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Impact of Airflow on Evaporative Cooling System by Analysis of Cooling Efficiency

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ABSTRACT

This research aims to investigate the impact of airflow on the performance of two evaporative cooling systems—spiral pipe and straight pipe, both used for direct evaporative cooling (DECs). An overview of the procedure was conducted using a rectangular-shaped rice straw (RS) cooling pad where the length is 33 cm, the width is 17 cm, and the thickness is 1.0 cm. It was selected for its abundance as an agricultural byproduct, cost-effectiveness, and natural porosity, which increases evaporation. Low air velocity (1.7 m/s), medium air velocity (2.3 m/s), and high air velocity (4.4 m/s) are the criteria for this investigation. The collected data encompass the inlet dry bulb temperature (DBT), wet bulb temperature (WBT), outlet dry bulb temperature, inlet humidity, outlet humidity, and input air velocity. These measurements evaluate the cooling efficiency of two evaporative cooling systems. The experimental findings are displayed through tables and graphs and are analyzed by established theories. As a result of the research, the spiral pipe consistently achieved higher cooling efficiency than the straight pipe. At low air velocity (1.7 m/s), the spiral cooler attained the average highest efficiency of 33.84%, while the straight pipe cooler reached an average highest efficiency of 29.37%. The main reason behind the high efficiency of spiral pipe is that it has a longer path, a wide surface area for heat exchange, and the presence of turbulent flow in the pipe, which enhances better air-water interaction and improves the evaporative cooling system's cooling efficiency. However, this paper focuses on three experiments; if more data could be collected, the result would be more accurate. It was concluded that if the airflow is low, it enhances cooling efficiency whereas if the airflow is high, it reduces cooling efficiency.

Keywords: Evaporative Cooling System, Airflow, Cooling Efficiency, Spiral Pipe, Rice Straw

1. Introduction

Evaporative cooling has been widely studied as a cost-effective approach to enhancing air conditioning performance in hot and arid climates. It has proven effective in lowering condenser inlet temperatures, which boosts cooling capacity and reduces energy consumption. R. H. Hashim et al. conducted experimental studies utilizing direct evaporative cooling (DEC) to achieve significant reductions in compressor energy usage and outlet air temperatures. Comparative studies have shown a close correlation between theoretical predictions and experimental findings, confirming the reliability of this technique for optimizing air conditioning systems.[1]
Evaporative cooling system play a critical role in energy-efficient building design, especially in arid climates where conventional air conditioning systems may be less effective. Previous study investigated how various air velocities affected a direct evaporating cooler's performance within a Malaysian environment and discovered that the velocity of air has an essential effect in enhancing the cooling effectiveness of a direct evaporative system [2].
M. Mehrabi et. al investigated how the adjustment of cellulose cooling pads affected the thermal performance of direct evaporative cooling systems. The study analyzed five angles—0°, 5°, 10°, 15°, and 20°— for the study at different air velocities, water flow rates, and intake circumstances. They discovered that a 15° placement angle showed excellent results, where temperature decreases (24%), relative humidity (9.3%), evaporation rate (41.5%), saturation efficiency (24.5%), and coefficient of performance (12%). Except for efficiency, all performance indicators increase as air temperature increases, which has environmental influences. Moreover, increased water flow rates enhanced cooling efficiency but reduced the system's overall energy efficiency at higher inlet water temperatures. This work underscores the importance of pad orientation for optimizing cooling performance in environmentally friendly systems [3].
Nattawut Chaomuang et. al. [4] studied that mangosteen peel waste can also be used as a cooling pad for an evaporative cooling system, which gives good performance. The results revealed that at 1.4 m/s velocity, the cooling pad achieved a maximum temperature drop of 4.6 ◦C, a saturation effectiveness of 77%, a cooling capacity of 0.59 kW, and a

COP of 3.5 while maintaining a tolerable pressure drop of 54 Pa. These findings indicates that its performance is standard as commercial cellulose cooling pad which opening the market for mangosteen peel waste.

T. O. Ahmadu et. al. [5] evaluated a modified system that combines a dehumidifying pad made from tamarind seed-based activated carbon and a luffa fiber cooling pad covered with a layer of charcoal that showed improved performance. The results revealed that a balance between humidity control and temperature reduction helps to achieve a maximum temperature drop of 11°C in the absence of a dehumidifying pad and where relative humidity is maintained at 49% with the pad. This novel integration helps to overcome the drawbacks of available evaporative cooling also by improving its sustainability used for human comfort.

