IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)
e-ISSN: 2319-2402,p- ISSN: 2319-2399.Volume 10, Issue 9 Ver. I (Sep. 2016), PP 65-72
www.iosrjournals.org

Enhancing the Cooling Effect of an Electrostatic Wet Scrubber

Emad A. Almuhanna
Department of Agricultural Systems Engineering, King Faisal University, Hofuf, Saudi Arabia

Abstract:*Elevated ambient air temperatures and excessive levels of air pollutants have generated a special need for indoor air cleaning and climate control. A prototype air cleaning and cooling device based on the principles of electrostatic wet scrubbing was designed and built. This study provides the possibility of combining an electrostatic wet scrubber with a porous wetting media using materials available in the local environment (wood shavings, cellulose cooling pad, and date palm fiber)to increase the cooling effect of the scrubber. The particle removal efficiency and cooling effectiveness of the device were experimentally investigated. The results of this study show the potential of utilizing available natural side products (e.g., wood shavings, date palm tissues) as a porous wetting media. Cellulose pads achieved the highest cooling efficiency at 90.84% followed by 84.72% for wood shavings and 73.24% for date palm fibers, compared to 68.1% with no media. Therefore, adding a suitable porous wetting media (e.g., cellulose pads) will significantly increase the cooling efficiency of the device. The humidity difference between the air entering and leaving the device varied from 54.6% for the cellulose pad, to 37.4% for date palm fiber, to 47.8% for the wood shavings and to 36% for no media at all. The negatively-charged water spray combined with wood shavings as a porous media was significantly ($P<0.05$) more effective in removing dust particles (η=77.7%) than either the date palm fiber (η=73.2%) or cellulose pad (η=69.1%), compared to no media (η=53.4%). Therefore, it can be concluded that this device was effective at removing airborne dust and could be used in various climatic conditions as an environmentally clean and energy-efficient system.*
Keywords: *Indoor air quality, Dust control, Charged water spray, Electrostatic force. Evaporative cooling.*

I. Introduction

Elevated ambient air temperatures and excessive levels of air pollutants have generated a special need for indoor air cleaning and climate control strategies. Air-conditioning systems have become more popular and even a necessity in life not only for humans but also for animals and plants to create a comfortable environment and functioning as an air cleaning device as well. Willits [1] and Toida et al. [2] have shown that in extreme environmental locations, where the ambient air temperature in the summer generally exceeds 40ºC, evaporative cooling is an efficient system that can lower the inside air temperature significantly below the ambient air. Due to its low cost and high potential efficiency, evaporative cooling has been introduced as an attractive option when compared to other existing technologies such as vapor compression, absorption/adsorption and thermoelectric refrigeration systems for both dry and hot air as well as more temperate climates [3]. Evaporative cooling substantially increases the rates of heat and mass transfer by forcing the movement of air past an enlarged liquid water surface area for evaporation by using fans. A vertically mounted porous pad can be wetted by dripping water onto the upper edge. The wet porous cooling pad can provide a large water surface in which air moisture contact is achieved [4]. Commercial pad cooling materials are usually complicated to manufacture, costly and difficult to attain. Therefore, it is necessary to investigate and evaluate locally available materials to use as cooling pads in rural, agricultural areas [5]. The underlying principle of direct evaporative cooling is the conversion of sensible heat to latent heat. Through a direct evaporative cooling system, hot outside air passes over a porous wetted medium. Heat energy is absorbed by the water as it evaporates from the porous wetting medium, so the air leaves the system at a lower temperature. It is an adiabatic saturation process in which the dry-bulb temperature of the air decreases as its humidity increases at constant enthalpy. Some of the sensible heat of the air is transferred to the water and becomes latent heat by evaporating some of the water. The latent heat follows the water vapor and diffuses into the air. The minimum temperature that can be obtained is the wet-bulb temperature of the entering air [6-8]. Furthermore, due to growing environmental concerns and stringent environmental regulations enforced worldwide on particulate emissions from various sources, attention was driven into alternative technologies that are simple, cost effective and exhibit a high performance when removing particulate matter from industrial effluents. Particulates may be either emitted into the atmosphere (primary particulates) or formed within the atmosphere itself (secondary particulates) as a result of primary chemical reactions [9].

