The evaluation of bulk charcoal as greenhouse evaporative cooling pad

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Abstract: The aim of this study was to evaluate the suitability of bulk charcoal as alternative evaporative cooling pad material used in greenhouses. A special test setup is designed to evaluate the performance of charcoal pad. The cooling efficiency and relative humidity difference were evaluated. The results show that the best average cooling efficiency in 209.58 kg m^{-3} charcoal's bulk density at 70%, with 1.38 m s^{-1} air velocity and 0.19 kg s^{-1} water flows for each square meter of pad.

Keywords: greenhouses, evaporative cooling pads, bulk charcoal, pad material

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1 Introduction

Ventilation is important in a greenhouse for many reasons, but during hot weather, it is especially important with cooling. Circulation fans will help to stay the greenhouse uniformly heated, while exhaust fans will thrust out stale air so that fresh air can move in. Suitable ventilation also prevents pest infestations, which can be a difficulty when plants are stressed.

In some areas, the sole method to fully cool a greenhouse will involve an evaporative cooler. These small units will allow heat to leave the greenhouse and keep plants cool. An evaporative cooler is an apparatus that cools air through the evaporation of water. Evaporative cooling uses the heat that required transforming a substance from liquid into gas at a pressure (often atmospheric pressure) (Garai, 2009). The temperature of dry air can be fallen by way of the phase transition of liquid to vapor (evaporation), which can cool air taking much less energy than refrigeration. In highly dry climates, evaporative cooling of air has the supplemented advantage of conditioning the air with more moisture for the consolation of greenhouse plants.

Direct evaporative cooling (open circuit) is used to lower the temperature of air by using latent heat of evaporation. In this process, the energy in the air does not change. The heat of the air is used to evaporate water. The relative humidity rises from 70 to 90%. The moist air has to be continually released to outside, or else the air becomes saturated and evaporation stops. Indirect evaporative cooling (closed circuit) is similar to direct evaporative cooling, but it uses some type of heat exchanger (Maheshwari et al., 2001). The cooled moist air never enters in direct contact with the conditioned air. The moist air stream is released outside, or is used to cool other external devices. While no moisture is added to the incoming air the relative humidity does raise a little. Conditioned air without added moisture raises the evaporation of perspiration improving the cooling effect of Indirect compared to Direct.

The most common way of executing evaporative cooling in a greenhouse is with a fan and pad system. Fan and pad systems consist of exhaust fans at one end of the greenhouse and a porous pad with a water-circulating pump through and over the pad installed at the opposite end of the greenhouse. If all vents and doors are closed

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when the fans operate, air is pulled through the wetted pads and water evaporates. The air will be at its lowest temperature immediately after passing through the pads. As the air moves across the house to the fans, the air picks up heat from solar radiation, plants, and soil, and the temperature of the air gradually rises. The most widely used type of pad material is corrugated cellulose that impregnated with wetting agents and insoluble salts to help to resist rot. These pads are expensive, but when properly maintained they do an excellent job of cooling air. With proper maintenance, corrugated pads should have a lifetime of ten years (Bucklin et al., 1993).

Chopped precision shaved aspen pads were usually used (Figure 1). Aspen pads are sensitive to algae infestation that leads to decay and compaction. This makes it difficult to keep a system operating efficiently without frequent and costly pad replacements. Other pad materials are also on the market, but none have seen wide acceptance. Among these are pads fabricated from aluminum and from plastic fibers. These pads types are expensive and show no advantages over corrugated cellulose. However, an operator planning to replace an old pad system or install a new one should check out, all the pad materials available. Compare costs, life expectancy claims, cooling efficiencies, and probability of maintenance problems before selecting the one that is best for operation.

Figure 1 Chopped precision shaved aspen

Many researchers have studied the object of natural ventilation in agricultural greenhouses. In this overview, empirical studies carry out in small scale with roof and side openings or in full scale greenhouses supplied with roof apertures, roof and side apertures or side apertures and by using porous screens along with different methods to evaluate ventilation rates have been surveyed (Sethi and Sharma, 2007).

