Recycled High-Density Polyethylene and Rice Husk as a Wetted Pad in Evaporative Cooling System

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Abstract: Problem statement: The low cost and easy-to-find materials, for being used as wetted pad of evaporative cooling system, are necessary for agriculture. This study, thus, studied the evaporative cooling efficiency and pressure drop of recycled High-Density Polyethylene (HDPE) and rice husk as a wetted pad in evaporative cooling system. **Approach:** The study was done by establishing the tested wetted pad with 25.4 and 50.8 mm of thickness. The velocity air flow through wetted pad was controlled at 1, 2 and 3 m sec^{-1} respectively. In addition, the dry bulb and wet bulb temperatures of inlet air were controlled at 30.1 ± 1.0°C and 23.2 ± 1.1°C, respectively. The commercial wetted pad was also tested in order to compare results with rice husk and recycled HDPE. **Results:** It was found that rice husk wetted pad gave the average saturation efficiency of 55.9 %, while HDPE gave the average saturation efficiency of 29.1%. However, the pressure drop across wetted pad of rice husk and recycled HDPE was significantly higher than that of commercial wetted pad. For the effect of air velocity on saturation efficiency and pressure drop, it was found that higher air velocity decreased saturation efficiency and increased pressure drop across wetted pad. **Conclusion:** Finally, the rice husk has a potential as wetted pad material. However, further study about optimum point between operation cost and materials cost of using rice husk wetted pad is needed.

Key words: High-density polyethylene, rice husk, evaporative cooling, saturation efficiency, conditioning technology, diameter pinhole, dry bulb thermometers, date palm fiber, pumice stones, air velocity, rectangular tunnel

INTRODUCTION

The proper air condition, the suitable temperature and humidity, is an important factor in increasing agricultural productivity. Therefore, the air conditioning technology is used to adjust air condition and enable agriculture and livestock in hard weather condition. Evaporative cooling system is an alternative of air condition systems. This system gives an advantage of energy saving and environmental friendliness. Its principle is simple i.e., heat and mass exchanging between water and air. When air flows though water surface, water will evaporate into the air resulting in decreasing temperatures and increasing humidity of the air. The most significant difference between evaporative cooling system and vapor compression cooling system is that vapor compression cooling system decreases both temperature and humidity, but evaporative cooling system decreases less

temperature and increases humidity. Thus, this system is more suitable with agriculture activity which generally does not require very low temperature. Considering initial and operating cost, evaporative cooling system has lower price, compared to vapor compression cooling system. Moreover, it uses less energy which makes it a better alternative for agriculture. There is a lot of research studying the characteristics of various types of evaporative cooling pads (Dağtekin *et al*., 2009; Setekleiv *et al*., 2008; Dai and Sumathy, 2002; Liao *et al*., 1998; Simmons and Lott, 1996; Koca *et al*., 1991; Dowdy *et al*., 1986). An important part of evaporative cooling system is wetted pad. Currently, there are 2 types of commercial wetted pad used in Thailand, Aspen Pad and Rigid Medium Pad. Although they give good saturation efficiency, both types are expensive and not suitable for farmers who have relatively low income. Hence, several researchers have paid attention in choosing easy- to-

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find local materials to substitute expensive wetted pad. Liao and Chiu (2002) developed evaporation cooling pad- fan setup, using 2 materials to make wetted pad. One is made of coarse fabric PVC sponge mesh 2.5 mm diameter in pinhole and the other is made of fine fabric PVC sponge mesh in 7.5 mm diameter pinhole. They found that pad thickness of 150 mm and air velocities ranged from 0.75-1.5 m sec^{-1}, the cooling efficiencies for coarse fabric PVC sponge varied from 81.75-84.48%, whereas 76.68-91.64% for fine fabric PVC sponge. Al-Sulaiman (2002) evaluated the performance of three natural fibers which are date palm fibers (stem), jute and luffa to be used as wetted pad in evaporative cooling. The results show that the average cooling efficiency is highest for jute at 62.1%, compared to 55.1% for luffa fibers, 49.9% for the reference commercial pad and 38.9% for date palm fiber. The results of the cooling efficiency degradation indicate that luffa has an overall advantage over the other fibers. Palm fibers and the commercial wetted pad have a significant reduction in the cooling efficiency, while jute has the highest deterioration. The total results indicate that luffa has an overall advantage over the other fibers. Gunhan *et al.* (2007) evaluated the suitability of some local materials such as pumice stones, volcanic tuff and greenhouse shading net as cooling pads. They found that volcanic tuff was a good alternative pad material. It gave an evaporative saturation efficiency of 63-81% with the airflow velocity about 0.6 m sec^{-1}. Ahmed *et al*. (2011) studied the performance of three different types of local evaporative cooling pads, celdek pads, straw pads and sliced wood pads, in greenhouses.