The electroscrubber uses Coulomb attraction or repulsion forces between electrically charged scrubbing droplets (collector) and dust particles for the removal of particles from a gas. Compared to inertial scrubbers, the electroscrubbers can operate at lower droplet velocities, but the collection efficiency for a single droplet can be > 1 [10]. In some cases, electrostatics have been used to augment particle removal efficiency of water droplets [11-12]. Almuhanna et al. [12] indicated the potential of electrostatically charged water spray in reducing the dust concentration in enclosed spaces under controlled conditions. Typically, the smaller the droplet size and the larger the number of droplets, the better is the ability to capture smaller-sized particles. When a dust particle enters the humid scrubber environment, the size of the particle increases due to its hygroscopic properties [13-14]. As the particle grows, increasing its diameter and mass, the chance of the particle being intercepted by sedimentation and impaction increases. Furthermore, design and operational parameters such as the specific surface area of the packing, spatial structure of the packing, water flow rate, and airflow rate might affect the removal efficiency [9]. Therefore, the main goal of this study is to evaluate the durability of adding three types of porous wetting media (wood shavings, cellulose cooling pad, and date palm fiber) to the electrostatically assisted wet scrubber to increase the cooling effect of the scrubber. Specific objectives include the following: (1) evaluating the durability of an electrostatically assisted wet scrubber as a cooling device, and (2) evaluating the effect of the material used (wood shavings, cooling pads, and date palm fibers) on the cooling and filtration efficiency.

II. Materials and Methods

Field measurements were conducted at the Agricultural and Veterinary Training and Research Station (AVTRS) of King Faisal University, Al-Ahsa, Saudi Arabia. A prototype air cleaning and coolingdevice based on the principles of electrostatic wet scrubbingwas designed and built. The design of the device includes the use of an electrostatically charged spraying nozzle (air-assisted inductioncharging nozzle) and different porous wetting media (wood shavings, cellulose cooling pad, and datepalm fiber). Figure 1 shows a schematic diagram of the prototype of thedevice. It consisted of the following components: (1) axial fan, (2) porous wetting medium (wood shavings, cellulose pad and date palm fiber), (3) electrostatic water spraying system, (4) air outlet, (5) air inlet and (6) ESS pump. A 0.31-m-diameter axial fan (model Windy DVN-121, Sungdo Corporation, 402, MoksanBldg, 252-156 Yongdu-Dong, Dongdaemun-gu, Seoul, Korea) provided variable volumetric flow of up to 30 m^3/min (1059.4 cfm) at a pressure of 13 mmHg. The fan was mounted in the inlet duct, and its motor speed was controlled by a voltage regulator. The air inlet was 0.16 m^2, and the air outlet was 0.0675 m^2. The area of porous media used was 0.16 m^2 in a mixing chamber of 0.216 m^3.

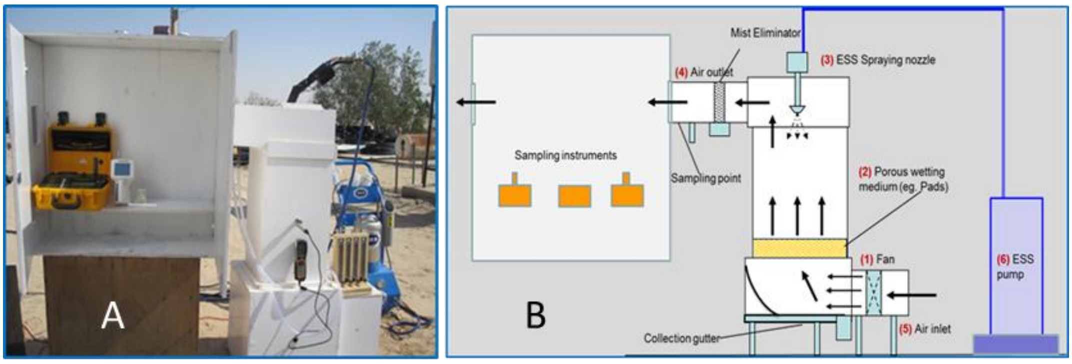

Figure 1. (A) Photograph of the test setup, (B) Schematic diagram showing the components of the air cleaning device (not drawn to scale).