Al-Sulaiman (2002) tested a setup for evaluating the performance of date palm fibers, jute and luffa that were used as wetted pads in evaporative cooling. The performance criteria were included thermal efficiency, material performance and cooling efficiency degradation. The results show that the cooling efficiency was the highest for jute at 62.1%. Liao and Chiu (2002) presented a compact wind tunnel for small-scale evaporative cooling-process for two alternative pad materials of coarse fabric PVC sponge mesh in Taiwan region. The effects of air velocity, water flow rate, static pressure drop across pad, and pad thickness on evaporative cooling efficiency were measured. Gunhan et al. (2007) evaluated the suitability of pumice stones, volcanic tuff as alternative pad materials. According to the results of this study, the volcanic tuff pads are the best alternatives pads at 0.6 m s^{-1} air velocity. Ahmed et al. (2011) evaluated performance of Celdek pads, straw pads, and sliced wood pads of evaporative cooling for greenhouses, they included environmental and crop parameters. They reported the greenhouses with sliced wood pads gave the highest yield, and the greenhouses with straw pads gave the least. Soponpongpipat and Kositchaimongkol (2011) studied saturation efficiency and pressure drop across wetted pad of high density polyethylene and rice husk as a wetted pad in evaporative cooling system. The results showed that rice husk and high density polyethylene is significantly higher efficiency than that of commercial wetted pad.

From the literary works, there is some report of experimental work about bulk charcoal as wetted pad materials. Charcoal is a black, porous, carbonaceous material, 85 to 98% carbon, produced by the destructive distillation of wood (Figure 2). Charcoal has a porous structure that can hold water and is easily available

(Douglas et al., 2011). Bulk charcoal placed in various types of evaporative cabinet cooler between the outer and inner metal container walls (Anyanwu, 2004). The charcoal may resist chemical degradation even when exposed to intense weathering in a tropical climate. No changes in quality of finely distributed bulk charcoal over time were founded (Schneider et al., 2011).

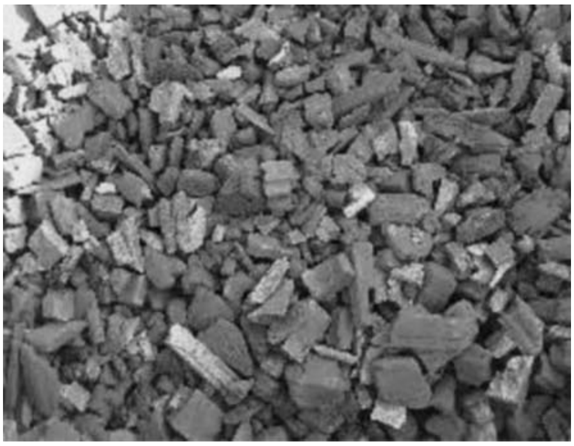


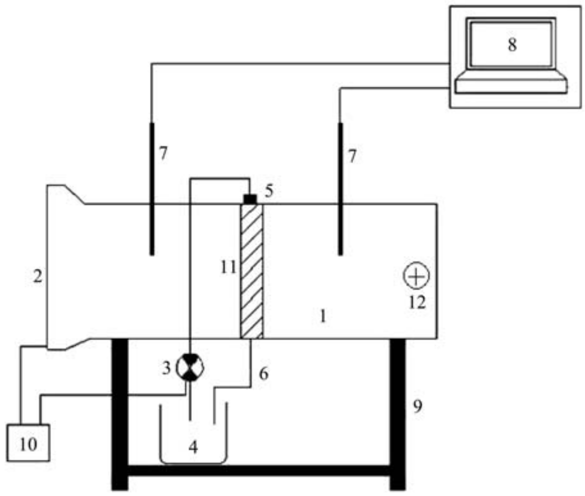
Figure 2 Bulk charcoal

In this paper, an attempt was made to evaluate the performance of bulk charcoal wetted pad experimentally. A special test setup was designed to appraise the charcoal pad's performances such as the cooling efficiency and the relative humidity difference. No similar work has been done on bulk charcoals.