From the research mentioned above, there are no studies about rice husk and recycled HDPE as wetted pad materials. In addition, both rice husk and recycled HDPE are low cost and easy-to-find in Thailand. Therefore, we consider using those materials as evaporative cooling pad in terms of saturation efficiency and pressure drop across wetted pad.

MATERIALS AND METHODS

Evaporative cooling test rig: A 0.53×0.53 m rectangular tunnel with 3.55 m in length was built as shown in Fig. 1. The tunnel consisted of 3 zones as follows.

The first zone is air inlet zone. Its length was 1.5 m. The 27 slots for humidity and air velocity probe were prepared in this zone. The 6 slots for wet bulb thermometers and the other 6 slots for dry bulb thermometers were also prepared. The second zone was an air outlet zone. This zone had 0.75 m in length and was insulated with thermal insulator.
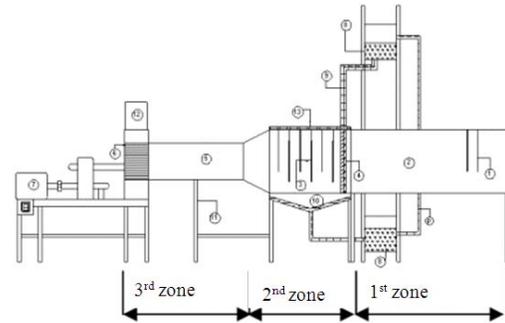

Fig. 1: Shows the experimental set up

Fig. 2: Shows wetted pads preparation. (a) Recycled HDPE (b) Rice husk

The tested wetted pad was installed in this zone. The 12 dry bulb thermometers were installed and 18 slots for humidity and air velocity probe were also prepared at the air exit side of wetted pad. The third zone is a 1.3 m of air drafting zone. By installing the drafted fan at the end of this zone, the inlet air from the first zone was drafted through the wetted pad and exited this zone to environment.

Wetted pad preparation: The local rice husk with average width of 2.02 ± 0.69 mm and length of 10 ± 0.23 mm and cylindrical recycled HDPE with diameter of 3.29 ± 0.62 mm and length of 4.13 ± 0.33 mm were selected as wetted pad materials in this study. In order to remove contaminated particle, the rice husk was cleaned with water for two times. Both materials were in the form of small particles and could not maintain its wetted pad shape without containers. Therefore, 2 weaves were required to hold husk and HDPE. Dimension of each weave was 0.50×0.50 m. Once the weaves were ready, the husk and HDPE were put in them and the weaves later were installed in the experimental setup. The prepared wetted pad is shown in Fig. 2.

Experiment procedures: There were 3 kinds of wetted pad conducted in this research i.e., rice husk, recycled HDPE and commercial wetted pad. The thickness of wetted pad used in the experiment was 25.4 and 50.8 mm. The inlet air velocity of each thickness was 1, 2 and 3 m sec⁻¹. The wetted pad was installed with 90 degree angle against the air flow direction. The water was pumped to flow over the wetted pad until the pad was saturated with water. At this point, the amount of water in the insulated tank was recorded. While the water was pumped, the fan was turned on to induce the air into the experimental setup at required air velocity. At steady state, wet bulb and dry bulb temperature of the air at inlet and outlet zone were recorded. The pressure drop of air flow across wetted pad and the water temperature in the insulated tank were also recorded. When data gathering of each experiment was complete, the amount of water in the insulated tank was measured.