Charged water spray was generated using a commercially available electrostatic water spraying device (ESS XT, Electrostatic Spraying Systems, Inc., Watkinsville, Ga.) developed for agricultural chemical application [15]. The spraying nozzle was positioned on top of the mixing chamber facing into the incoming air stream. The spraying system was operated at a liquid flow rate of 120 mL/min [at a water tank pressure of 103 kPa (15 psi)]. The droplets ranged in size from approximately 25 to 60 μm as stated by the manufacturer. The mean net charge-to-mass ratio of the charged droplets was -6.5 mC/kg (SD=0.9 mC/kg) for the negatively charged water spray [12]. Almuhanna [11] studied the size distribution and concentration of the airborne droplets by using the Aerodynamic Particle Sizer (APS) Spectrometer model 3321 (TSI Incorporated, 500 Cardigan Road, Shoreview, MN 55126, USA). This spectrometer measures the equivalent aerodynamic diameter of particles from 0.54 to 20 µm, and uses an air sampling rate of 1.0 L/min. The spectrometer was connected to a dilution unit (TSI Aerosol Diluter 3302A), which was set at a 1:100 dilution ratio. The spraying system operated at a liquid flow rate of 120 mL/min (water tank pressure of 15 psig). Figures 2A and 2B show the droplet size distributions based on the number and mass concentrations, respectively, of the water spray.

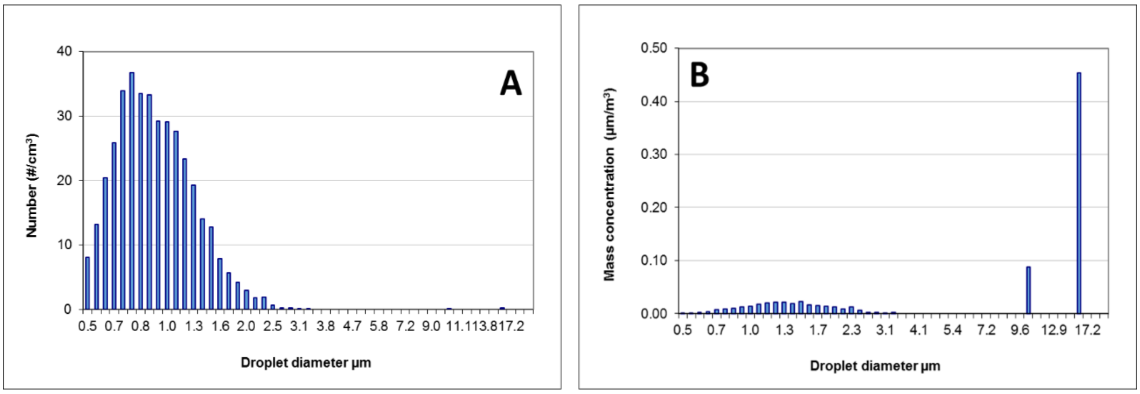

Figure 2. Droplet size distribution, (A) number and (B) mass concentration for the electrostatic spraying system during operation.

The prototype air cleaning and coolingdevice was equipped with a changeable tray with dimensions of 40-cm high, 40-cm wide, and 10-cm thick to exchange the porous media[A: wood shavings**,** B: cooling pads (cross-fluted cellulose pad known as CELdek), C: date palm (*Phoenix dactylifera*) fibers], which was installed in the electrostatic wet scrubber air bath (Fig. 3).

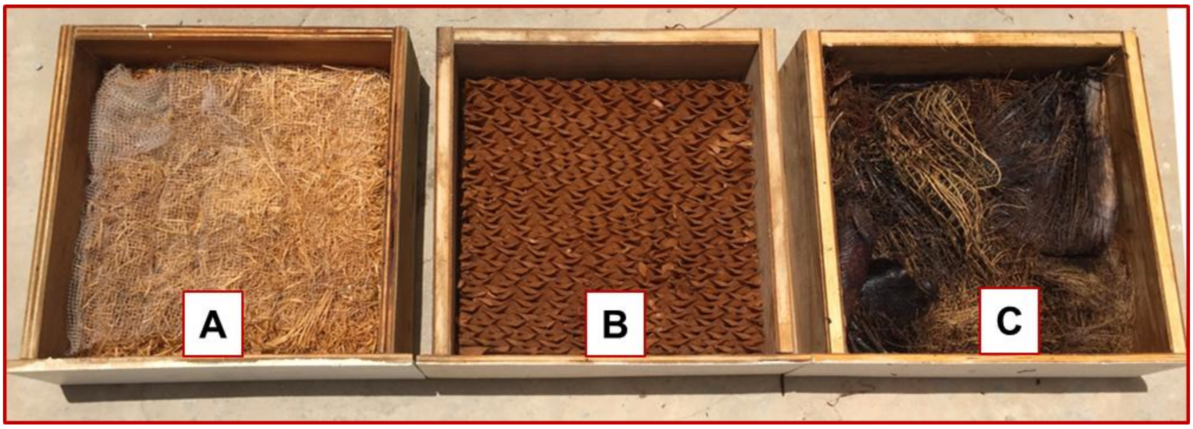

Figure 3. Porous wetting media used (A: wood shavings, B: cellulose cooling pads, C: date palm fibers).