2 Materials and methods

To evaluate the cooling performance of the pads, a special cooling chamber was constructed. The chamber consisted of a hollow rectangular conduit (50 cm × 50 cm × 120 cm) made of stainless steel sheets (Figure 3). A 450 W variable speed fan was installed at the end and a fiber box was fitted in the middle section. The U type fiber box (Figure 4) was made of a screen that allows air to pass through the fibers and a water inlet and drainage holes was installed on the top and bottom.

Temperature and relative humidity were measured before and after fiber box using humidity/temp meter (HT-3015 Lutron, Taiwan) props at 25 cm distance from each side. Parameters were automatically measured through a PC connected to RS232 interface. Air velocity was measured by anemometer vane type prop (AM-4206 Lutron, Taiwan) through of inlet air.



1. Chamber 2. Fan 3. Water pump 4. Tank 5. Diffuser 6. Drainage
7. Prop 8. PC 9. Fundation 10. Dimmer 11. Pad 12. Air flowmeter

Figure 3 Schematic diagram of test apparatus

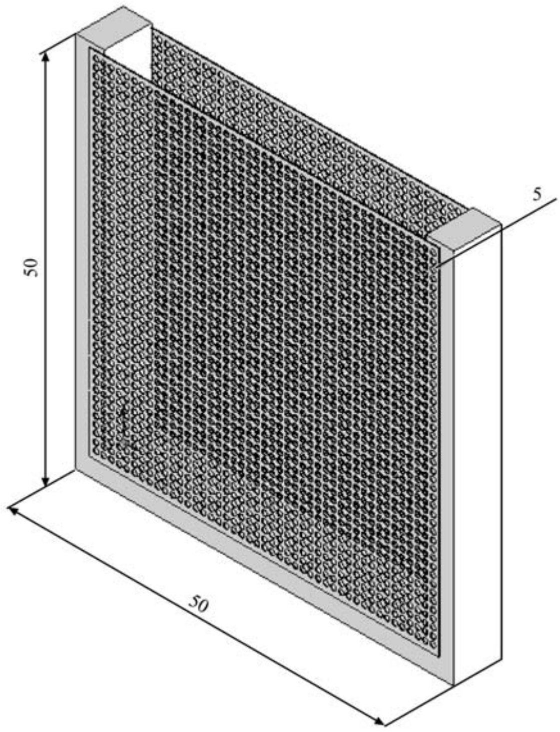


Figure 4 U type fiber box

The charcoals first washed and then weighted in a specific volume to define bulk densities. The charcoals were categorized in 200.14, 206.22 and 209.58 kg m^{-3} bulk densities. The repetitions were conducted using three replicate test specimens. The water flow rates were 0.6, 0.19 and 0.42 l (s m^2)$^{-1}$ and air flows were 0.47, 1.38, and 2.28 m s^{-1}.

The evaluation of the cooling performance of the selected pad was done according to the cooling efficiency and the relative humidity difference. The cooling efficiencies of the pad were determined by using the Equation (1) and Equation (2) as (Al-Sulaiman, 2002):

$$\eta = \frac{t_1 - t_2}{t_1 - t_{wb}} \quad (1)$$

$$\varphi = RH_{outlet} - RH_{inlet} \quad (2)$$

where, η is cooling efficiency; t_1, t_2 and t_{wb} are inlet dry bulb temperatures, outlet dry bulb temperature and wet bulb temperature in °C of the inlet air, respectively. φ is the difference of relative humidity of air inlet and outlet. The values of t_1 and t_2 are the averages of the temperatures that were measured by the props continuously during the experiments with the intervals of 0.2 second. The values of the t_{wb} were determined by using Trane psychometric chart calculator software.