To measure the efficiency of wetted pad, saturation efficiency is used. The saturated efficiency can be determined as follows:

$$\varepsilon_{sat} = \left(\frac{T_{dbi} - T_{dbe}}{T_{dbi} - T_{wbi}} \right)$$

Where:

ε_{sat} = Saturation efficiency
T_{dbi} = Dry bulb temperature of inlet air
T_{wbi} = Wet bulb temperature of inlet air
T_{dbe} = Dry bulb temperature of outlet air

RESULTS

Daily saturation efficiency characteristic of tested wetted pads: Figure 3 shows daily saturation efficiency of rice husk and recycled HDPE wetted pad of 50.8 mm thickness and 1 ms⁻¹ air velocity. It is seen that the efficiency of wetted pad directly depends on the period of the day. Each period has different temperature and humidity. The most effective time period is between 2.00-4.00 pm when it has highest temperature and lowest humidity of the day, allowing the system to evaporate more water into the air. As seen in the fig. 3, the lowest efficiency of husk wetted pad was 52.0% at the dry bulb and wet bulb temperature of the inlet air of 25.0 and 20.0°C, respectively and the dry bulb temperature and relative humidity of the outlet air of 22.4 and 80.1%, respectively. The highest efficiency of rice husk wetted pad was 66% at 4.00 pm. at the dry bulb and wet bulb temperature of the inlet air of 30.0 and 25.0°C, respectively and the dry bulb temperature and relative humidity of the outlet air of 26.7 and 87.1%, respectively. The average efficiency of rice husk wetted pad was 55.9%.
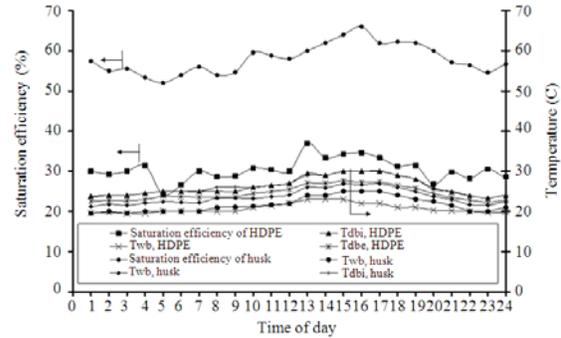

Fig. 3: Shows the daily saturation efficiency of rice husk and recycled HDPE wetted pad of 50.8 mm thickness and 1 m sec⁻¹ air velocity

For recycled HDPE, it provided less efficiency than rice husk. The lowest efficiency of recycled HDPE wetted pad was 24.2% at the dry bulb and wet bulb temperature of the inlet air of 25.0 and 20.0°C, respectively. The dry bulb temperature and relative humidity of the outlet air was 23.8°C and 70.0%, respectively. The highest efficiency of recycled HDPE wetted pad was 36.9% at 29.5 and 23.0°C of dry bulb and wet bulb temperature of the inlet air, 27.1°C and 79.0% of dry bulb temperature and relative humidity of the outlet air. The average efficiency of recycled HDPE wetted pad was 29.1%.

Effect of air velocity on saturation efficiency: Fig. 4 and 5 show the effect of air velocity on saturation efficiency of 25.4 mm and 50.8 mm wetted pad thickness, respectively. The dry bulb and wet bulb temperature of inlet air was controlled at 30.1±1.0°C and 23.2 ± 1.1°C, respectively. From Fig. 4, at air velocity of 1, 2 and 3 m sec⁻¹, the 25.4 mm rice husk wetted pad gave 54.84, 51.68 and 49.83% of saturation efficiency, respectively. The 25.4 mm recycled HDPE gave 31.07, 30.28 and 29.81% of saturation efficiency, respectively. The 25.4 mm, commercial wetted pad gave 26.62, 23.93 and 22.14% of saturation efficiency, respectively. From Fig. 5, the 50.8 mm-rice husk wetted pad gave 61.88, 58.77 and 55.365% of saturation efficiency, respectively. The 50.8 mm recycled HDPE gave 43.4, 39.58 and 38.37% of saturation efficiency, respectively. The 50.8 mm commercial wetted pad gave 54.23, 43.13 and 42.37% of evaporative cooling efficiency, respectively.