The evaporative cooling system is based on the process of heat absorption during the evaporation of the sprayed water. It mainly consisted of porous media (e.g.,cellulose pad) and an extracting fan in the evaporative cooling system depicted in Fig. (4A). The transformation of heat and mass between air and water causes a decrease in the air-dry-bulb temperature and an increase in its humidity, while the enthalpy remains constant in a perfect process. The minimum temperature that can be attained is the wet-bulb temperature of the incoming air (point 2), as shown in Fig. (4B).

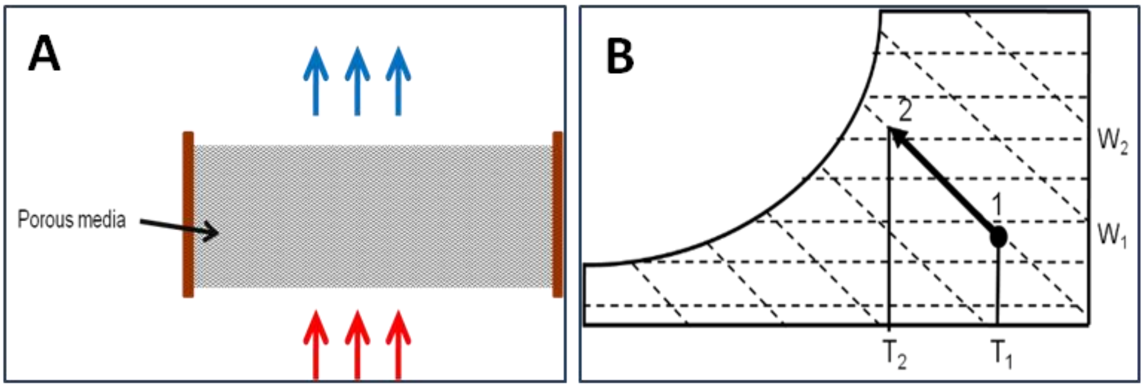

Figure 4. Schematic diagram of (A) air bath within porous wetting media, (B) evaporative cooling process.

The cooling efficiency (η_c) was computed by determining the mean degree of cooling ($T_{ao} - T_{ai}$) and the wet-bulb depression ($T_{ao} - T_{wb}$) using the ASHRAE equation [16]:

$$\eta_c = \frac{T_{ao} - T_{ai}}{T_{ao} - T_{wb}} \times 100 \qquad (1)$$

where T_{ao} and T_{ai} are the outlet and inlet dry-bulb temperatures of the air stream, respectively, and T_{wb} is the wet-bulb temperature of the outgoing air.

The air velocity was measured at various points along the scrubber inlet and outlet cross-section using a Testo 435-2, (Testo Inc. 40 White Lake Road Sparta, N.J. 07871 – USA) multi-function instrument equipped with a hot wire anemometer probe. The required sampling flow rates for isokinetic sampling were determined by traversing the velocity probe over the sampling area prior to sampling [17]. The dust collection filters (Type AE, SKC, Eighty-Four, Pa.) were conditioned by placing them in the oven for 24 h at 103°C before and after sampling. Filter conditioning was done to minimize the effect of humidity and collected water droplets on filter weights. All filters were weighed in an electronic analytical balance (Model AWD-120D, Shimadzu Corporation, Kyoto Japan) with a sensitivity of 0.01 mg.

The removal efficiency of the device was determined by comparing the dust concentrations at the inlet and exhaust of the scrubber. The dust removal efficiency (η_d) for the device was calculated using the following equation:

$$\eta_d = \frac{C_i - C_o}{C_i} \times 100 \qquad (2)$$

where C_i is the mean dust mass concentration at the scrubber inlet and C_o is the mean dust mass concentration at the scrubber exhaust.

