

Direct and Indirect Evaporative Cooling Using a Flat Plate Heat Exchanger

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Abstract: This study focused on the design, analysis, and testing of a flat plate heat exchanger used for the simultaneous passive cooling of two air streams via evaporative cooling. The primary air stream flows inside copper tubes while the secondary air flows across the exposed flat plate surfaces and external surfaces of the tubes. The external surfaces are wetted with water and are cooled as water evaporates on them, thus performing direct evaporative cooling on the secondary air stream and indirect evaporative cooling on the primary air stream. The materials used are aluminum, copper, and galvanized steel for plates, tubes, and casing, respectively. For this study, continuous and intermittent water spraying methods were compared on their impact on the performance on the direct and indirect evaporative cooler processes. In two aspects: (a) temperature drop and (b) efficiency. Based on this study, results showed that while both the continuous and intermittent types were able to reduce the primary air temperature near its dew-point temperature (DPT), the intermittent type is concluded to be more efficient as it achieves higher rates of evaporation and better air cooling. The lowest temperature reductions achieved were 4.5°C (from 32 °C ambient) in the primary air at an average cooling effectiveness of 87.8%.

Key Words: direct evaporative cooling; flat plate heat exchanger; indirect evaporative cooling; passive cooling; psychrometry

1. INTRODUCTION

In a combined direct and indirect evaporative cooling system, the wetted surface is exposed to one air stream (in this paper, the secondary air stream) while the unwetted (or dry) surface is exposed to another air stream (in this paper, the primary air stream). As evaporative cooling takes place on the wetted surface, the latent heat of evaporation needed by the water to evaporate is taken from the secondary air and the wetted surface in contact with it, thus lowering the dry bulb temperature of the secondary air and the wetted surface simultaneously. This is the direct evaporative cooling (DEC) of the secondary air which results in both the lowering of the dry bulb

temperature but with an increase in humidity as the evaporated moisture is mixed with it. At the same time as this is happening, the unwetted surface also becomes cold and performs cooling of the primary air without any increase in moisture content. This is the indirect evaporative cooling (IEC) of the primary air. As such, direct evaporative cooling is a cooling and humidification process where the temperature decreases with an increase in moisture content, while indirect evaporative cooling is a sensible cooling process where the moisture content is constant as temperature decreases. These flow characteristics are illustrated in Fig. 1. Note that the wetted and unwetted surfaces are the outside and inside surfaces of the heat exchanger tubes.

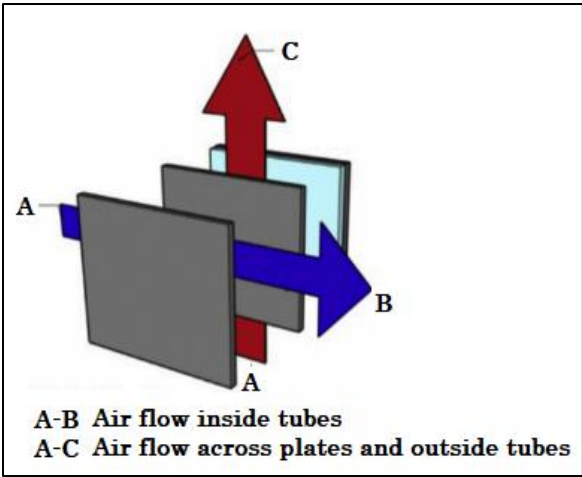


Fig. 1. Direct and indirect evaporative cooling flow configurations

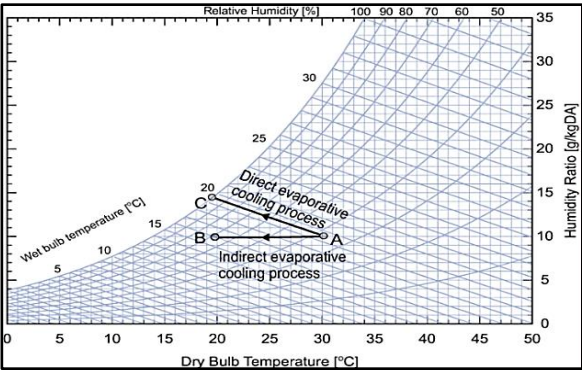


Fig. 2. Direct evaporative cooling (A-B) and indirect evaporative cooling (A-C) processes as shown in the psychrometric chart