Duncan tests analysis were carried out to determine significance and combined effect of the parameters on the cooling efficiency of the pad.

3 Results and discussion

Table 1 shows the ANOVA test results of cooling efficiencies (η) and air difference of relative humidity (φ) for charcoal pad. This table shows that significant difference among the treatments and reciprocal effect at the 99.0% confidence level. The effects of charcoal bulk density on η and φ are shown in Table 2. According to the Duncan test results as is shown in Table 2, the differences among levels are significant, so with the rising of bulk density the cooling efficiencies have been elevated.

Table 1 The ANOVA test results of cooling efficiencies (η) and air relative humidity difference (φ) for charcoal pad

Source	df	Sum of squarer		Mean squarer		F	
		η	φ	η	φ	η	φ
density	2	0.183	96.629	0.092	98.346	1783**	1149**
water flow	2	0.007	24.405	0.003	12.203	67.09**	142.575**
air flow	2	0.002	256.366	0.001	128.183	22.262**	1498**
density× water flow	4	0.042	102.18	0.01	25.545	203.148**	298.496**
density× air flow	4	0.007	18.108	0.002	4.527	31.690**	52.892**
air flow× water flow	4	0.002	2.147	0.001	0.537	8.053**	6.271**
air flow×water flow×density	8	0.005	14.375	0.001	1.797	12.342**	20.995**

Note: ** Significant difference at the 99.0% confidence level.

Table 2 Charcoal bulk density effects on cooling efficiencies (η) and air relative humidity difference (φ)

Bulk density /kg m^{-3}	Means	
	η	φ
200.14	0.563(a)	45.23(a)
206.22	0.604(b)	47.21(b)
209.85	0.678(c)	49.05(c)

Note: Means followed by the same letter are not significantly.

Figures 5, 6, 7 and 8 show the variation of water flow on cooling efficiencies with charcoal bulk density of 200.17, 206.22 and 209.58 kg m^{-3}. As is shown in Figures 5 and Figure 6, rising cooling efficiency caused by increasing water flow and received a maximum amount then reduced with increase in flows. Mekonnen (1996) and Al Amri (2000) suggested this subject and also in some local materials as cooling pads. However, Figure 7 shows unlike, increasing water flow causes falling in cooling efficiency. This level of bulk density does not have enough porosity for evaporative surfaces. Figures 8, Figure 9, and Figure 10 show the variation of air velocity on cooling efficiency with various charcoal bulk densities. As is shown in Figures 8 and Figure 9, rising cooling efficiency caused by increasing air velocity and then reduced with increase in air velocity. Except Figure 10, increasing air velocity causes falling in cooling efficiency because of decreasing charcoal's porosity which is needed for evaporation from surfaces. Figure 11, Figure 12 and Figure 13 show the variation of air velocity on relative humidity difference with various charcoal bulk densities. As is shown in Figure 11, Figure 12 and Figure 13, rising air velocity resulted less relative humidity difference. Similar findings have been reported by Malli et al. (2011) in their researches on cellulose pads.

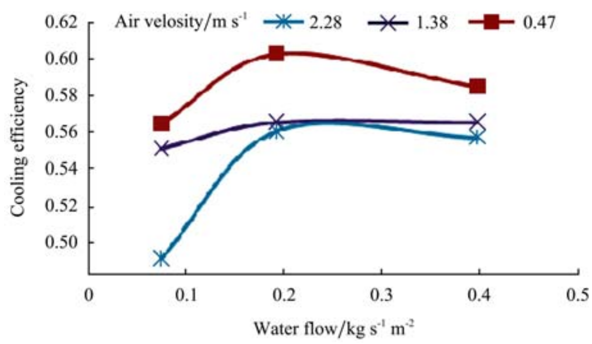


Figure 5 Effect of water flow on cooling efficiency in 200.14 (kg m^{-3}) density