Effect of air velocity on pressure drop across wetted pad: Fig. 6 and 7 show the relationship of air velocity and pressure drop across wetted pad. From Fig. 6, at air velocity of 1, 2 and 3 m sec⁻¹ and the wetted pad thickness of 25.4 mm, the pressure drop across rice
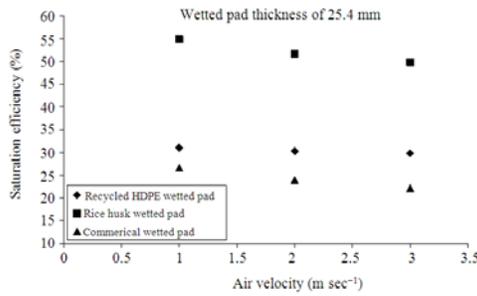
Fig. 4: Shows relationship between saturation efficiency and air velocity of 25.4 mm thickness of husk, recycled HDPE and commercial wetted pad
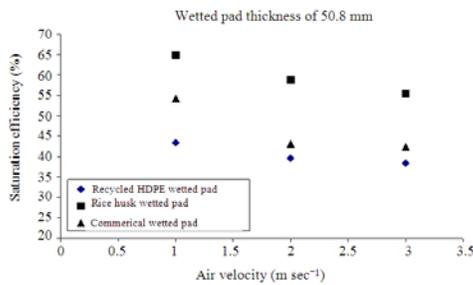

Fig. 5: Shows relationship between saturation efficiency and air velocity of 50.8 mm thickness of husk, recycled HDPE and commercial wetted pad
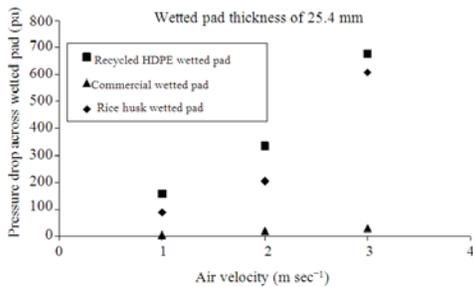

Fig. 6: Shows the relationship of air velocity and pressure drop across 25.4 mm wetted pad
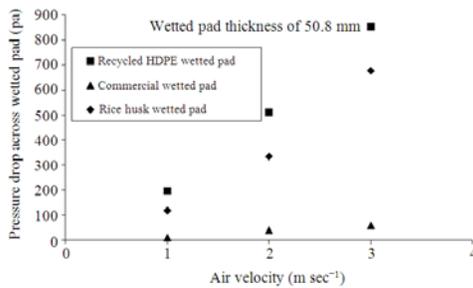

Fig. 7: Shows the relationship of air velocity and pressure drop across 50.8 mm wetted pad

husk wetted pad was 88.3, 204.3 and 608.2 Pa, respectively. The pressure drop across recycled HDPE wetted pad was 157, 334 and 677 Pa and the pressure drop across commercial wetted pad was 4.9, 19.6 and 29.4 Pa. From Fig. 7, the pressure drop across 50.8 mm wetted pad at air velocity of 1, 2 and 3 m sec^{-1}, for rice husk wetted pad, was 117.7, 333.5 and 676.9 Pa. For recycled HDPE wetted pad, the pressure drop was 196, 510.1 and 853.5 Pa. The pressure drop, for commercial wetted pad, was 9.8, 39.2 and 58.9 Pa., respectively.