In this study, the primary air is taken as the cooled air produced by the indirect evaporative cooling as the target application is the cooling of electronic components (i.e. a computer CPU) where increased moisture may become an issue. As it is, both the primary air and secondary air can be used for cooling applications with the primary air intended for systems that are sensitive to moisture, while the secondary air stream for systems that can withstand increased moisture (i.e. passive ventilation).

Fig. 2 shows the two processes on the psychrometric chart. Note that both processes tend to approach saturation. The limiting condition is when the secondary air has reached saturation as no further evaporation of water will be achieved thereafter.

2. METHODOLOGY

For this study, the crossflow flat plate heat exchanger used consists of 50 plates and a copper tube with 30 passes. A crack/hole type PVC pipe was used to spray the water for the secondary air, which was maintained at a temperature of 29°C for all the trials made to test the system performance.

Two spraying methods were utilized in the experimentation, namely the intermittent spraying and the continuous spraying. The ambient air was supplied using blowers where the primary air passes inside the copper tubes, and the secondary air is blown over the external surfaces. The weather during the experimentation was observed to be cloudy, exhibiting an average temperature of 32.6 degrees Celsius and an average relative humidity of 66.15%. A pump was used to circulate the water sprayed onto the external surfaces. For the continuous spraying method, the water pump was left running for the whole 40-minute duration of the test. For the intermittent spraying method, the water pump is turned on for 10 seconds and is turned off in 1-minute intervals for 40 minutes. For every 10-minute interval, the following parameters are measured: dry bulb temperature, relative humidity, humidity ratio, velocity of the inlet (ambient) and outlet (product) air for both channels, and amount of water supplied. In order to extract reliable data, both the intermittent and continuous spraying methods were run at different days and times from October to November. This allows the researchers to test the effectiveness of the cooler with different ambient air conditions, typically and normally experienced in the Philippines. The setup for the performance tests is shown in Fig. 3.

The performance of air cooling was determined by comparing the actual extent of the cooling achieved versus the maximum extent of cooling that is theoretically possible. These are shown in Fig. 4.

As such for the indirect evaporative cooling (IEC), the cooling effectiveness is shown by Eq. 1 and

for the direct evaporative cooling, the cooling effectiveness is shown by Eq. 2.



Fig. 3. Test setup of the DEC and IEC system

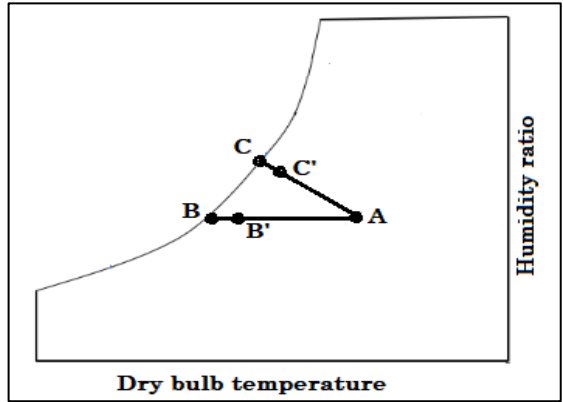


Fig. 4. Cooling effectiveness of the DEC and IEC

$$\epsilon_{direct} = \frac{T_A - T_{B'}}{T_A - T_B} \quad (\text{Eq. 1})$$

where:

- ϵ_{direct} = effectiveness of direct evaporative cooling
- T_A = dbt of entering air

- $T_{B'}$ = dbt at exit of primary air (inside tubes)
- T_B = dpt of entering air

$$\epsilon_{indirect} = \frac{T_A - T_{C'}}{T_A - T_C} \quad (\text{Eq. 2})$$

where:

- $\epsilon_{indirect}$ = effectiveness of indirect evaporative cooling
- T_A = dbt of entering air
- $T_{C'}$ = dbt at exit of secondary air (external flow)
- T_C = saturation temperature along A-C'

3. RESULTS AND DISCUSSION

As is typical for evaporative cooling systems, the temperature reduction (delta T) achieved is higher for air streams with higher ambient temperature and lower relative humidity.