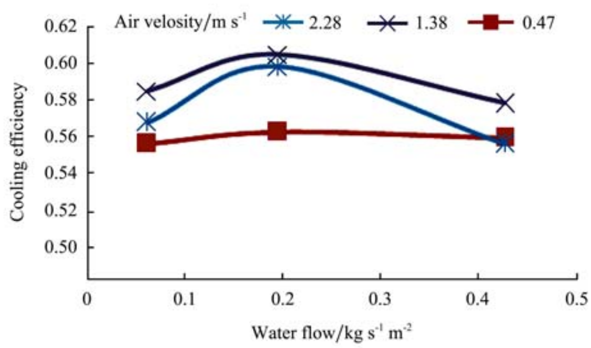


Figure 6 Effect of water flow on cooling efficiency in 206.22 (kg m^{-3}) density

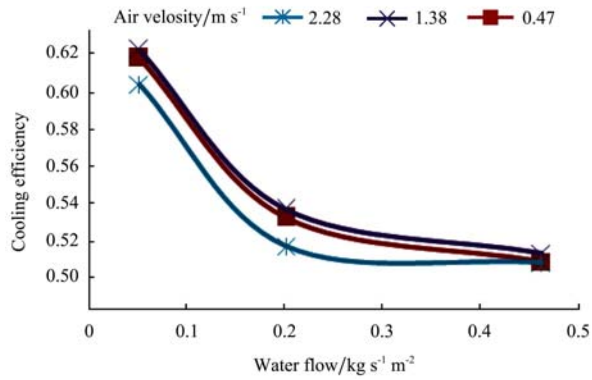


Figure 7 Effect of water flow on cooling efficiency in 209.58 (kg m^{-3}) density

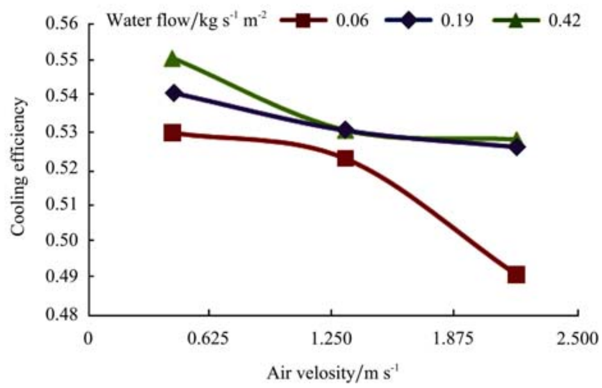


Figure 8 Effect of air velocity on cooling efficiency in 200.14 (kg m^{-3}) density

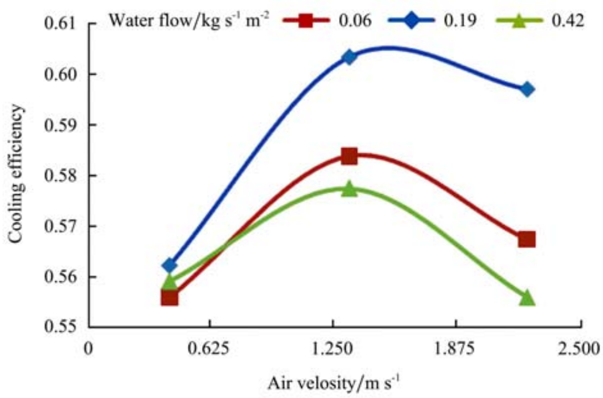


Figure 9 Effect of air velocity on cooling efficiency in 206.22 (kg m^{-3}) density

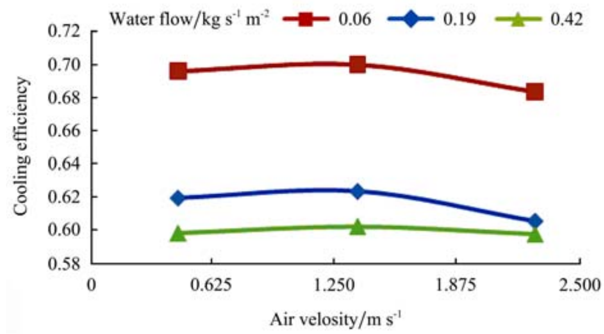


Figure 10 Effect of air velocity on cooling efficiency in 209.58 (kg m^{-3}) density