According to Weichao Yan et. al.[6] hollow fiber membrane-based evaporative cooling systems solve issues like bacterial contamination and water droplet drift by using membranes that separate air from water. A validated numerical model developed using COMSOL Multiphysics demonstrated a maximum discrepancy of 7% compared to experimental data. Results showed that the outlet air temperature increases when the inlet air humidity is higher; on the other hand, higher air velocity reduces cooling efficiency. Cooling efficiency improves by keeping the air velocity below 1.5 m/s.

Jain and Hindoliya [7] explored the effectiveness novel cooling media in evaporative cooling systems. They experimented with coconut and palash fibers and contrasting them to ordinary pads like khus and aspen. The results showed that the effectiveness of palash fibers was found to be 13.2% and 26.31% more than that of aspen and khus respectively. Whereas effectiveness of pad with coconut fibers was found to be 8.15% more than that of khus and comparable with that of aspen pad.

Several papers have explored cooling pad materials and airflow effects in evaporative cooling systems but different airflow paths such as straight and spiral pipes have not been explored thoroughly. Most of the existing researches focuses on alternative materials or, improving of cooling pad but ignored the comparison of airflow paths on cooling performance. Also, there are limited studies present which actually highlighted about the temperature drop and cooling efficiency. To explore this gap, this paper aims construct and compare two evaporative cooling systems with spiral pipe and straight pipe also by using eco-friendly and biodegradable rice straw as cooling pad.

2. Experimental Setup

2.1 Materials and Equipment

a) A water reservoir (30 L): Used to supply water into both cooling systems.
b) Cooling Pad: Cooling pads were made from rice straw and rectangular-shaped (dimensions: 33 cm x 17 cm x 1.0 cm)
c) Pipes: One spiral pipe and one straight pipe used to supply water to both cooling systems.
d) Water pumps(12V): Fours water pumps were used to supply water smoothly into both cooling systems.

2.2 Measurement Devices

- Infrared-Thermometer(Model:JPD-FR202): Used to measure the temperature.
- Digital Anemometer (Model: AS816): Measured the inlet air velocity. Also to adjust the velocity of the external fan to set the desire velocity for the experiment.
- ZEAL DBT& WBT meter: Measured the inlet and outlet DBT also WBT.
- Humidity meter: Measured inlet and outlet relative humidity (RH).

Others:

External fan: To supply airflow by the help of a regulator at three different modes (low, medium and high).

Plastic boxes: Tow identical container used to run the experiment.

2.3 Box Setup

Two identical boxes used to conduct this experiment where pipe conditions were different –

a) Spiral pipe: Where the water flow was in circular motion
b) Straight pipe: Where the water flow was in linear motion.

2.4 Experimental Conditions

The experiment was conducted under ambient condition. Parameters are:

- Airflow speed: Fan speeds were set at 1.7 m/s, 2.3 m/s, and 4.4 m/s for both cooling systems.
- Measurement Intervals: Readings were taken 3 times every 15 minutes over a period of 45 minutes for each test.
- Repetition: Each measurement was repeated five times to get incorrect reading.
- Temperature and Humidity meter: Dry-bulb temperature (DBT), and relative humidity (RH) were recorded at both the inlet and outlet of each system using calibrated devices. Also, the wet-bulb temperature (WBT) was recorded.

2.5 Step-by-step process

a) Initial Stage –

- The water reservoir was filled, and the pumps were activated to uniformly supply water.
- For the first test, the axial fans were set to the first speed setting at 1.7 m/s.

b) Measurement –

- To measure the air velocity, an anemometer was placed at the inlet.
- An infrared thermometer was used to monitor temperature changes over the cooling pads.
- DBT and WBT were recorded together to calculate cooling efficiency.

c) Airflow variation –

- After completing readings for the first speed setting, the fan speed was increased to 2.3

m/s and then to 4.4 m/s by the help of the regulator.
- The same measurement system was followed strictly at each speed setting.

2.6 Reproducibility

- To ensure accurate result, every device was calibrated before conducting the experiment.
- All the measurements, experimental conditions and observations were kept.