DISCUSSION

Daily saturation efficiency characteristic of tested wetted pads: From fig. 3, it could be seen that recycled HDPE gave lower saturation efficiency than rice husk. It was because the wetting angle of water- recycled HDPE surface was lower than that of water- rice husk surface. This led to lower contact area of water on recycled HDPE surface, compared with rice husk surface. Since the contact area plays an important role in heat and mass transfer between water and air, thus, the lower water contact area results in lower heat and mass transfer, consequently, lower saturation efficiency.

Thus, it can be concluded from Fig. 3 that rice husk wetted pad provides more saturation efficiency than recycled HDPE wetted pad. The average saturation efficiency of rice husk wetted pad, for thickness of 50.8 mm and 1 ms^{-1} of air velocity, was 55.9%, while the average saturation efficiency of recycled HDPE wetted pad was 29.1%.

Effect of air velocity on saturation efficiency: From Fig. 4 and 5, it is clearly seen that lower air velocity provides higher saturation efficiency for both 25.4 and 50.8 mm thickness of wetted pads. This is because lower air velocity provides more time for the air to contact and absorb the water from the surface of wetted pads. It, thus, results in reducing of the air temperature and increasing of the water evaporation that provides the higher saturation efficiency. These results agree with Liao and Chiu (2002) who state that the saturation efficiency is reduced when the air velocity is increased. In addition, 50.8 mm thickness of wetted pad give better saturation efficiency than the 25.4 mm thickness wetted pad because 50.8 mm thickness of wetted pad provides higher contact surface area between air and water.

Therefore, it can be concluded that the rice husk wetted pad gives higher saturation efficiency than recycled HDPE and commercial wetted pad for all thickness and air velocity. The increasing of the air velocity results in lower saturation efficiency.

Effect of air velocity on pressure drop across wetted pad: From Fig. 6 and 7, these results show that the higher thickness of wetted pad and higher air velocity results in higher pressure drop across all kinds of wetted pad. For the similar air velocity, the recycled HDPE has the highest pressure drop and the rice husk has a significantly higher pressure drop than commercial wetted pad. This is because the recycled HDPE wetted pad has a small void. The air can flow through wetted pad by using these voids as flow passage. The fluid mechanics show that the small in diameter of flow passage results in high pressure drop. Thus, it is clear that small void of recycled HDPE wetted pad causes a high pressure drop of air flow. The rice husk wetted pad has a larger void than recycled HDPE wetted pad, so the pressure drop of rice husk wetted pad is smaller. Because of a very large flow passage of commercial wetted pad, the pressure drop across commercial wetted pad is very low.

In addition, all data above indicate that rice husk wetted pad is most suitable in terms of saturation efficiency. However, the electrical cost of fan needs to be paid for drafting air through the rice husk that has a high pressure drop across wetted pad. Since the rice husk is a local and easy-to find materials as well as easy to prepared as wetted pad, these advantages result in low wetted pad cost and can be compensated with disadvantage about pressure drop. Hence, it is necessary to further study about economics of rice husk wetted pad. The method for analysis of economics optimum point was introduced by Soponpongpipat *et al.* (2010).

In conclusion, the commercial wetted pad has the lowest pressure drop across wetted pad followed by rice husk and recycled HDPE. All of the data indicate that rice husk wetted pad has a potential to be used as wetted pad instead of commercial wetted pad. However, further study about optimum point between operation cost and materials cost of using rice husk wetted pad is needed.

CONCLUSION

This study studied saturation efficiency and pressure drop across wetted pad of recycled High-Density Polyethylene (HDPE) and rice husk as a wetted pad in evaporative cooling system. After comparing to commercial wetted pads, the results showed that rice husk wetted pad gave the average saturation efficiency of 55.9%, while HDPE gave the average saturation efficiency of 29.1%. However, the result of pressure drop across wetted pad of rice husk and recycled HDPE is significantly higher than that of commercial wetted pad.

For the effect of air velocity on saturation efficiency and pressure drop, it can be concluded that higher air velocity decreased saturation efficiency and increased pressure drop across wetted pad.

However, further study about optimum point between operation cost and materials cost of using rice husk wetted pad is needed.

ACKNOWLEDGEMENT

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