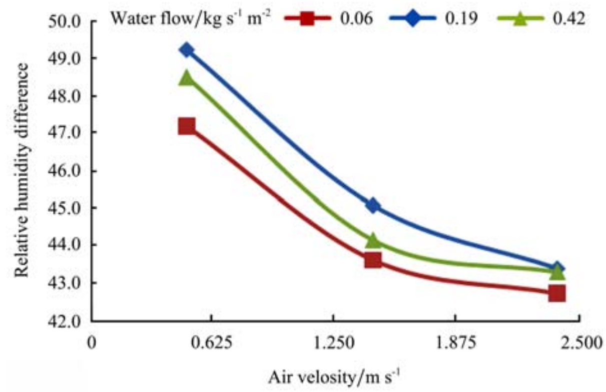


Figure 11 Effect of air velocity on relative humidity difference in 200.14 (kg m^{-3}) density

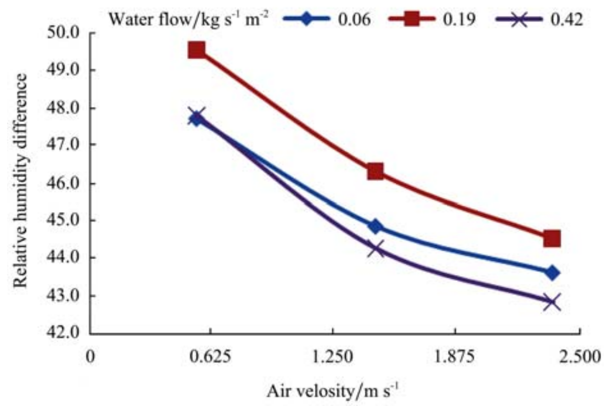


Figure 12 Effect of air velocity on relative humidity difference in 206.22 (kg m^{-3}) density

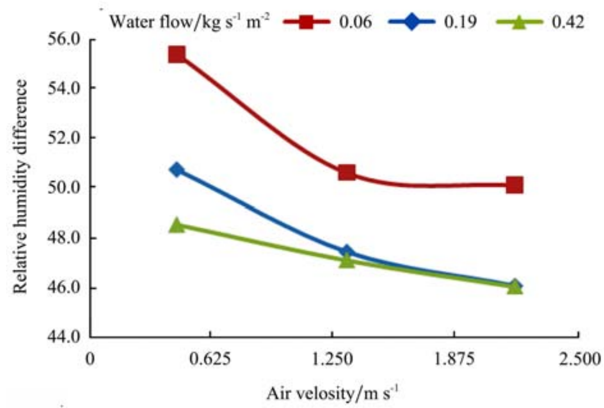


Figure 13 Effect of air velocity on relative humidity difference in 206.22 (kg m^{-3}) density

4 Conclusions

Bulk charcoal is an alternative evaporative cooling pad material with a cooling efficiency ranging from 48% to 70%. In 200.14 and 206.22 (kg m^{-3}) bulk densities rising water flow to 0.2 L s^{-1} for each square meter of pad with 5 cm thickness elevated cooling efficiency to 60%, while in 209.58 (kg m^{-3}) charcoal's bulk density, increasing water flow over 0.08 L s^{-1} for each square meter caused reduction in efficiency. In 200.14 (kg m^{-3}) bulk densities rising air velocity over 0.47 L s^{-1} decreased cooling efficiency in any water flow rates, while in 206.22 and 209.58 (kg m^{-3}) bulk densities increasing air velocity to 1.38 m s^{-1} showed higher efficiency. However, further investigations are required to find the best water flow and air velocity for a special bulk charcoal cooling pad in workable greenhouse.

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