Fig.1 Experimental Setup

3. EVALUATION PARAMETERS

Cooling efficiency evaluated by applying these equations two equations:

The temperature difference (ΔT) of the evaporative cooling will get by using the following equation 1.

$$\Delta T = T_1 - T_2 \qquad (1)$$

where T_1 for the inlet temperature and T_2 for outlet temperature. The evaporative cooling efficiency (η) will find by the equation 2:

Cooling Efficiency,

$$\eta = (T_1 - T_2) / (T_1 - T_{wb}) \times 100 \qquad (2)$$

where T_{wb} is evaporative inlet wet bulb temperature °C.

4. Results and Discussion

The experimental results discovered important observations into the cooling performance of spiral and straight pipe evaporative coolers at different air velocities (from Table 1).

Cooling performance at different velocities:

a) Spiral Pipe: It achieved average maximum efficiency of 33.84% at low velocity 1.7 m/s. The efficiency decreased to 22.00% and 15.07% at medium (2.3 m/s) and high (4.4 m/s) velocities. The spiral evaporative cooling system improved water distribution and evaporation by creating a swirling motion.

b) Straight Pipe: It also achieved its average maximum efficiency of 29.37% at low air velocity of 1.7 m/s. But as the velocity increases at medium (2.3 m/s) and high (4.4 m/s), the efficiency decreases to 21.20% and 15.91% as reduced air-pad contact time affects heat and mass transfer.

Also, both coolers achieved a significant temperature drop at low air velocity (1.7 m/s). From Table 1, we can see that, for spiral pipe, the temperature drop was 1.8 °C, whereas for straight pipe it was 1.53 °C. Due to less contact time between the air and the cooling pads at medium (2.3 m/s) and high (4.4 m/s) velocities, the temperature drop, and cooling efficiency decreased.

Table 1 Average experimental results of Cooling Efficiency and Temperature Drop for Spiral and Straight pipe:

Air Velocity (m/s)	Cooling Efficiency (%)	Temperature Drop(°C)
1.7 (Low)	33.84 (Spiral) 29.37 (Straight)	1.8 (Spiral) 1.53 (Straight)
2.3 (Medium)	22 (Spiral) 21.20 (Straight)	1.16 (Spiral) 1.10 (Straight)
4.4 (High)	15.07 (Spiral) 15.91 (Straight)	0.80 (Spiral) 0.83 (Straight)

The cooling efficiency of spiral pipe decreases with increasing velocity and time as shown in Fig. 2. This aligns with findings by Weichao Yan et. al. [7], where airflow management significantly influenced cooling efficiency. However, efficiency for both systems decreased at higher velocities due to reduced air-pad contact time.

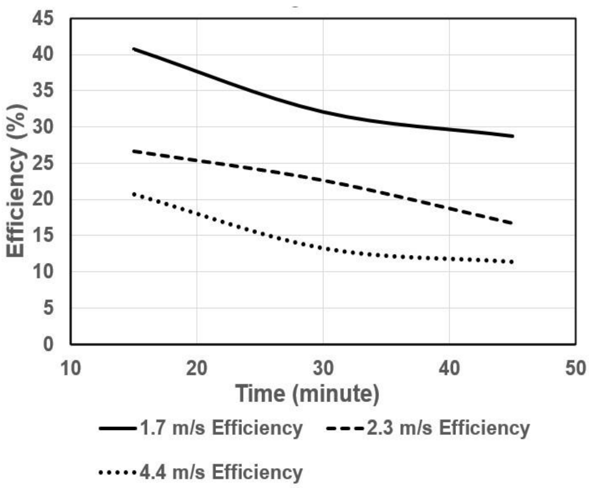

Fig.2 Time vs. Efficiency for Spiral pipe

In this study, the spiral pipe achieved higher efficiency than the straight pipe with a significance difference more than 4.47% at low air velocity. As the spiral shape has a longer path, a wide surface area for heat exchange, and swirling motion, which enhances better air-water interaction and helps to improve the cooling efficiency.

Straight pipe has a linear path, which actually has less air-pad contact time; for this reason, its maximum efficiency is less than the spiral pipe. But it also has similarities to a spiral pipe, as its maximum efficiency is achieved at low air velocity and reduces with time and increasing velocities, as shown in Fig. 3.

