rates (water flow rate Q is in l min^{-1}): (a) SLP; (b) DLP; (c) TLP





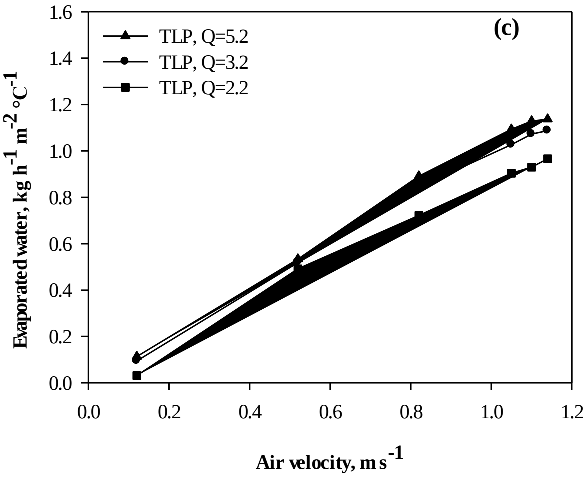


Figure 7 Effect of air velocity through large size charcoal pad configuration on specific water consumption at different water flow rates (water flow rate Q is in l min^{-1}): (a) SLP; (b) DLP; (c) TLP

3.4 Comparative view

Table 2 shows comparison of the results from the current study to existing local pad materials in the literature. From the table, it can be seen that the charcoal pad material and the tested pad configurations in this study have good prospects to be used as an alternative for cooling purposes. Nevertheless, it is important to mention that it was not easy to a draw comparison amongst several other local pad materials because of the variation in experimental test climatic conditions and type of test rig employed. Gunhan et al. (2007) reported that an ideal pad must provide the highest evaporative cooling efficiency and the lowest airflow resistance. Although increasing the pad thickness increases the cooling efficiency of evaporative coolers, this will increase the fan capacity which will increase costs.

Table 2 Comparison of evaporative cooling performance for different materials

Pad material	Pad thickness, mm	Air velocity, m s^{-1}	Water flow rate, l min^{-1}	Pressure drop, Pa	Efficiency, %	Reference
Palm fruit fiber	30	4	24	N/A	90	Ndukwu et al. (2013)
Jute	N/A	2.4	N/A	N/A	62.10	Al-Sulaiman (2002)
Luffa fibers	N/A	2.4	N/A	N/A	55.10	
Date palm fiber	N/A	2.4	N/A	N/A	38.90	
Rice straw	30	0.3-1.05	1.64	N/A	71.42-76.51	Darwesh et al. (2007)
	100	0.3-1.05	1.64	N/A	68.21-69.57	
	150	0.3-1.05	1.64	N/A	60.24-69.30	
Palm leaf fiber	30	0.3-1.05	1.64	N/A	59.38-65.40	
	100	0.3-1.05	1.64	N/A	58.72-60.98	
	150	0.3-1.05	1.64	N/A	55.49-56.58	
Coarse pumice stones	100	1.6	1.75	266	76.1	Gunhan et al. (2007)
Fine pumice stones	150	1	1.75	225.6	93.1	
Volcanic tuff	100	1.6	1.75	203.9	81.1	
Shading net	150	0.6	1.75	2.9	82.1	
Small size charcoal	SLP*	0.12-1.14	2.2-5.2	2.67-142.67	58.71-72.21	Current study
	DLP	0.12-1.14	2.2-5.2	10.33-201.33	76.60-89.01	
	TLP	0.12-1.14	2.2-5.2	12.22-230.33	79.21-96.10	
Large size charcoal	SLP*	0.12-1.14	2.2-5.2	3.00-101.33	45.41-54.82	
	DLP	0.12-1.14	2.2-5.2	1.33-152.33	75.22-85.14	
	TLP	0.12-1.14	2.2-5.2	4.33-170.33	76.42-90.06	

*Note: The pad thickness for SLP = 100 mm; DLP = 100 mm x 2; TLP = 100 mm x 3

4 Conclusions

In this work, three different pad configurations were tested in order to obtain their operational parameters and their suitability to enhance evaporative cooling. The resistance to air flow through the three pad configurations increased at high air velocity and water flows. The largest impacts on pressure drop are however due to the changes in the air velocity. High pressure drop is obtained in TLP configuration compared to DLP and SLP configurations and the differences between the investigated pad configurations is significantly different ($P < 0.01$) at the same air velocity and water flow rate. The cooling efficiency decreases as the air velocity increases but increases as the number of pad layers in the wind tunnel increases. The effect of water flows on the cooling efficiency is small within the range of air velocities tested since the water is evenly distributed and the pads are fully wetted. In general, DLP and TLP configuration with larger wet surface area provide high cooling efficiencies and high pressure drops, though it evidently leads to increase in water consumption. Therefore, DLP and TLP configurations at low air velocity are recommended. Finally, this research showed that low-cost material, such as charcoal, can be used as an alternative material for evaporative media pads based on the multi-layer pad concept developed in this study.

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