Wherein, "ambient" refers to the air condition flowing through the inlet pipes. These are shown by comparing Fig. 5 and Fig. 6 below for continuous spraying and Fig. 7 and Fig. 8 for intermittent spraying. It is also worth noting that the relative humidity and the ambient temperature are individually taken into account in getting the temperature reduction (delta T).

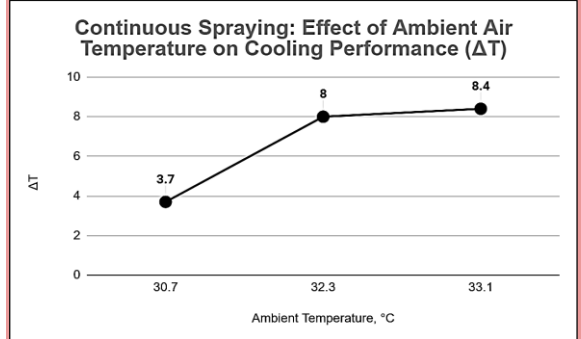


Fig. 5. Continuous spraying: ambient air temperature vs delta T

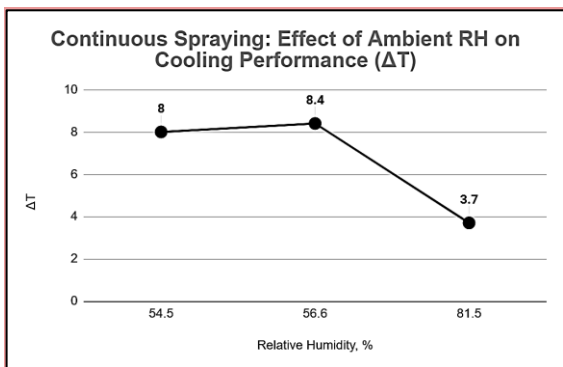


Fig. 6. Continuous Spraying: Ambient Air Relative Humidity vs Delta T

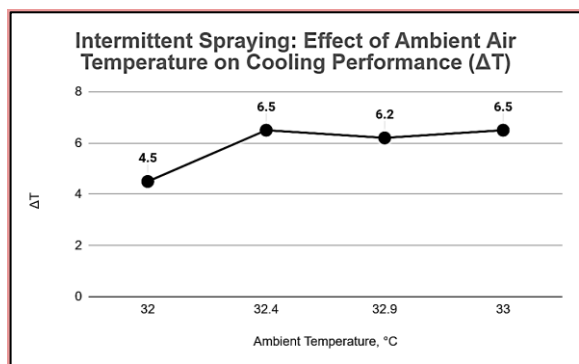


Fig. 7. Intermittent Spraying: Ambient Air Temperature vs Delta T

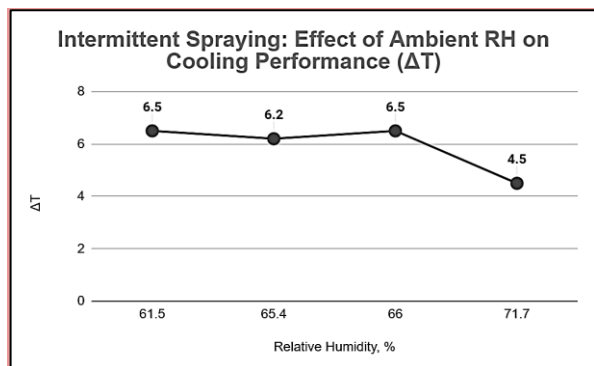


Fig. 8. Intermittent Spraying: Ambient Air Relative Humidity vs Delta T

The cooling effectiveness achieved in the primary air and secondary air are shown in Fig. 9 for continuous spraying and in Fig. 10 for intermittent spraying. The extent of cooling achieved is correlated to the amount of water evaporated via evaporative cooling. These are shown in Fig. 11 and Fig. 12.