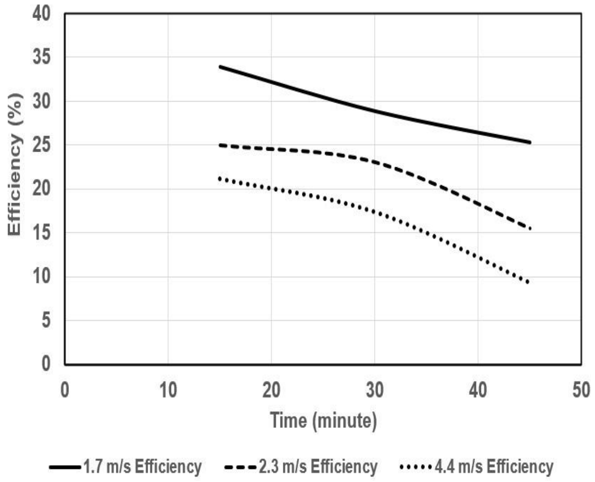

Fig.3 Time vs. Efficiency for Straight pipe

Rice straw is chosen for its eco-friendly and agricultural byproduct, as in [5], where mangosteen peel waste is used as a cooling pad, which actually gives the same performance as a traditional cellulose cooling pad. Though rice straw gave lower performance than the traditional cooling pad, an interesting fact observed during the study is its reusability. As rice straw dried out within a day, later it can be used, so there is no need to replace those pads as like traditional cellulose cooling pads. This reusability actually gives benefits for applications and also reduces the experimental cost.

5. Conclusion

In this study, we compared the cooling efficiency of spiral pipe and straight pipe using eco-friendly rice straw cooling pads at different air velocities. The spiral pipe cooler showed high performance by achieving a maximum average cooling efficiency of 33.84% at a low air velocity of 1.7 m/s, higher than the straight pipe cooler’s 29.37% under the same conditions. Though both systems cooling efficiency decreased at higher air velocities due to less air-pad contact time, which actually focused on the improvement of airflow paths improvement. The rice straw pads underperformed compared to traditional cellulose cooling pads; despite this, the material showed significant promise due to its reusability. Rice straw dried out within a day, making them reusable without the need for several replacements like traditional cellulose cooling pads, which helps to reduce costs and waste generation. Overall, this research helps us to understand how cooler paths and eco-friendly cooling pads can help to offer sustainable solutions for environmentally friendly cooling systems.

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References

[1] S. H. H. a. A. A. E. Rasha Hayder Hashim*, "Enhancement of air conditioning system using direct evaporative cooling: Experimental and theoretical investigation," *De Gruyter , Open Engineering,* vol. 13, pp. 1 - 11, 2023.

[2] M. S. M. N. J. S. M. A. Z Hassan, "The effect of air velocity on the performance of the direct evaporative cooling system," *IOP Conf. Series: Materials Science and Engineering,* vol. 1217, no. 1, pp. 1 - 7, 2022.

[3] K. G. a. S. D. F. M. Mehrabi1, "Experimental study of the influence of pad angle on the thermal performance of a direct evaporative cooling system," *International Journal of Air-Conditioning and Refrigeration,* vol. 31, no. 1, p. 24, 2023.

[4] T. N. a. S. R. Nattawut Chaomuang *, "Performance Evaluation of a Wet Medium Made of Mangosteen Peels for a Direct Evaporative Cooling System," *AgriEngineering,* vol. 5, no. 4, pp. 1865 - 1878, 2023.

[5] Y. S. S. a. F. U. T. O. Ahmadu*, "Experimental evaluation of a modified direct evaporative cooling system combining luffa fiber-charcoal cooling pad and activated carbon dehumidifying pad," *Journal of Engineering and Applied Science,* vol. 69, p. 63, 2022.

[6] X. C. X. Y. L. J. X. M. Weichao Yan, "Performance evaluation of a direct evaporative cooling system with hollow fiber-based heat exchanger," *IOP Conf. Series: Earth and Environmental Science,* vol. 463, pp. 1 - 6, 2020.

[7] D. H. J.K. Jain, "Experimental performance of new evaporative cooling pad materials," *Sustainable Cities and Society, ScienceDirect, ELSEVIER,* vol. 1, no. 4, pp. 252-256, 2011.

NOMENCLATURE

T_1 : inlet dry bulb temperature, ºC
T_2 : outlet dry bulb temperature, ºC
ΔT : temperature drop of air
T_{wb} : wet-bulb temperature, ºC
η : cooling efficiency, %