1.1. Measurements and data acquisition

The air temperatures and relative humidity just entering and leaving the device were measured using a HOBO® U12 Logger (Onset Computer, Bourne, MA) with a manufacturer stated accuracy of ±0.35°C. The data updated by a scan of all sensors every 1s and the mean of 60 scans recorded every minute. The size distribution and number concentration of airborne particles were monitored using a particle counter (Model GW3016A, GrayWolf Sensing Solutions, Advanced Environmental Measurements, 12 Cambridge Drive, Trumbull, CT 06611 USA). The spectrometer measured particles with aerodynamic diameters ranging from 0.3 to 10 mm at an air sampling rate of 2.83 LPM (0.1 CFM). Moreover, six channels were used, and a counting efficiency of 100% was employed for particles with diameters of >0.45 μm. The spectrometer displayed the particle count and mass concentration readings in μg/m^3. The mass concentration was measured by Real-time EPAM -5000 Particulate Sampler EPAM-5000 Aerosol Monitor（HAZ-DUSTTM MODEL EPAM-5000，Environmenta Devices Corporation， Haverhill， MA, USA), while the electrostatic charge was measured with a dynamic Faraday cage sampler [18]. The mean η values were analyzed statistically by using PROC GLM of SAS (Version 9.1, SAS Institute, Inc., Cary, N.C.). Means were compared at a level of significance of 5%.

III. Results and Discussion

1.2. Effect of different porous media on cooling efficiency:

Evaporative cooling is an environmentally friendly and energy-efficient method for cooling air in hot and dry regions. Therefore, the work for this research was conducted during Jun 2015 to evaluate the cooling effect of the electrostatically assisted wet scrubber and the durability of adding three types of porous wetting media to increase the cooling efficiency. The wet scrubber was operated for five days for a 60-min run time during noon (11:00-12:00). The average environmental parameters during the test period are shown in table 1.

Table 1. Measured environmental parameters during the testing period

Parameter	Mean	SD
Temperature (°C)	45.5	2.2
Relative humidity (%)	10.1	2.8
Dust mass concentration (μg/m^3)	1020	340
Geometric mean diameter (μm)	6.9	0.2
Geometric standard deviation	1.2	0.1

The air temperature difference between the air entering and leaving the device varied from 16.3^{o}C for the cellulose pad, to 15.4ºCfor the date palm fiber, to 15.5ºC for the wood shavingsand to 14.2ºC with no media. Figure 5 shows the temperature difference between inlet and outlet air for different porous wetting media.

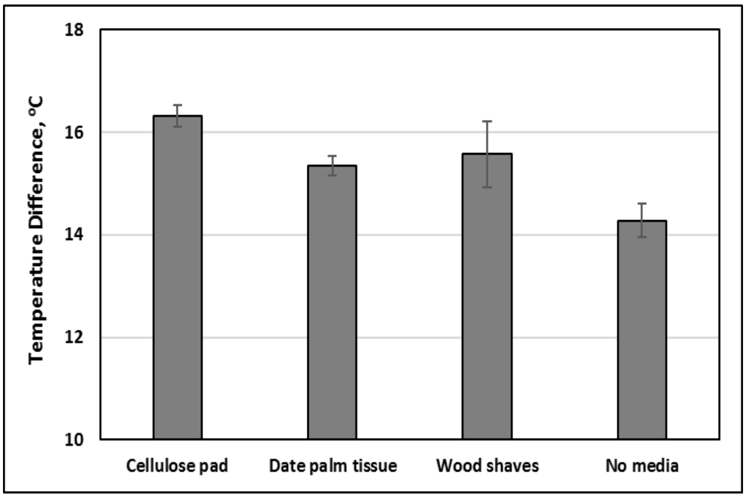

Figure 5. Temperature difference between inlet and outlet air for different porous wetting media

As seen in the results for the hourly average cooling effectiveness of the device shown in Table 2, the cellulose pads achieved the highest cooling efficiency at 90.84%, followed by 84.72% for the wood shavings, 73.24% for date palm fiber and 68.1% with no media. This finding indicates that the cellulose pad increased cooling effect with (22.74%), followed by the wood shavings (16.62%) and the date palm tissues (5.14%), compared with no media present. Therefore, adding suitable porous wetting media (e.g., cellulose pads) will significantly increase the cooling efficiency of the device. Furthermore, this method provides good potential for utilizing available natural side products (e.g., wood shavings, date palm tissues).

Table 2. Cooling efficiencies of different porous wetting media

Treatment	Cooling Efficiency		No. of Reps
	Mean[*]	SD	
Cellulose pads	90.84a	4.10	4
Date palm (*Phoenix dactylifera*) fibers	73.24b	3.20	3
Wood shavings	84.72c	2.90	3
Control (i.e., only the fan was operated)	68.1d	5.20	4

[*] Column means followed by the same letter are not significantly different at the 5% level of significance.

Equations for the variables (different porous wetting media) were used to predict outlet air temperature with inlet air temperature and vice versa. For the cellulose pad, a strong association (r = 0.99) was observed between inlet and outlet air temperature. This result indicates that an increase in the inlet air temperature is mostly due to an increase in the outlet air temperature.