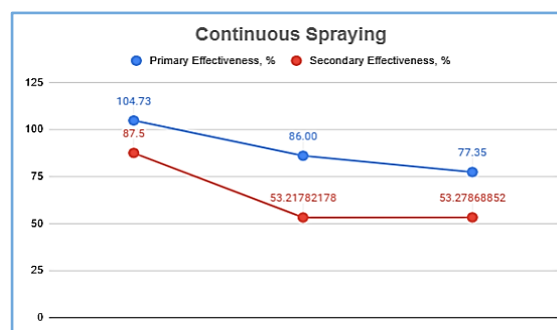


Fig. 9. Continuous spraying effectiveness

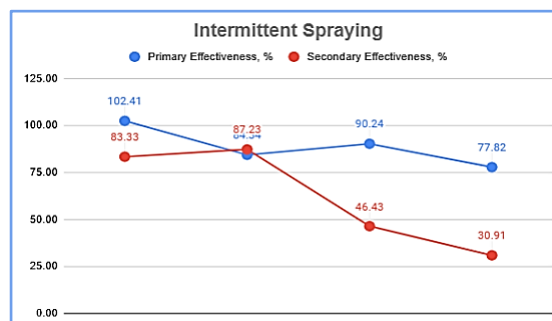


Fig. 10. Intermittent spraying effectiveness

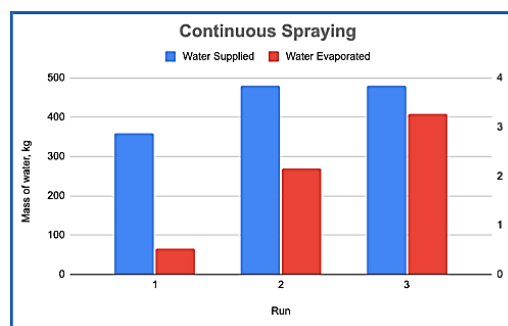


Fig. 11. Amount of water evaporated during continuous spraying.

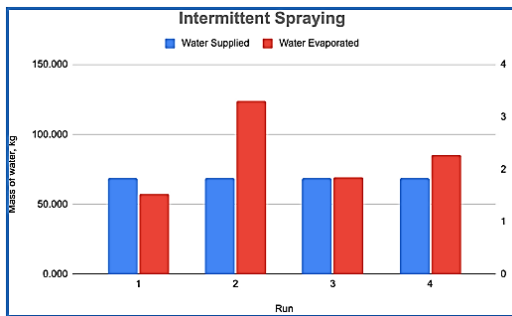


Fig. 12. Amount of water evaporated during intermittent spraying.

4. CONCLUSIONS

This study concludes that while both the continuous and intermittent types were able to reduce the primary air temperature down to its saturation point, the intermittent type tends to be more efficient as it achieves better water evaporation. Moreover, the intermittent type, in general, consumes less water, which is effectively transformed into a cooling medium. The lowest change in temperature in the primary air was recorded to be 4.5°C and 3.7°C in the continuous and intermittent methods, respectively. Overall, the average cooling effectiveness achieved was 87.7% for the primary air and 62% for the secondary air.

Aside from these, the researchers also acknowledge that while a considerable amount of cooling can be achieved in the Philippines' climate, its maximum potential will mostly be felt in hot, arid areas. This aligns with several different studies on indirect-direct evaporative cooling, such as those by Alfraidi et al. (2024), Duan et al. (2012), and Sajjad et al. (2021).

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