For the cellulose pad: $T_{out} = 0.5757(T_{in}) + 3.302$ ($R^2 = 0.973$) (3)

For the wood shavings, a fair association (r = 0.85) was found between inlet and outlet air temperature. This relationship shows that an increase in the inlet air temperature was mostly due to an increase in the outlet air temperature.

For the wood shavings: $T_{out} = -1.8519(T_{in}) + 118.12$ ($R^2 = 0.722$) (4)

For the date palm fiber, a fair association (r = 0.66) was found between inlet and outlet air temperature. This relationship shows that an increase in the inlet air temperature was mostly due to an increase in the outlet air temperature.

For the date palm fiber: $T_{out} = 0.6193(T_{in}) + 1.897$ ($R^2 = 0.431$) (5)

In the absence of any media, a strong association (r = 0.97) was found between inlet and outlet air temperature.

For the absence of any media: $T_{out} = 2.9287(T_{in}) - 104.67$ ($R^2 = 0.932$) (6)

The difference in humidity between the air entering and leaving the device varied from 54.6% for the cellulose pad, to 37.4%for date palm fiber, to 47.8% for wood shavingsand to 36% with no media present during the experimental period. Figure 6 shows the humidity difference between the inlet and outlet air of different porous wetting media.

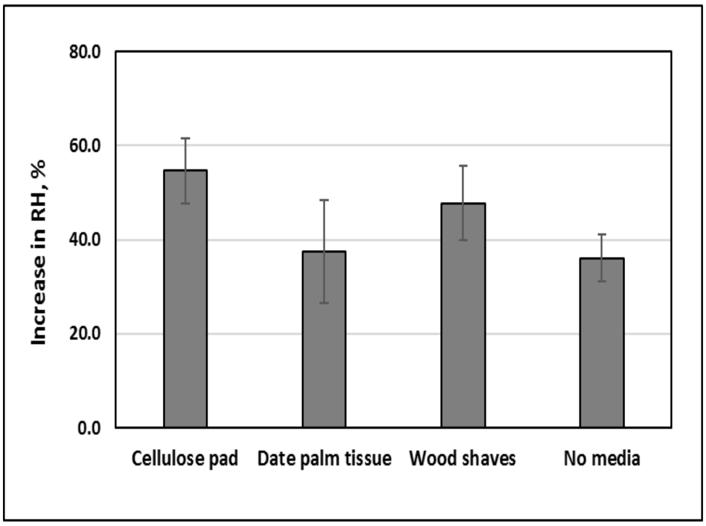

Figure 6. Relative humidity (%) difference between inlet and outlet air for different porous wetting media

1.1. Effect of using different porous media on dust removal efficiency:

Without porous wetting media and when the water droplets are highly charged, as in this device, the electrostatic forces enhance the capture of the dust particles by the water droplets [19], resulting in an improvement in the overall collection efficiency of the droplets. The removal of dust particles was likely primarily due to impaction of the particles with the water droplet. When the porous wetting media was installed, particle removal was enhanced by impaction and interception between particles and media elements. The combined effects of the porous wetting media and charged water droplets as collection surfaces could have been enhanced by electrostatic forces. As such, it is expected that adding the porous wetting media to the electrostatic wet scrubber would be more effective for particle removal.

Table 3 summarizes the mean dust removal efficiency (η) values for the air cleaning and cooling device. The negatively charged water spray and wood shavings were significantly ($P<0.05$) more effective in removing dust particles (η=77.7%) than either the date palm fiber (η=73.2%) or the cellulose pad (η=69.1%), compared with no media (η=53.4%).

Table 3. Dust removal efficiencies for different porous wetting materials with a charged water spray (mass basis).

Treatment	Removal Efficiency	
	Mean[*]	SD
Cellulose pad	69.1a	3.1
Date palm fiber	73.2b	2.3
Wood shavings	77.7c	6.9
No media	53.4d	7.7

[*]Column means followed by the same letter are not significantly different at the 5% level of significance.

Dust removal efficiencies for different porous wetting materials while using a charged water spray are plotted in Figure 7. It is clear that the wood shavings achieved the highest removal efficiency, followed by date palm fiber and cellulose pad. This may be related to an increase in collection surface area.

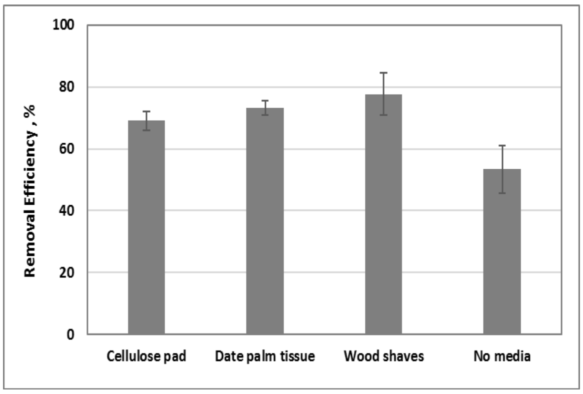

Figure 7. Dust removal efficiencies for different porous wetting materials while using a charged water spray.

Figure 8 shows the particulate removal efficiency of the three particles sizes (TSP, PM_{10}, and $PM_{2.5}$) at the inlet and outlet of the scrubber, representing the reduction in dust concentration due to the scrubbing effect of the negatively charged water spray and installed porous wetting media. Wood shavings achieved the highest removal efficiency at all sizes (89.5%, 72.7%, and 61.1%), followed by the date palm tissues (81.6%, 69.2%, and 50.2%), cellulose pad (77.2%, 59.1%, and 44.3%), and the absence of any media (72.4%, 53.4%, and 33.1%) for TSP, PM_{10}, and $PM_{2.5}$ respectively. It is noted that the wood shavings and date palm tissues achieved better removal efficiency than the cellulose pads due to the tightness of the fibers, even though both had a lower cooling efficiency than the cellulose pads.

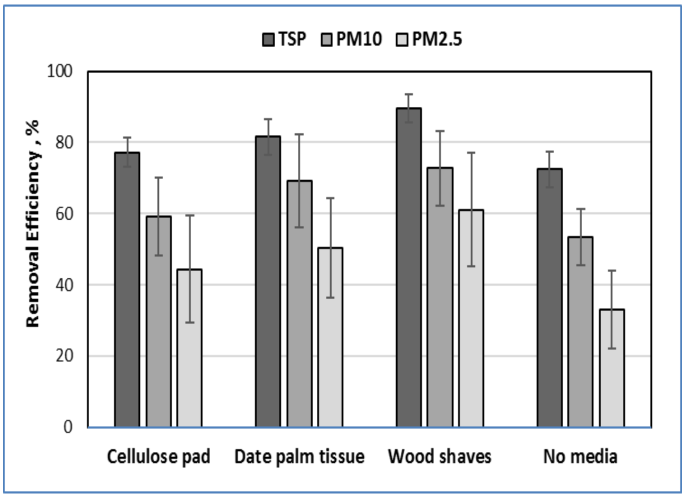

Figure 8. Particulate removal efficiency for the three particles sizes (TSP, PM_{10}, and $PM_{2.5}$) by the scrubber.

Future work is needed to optimize the design and further enhance the performance. Increase number of ESS nozzles, more types and different thickness of porous media, are potential improvements that depends on the application and size of the building.

IV. Conclusion

A prototype air cleaning and cooling device based on the principles of electrostatic wet scrubbing equipped with different porous wetting media (wood shavings, cellulose cooling pad, and date palm fiber) was designed and built. The following conclusions were drawn from this research:

- The outdoor hourly average air temperatures recorded was 45.5ºC, while relative humidity was 10.1%, and the dust mass concentrations were 1020 $\mu g/m^3$.
- The air temperature difference between the air entering and leaving the device was measured to be 16.3ºC for the cellulose pad, 15.4ºC for the date palm fiber, 15.5ºC for the wood shavings and 14.2ºC with no media during the experimental period, indicating that the cellulose pad possessed the highest cooling effect.
- The air humidity difference between the air entering and leaving the device was found to be 54.6% for the cellulose pad, 37.4% for the date palm fiber, 47.8% for the wood shavings and 36% with no media.
- The cellulose pads achieved the highest cooling efficiency of 90.84%, followed by 84.72% for the wood shavings, 73.24% for the date palm fiber and 68.1% with no media. Therefore, adding a suitable porous wetting media (e.g., cellulose pads) will significantly increase the cooling efficiency of the device.
- The device has good potential for utilizing available natural side products (e.g., wood shavings, date palm tissues).
- The negatively charged water spray combined with wood shavings as a porous wetting media was significantly ($P<0.05$) more effective in removing dust particles (η=77.7%) than either the date palm fiber (η=73.2%) or cellulose pad (η=69.1%), compared with no media (η=53.4%).
- Wood shavings achieved the highest removal efficiency, followed by the date palm fiber and cellulose pad. This may be related to an increase in the collection surface area.

Therefore, this combined cooling system can be used in various climatic conditions as an environmentally and energy-efficient air cleaningand cooling system.

Acknowledgements

The author appreciated the technical support provided by the Agricultural and Veterinary Training and Research Station (AVTRS) of King Faisal University. Acknowledgements are also extended to the agencies, publishers and authors mentioned for their supportive and valuable information.

References

[1] D. H. Willits. Cooling fan ventilated greenhouse; A modeling study, *Bio-Systems Engineering, 84(3), 2003*,315-329.

[2] H. Toida,T. Kozai, and K. Ohyama, Enhancing for evaporative rate using an upward air stream to improve greenhouse-cooling performance,*Bio-systems Engineering, 93(2), 2006*,205-211.

[3] B. CostelloeandD. Finn, Indirect evaporative cooling potential in air-water systems in temperate climates,*Energy and Buildings, 35(6),2003*,573-591.

[4] C. Liao, and K. Chiu, Wind tunnel modeling the system performance of alternative evaporative cooling pads in Taiwan region. *Building and Environment, 37(2),2002,* 177-187.

[5] M. A. Helmy, M. A. Eltawil, R. R. Abo-shieshaaand N. M. El-Zan, Enhancing the evaporative cooling performance of fan-pad system using alternative pad materials and water film over the greenhouse roof. *AgricEngInt: CIGR Journal Open access at http://www.cigrjournal.org. 15(2), 2013*,173-187

[6] J. R. Camargo, C. D. Ebinumaand J. L. Silveria, Experimental performance of a direct evaporative cooler operating during summer in a Brazilian city,*International journal of Refrigeration, 28, 2005, 1124-1132.*

[7] J. Yu, C. W. Jian, W. Y. Wen, and Y. Ye, A simple dynamic model of cooling coil unit,*Energy Conversion and Management, 47(15-16),2006, 2659-2672.*

[8] J. M. Wu, X. Huang and H. Zhang, Numerical investigation on the heat and mass transfer in a direct evaporative cooler,*Applied Thermal Engineering, 29, 2009*,195-201.

[9] R. W. Melse, P. Hofschreuder, and N. W. M. Ogink, Removal of particulate matter (PM10) by air scrubbers at livestock facilities: Results of an on-farm monitoring program. *Transactions of the ASABE, 55(2),2012*,689-698.

[10] A. Jaworek, W. Balachandran, A. Krupa, J. Kulon and M. Lackowski, Critical Review: Wet electroscrubbers for state of the art gas cleaning. *Environmental Science & Technology. 40(20), 2006,* 6197-6207.

[11] E. A. Almuhanna, Dust control in livestock buildings with electrostatically charged water spray. PhD diss. Manhattan, Kansas, USA: Kansas State University, 2007.

[12] E. A. Almuhanna, R.G. Maghirang, J.P. Murphy, and L.E. Erickson. Effectiveness of electrostatically charged water spray in reducing dust concentration in enclosed spaces. *Transactions of the ASABE 51(1), 2008*, 279-286.

[13] S. M. Kreidenweis, M. D. Petters, and P. J. DeMott, Single parameter estimates of aerosol water content. *Environ.Research Letters, 3(3),2008*, 035002, 1-7.

[14] N. Hiranuma, S. D. Brooks, B. W. Auvermann, and R. Littleton,Using environmental scanning electron microscopy to determine the hygroscopic properties of agricultural aerosols. *Atmos. Environ, 42(9), 2008,*1983-1994.

[15] S. E. Law, Embedded-electrode electrostatic-induction spray-charging nozzle: Theoretical and engineering design. *Trans. ASAE 21(6), 1978,* 1096-1104.

[16] ASHRAE, Handbook of Fundamentals,*American Society of Heating, Refrigerating and Air Conditioning Engineers, New York, USA. 2005.*

[17] B. Z.Predicala, and R. G. Maghirang, Measurement of particulate matter emission rates from mechanically ventilated poultry barns. *Trans. ASAE 47(2), 2004,* 557-565.

[18] E. A. Almuhanna, and R.G. Maghirang. Measuring the electrostatic charge of airborne particles. *Journal of Food, Agriculture & Environment, 8 (3&4), 2010,* 1033-1036.

[19] S. E. Law, and D. K. Giles, Electrostatic abatement of airborne respirable dust emission from mechanized tree-nut harvesting: theoretical basis,*J. Electrostatic 67(2-3), 2009,* 84-88.