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Potential of direct evaporative cooling system under metal plate attachment to wetted pad application

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ABSTRACT

Direct evaporative cooling (DEC) system, even in the simpler configuration, is concerned with the wet pad design for improving system cooling performance. The performance measure is assessed by the evaporation of the pad liquid content and changes of mainstream flow properties. This article examined a potential DEC design in laboratory scale that incorporates a water-based wet pad with metal plate attachment. The proposed system is modelled by a low speed uniform air flowing over a heated wet pad. The influence of metal thermal conductivity and the surface contact on air temperature and humidity was evaluated. The results shows that efficiency increases nearly 50 % despite poor influence of metal property and contact area on mainflow properties. Increasing contact area of metal plate plays a major role to preserve the cooling efficiency. Since, base pad without metal plate shows superior performance than that of with metal plate due to the loss sensible heat, DEC system must be designed with consideration of providing more homogenous air mixture and preventing the loss sensible heat.

INTRODUCTION

Cooling system is widely applied in industrial sectors such as agriculture, automotive, healthcare and many more. There are several types of cooling system such as refrigerate, full evaporative and partial evaporative cooling system. Historically, the older form of evaporative cooling system was used by the ancient Egyptians, Greeks and Romans through their wet mats – nowadays known as cooling pads to reduce the indoor temperature [1]. Modern cooling system has evolved and developed from economical and design perspectives. Evaporative cooling techniques is widely incorporated in cooling devices because heat transfer occurs naturally resulted in simple architecture with inexpensive components and development, low noise emission and power consumptions.

Evaporative cooling cools the mainstream flow of air and the process performances is quantified as the evaporative cooling efficiency, defined as the difference between the wet-bulb and dry-bulb temperatures of the flow. The reduction of temperature implies that, under adiabatic conditions, sufficient amount of sensible heat of the mainflow is transferred to the source of water content for evaporation [2]–[3]. Wet pad may be introduced as a heat absorber with varying level of flow resistance to produce an outflow of air with greater humidity level. Higher humidity is associated with the temperature falls as the cooled main flow regain the latent heat of the vaporised water. The larger temperature difference, the greater the cooling effects.

The evaporative cooling technology can be classified direct evaporative cooling (DEC) and indirect evaporative cooling (IEC) systems. Climate and environmental conditions pose the biggest challenge in the design and development of both cooling systems. IEC system is expensive and typical system incorporates separate humidifier and heat exchanger sections to achieve the desired thermal condition. The low humidity hot primary air flows over large wetted surface for evaporation and the cooled primary mainflow is used for cooling secondary air flow [4]. The DEC system is commonly designed for low wet bulb temperature ambient and reasonably efficient for high dry bulb temperature in either hot or dry climates.

Direct evaporative system, even in its simpler configuration, is concerned with the wet pad design for improving cooling system design and environmental requirements [5-8]. For instance, Al-Sulaiman [9] experimentally demonstrate the use of biodegradable material luffa and jute fibre treated with mold forming resistance and reported reasonably good cooling. Likewise, Maurya et al [10] experimentally observed that good potential of coconut coir as the cooling pad alternative. They also reported that the cooling performance was affected by both the geometrical dimension of the pad and flow properties. It was suggested that lower contact time for evaporation degrade the cooling efficiency although much improvements was shown with increasing pad thickness.

This article is intended to stablish potential of wet pad prototype for a laboratory scale DEC system. The objective of the investigation is to experimentally inspect the functional relationship between cooling performances and the wet pad properties that influenced by the heat transfer mechanisms of metal plate. The contact area and thermal property of plate were varied to investigate their effects to the temperature reduction, humidity increase and cooling efficiency.

EXPERIMENTAL SETUP AND PROCEDURE

Schematic view and actual view of the experimental setup are shown in **Fig. (1)**. The model of evaporative cooling system comprises inlets duct, an ambient flow mixing chamber, evaporative cooling pad box and outlet duct. The blow down open air duct rig is made from acrylic walls with square constant cross sectional area of 200 mm × 200 mm × 610 mm long. The inlets duct is fitted with an axial flow fan and filament heating blower to provide two separate airflow with different thermodynamics states in the ambient flow mixing chamber. The direction of air mixture flow is aligned using a customised 250 mm long flow straightener made from 7.5 mm diameter polypropylene drinking straw. The resulting mainflow enters the pad box and cooled by a proposed cooling pad design. The pad consist of 5 pairs of metallic plate-sponge that are arranged in series. A commercial wetted sponge which is a porous polymeric media is used throughout the measurement. The present investigation examine different metals and the corresponding properties is tabulated in **Table 1**. The fin-like shape cooling media is vertically oriented and parallel to the direction of the mainflow. The cooled mainflow leaves the rig through the outlet duct.

Preparation of the test rig include soaking the sponges with water at room temperature. Pairs of metal plate-saturate sponges are then clamped and placed in the pad duct. Ambient air is introduced into the test rig at average speed of 0.7 m/s. The hot air is allowed to enter the ambient mixing chamber after 7 minutes, followed by acquisition of air temperatures and humidity at the upstream and downstream of the cooling pad duct using DHT22 thermistor humidity sensors. Thermometer, soaked with wet cloth and placed in the outlet duct, provide the wet-bulb temperature of the cooled mainflow of air. The measured values are processed using a customised computer data acquisition system to determine the temperature reduction, ΔT, humidity increase, Δh and cooling efficiency, ε are defined respectively as follows:

$$\Delta T = T_1 - T_2 \tag{1}$$

$$\Delta h = h_2 - h_1 \tag{2}$$

$$\varepsilon = \frac{T_1 - T_2}{T_1 - T_1'} \times 100 \quad (3)$$

where the subscript 1 and 2 refers to values at upstream and downstream cooling pad, *T* and *T'* are the dry-bulb and wet-bulb temperatures. Details of experimental conditions and parameters are tabulated in **Table 2.**

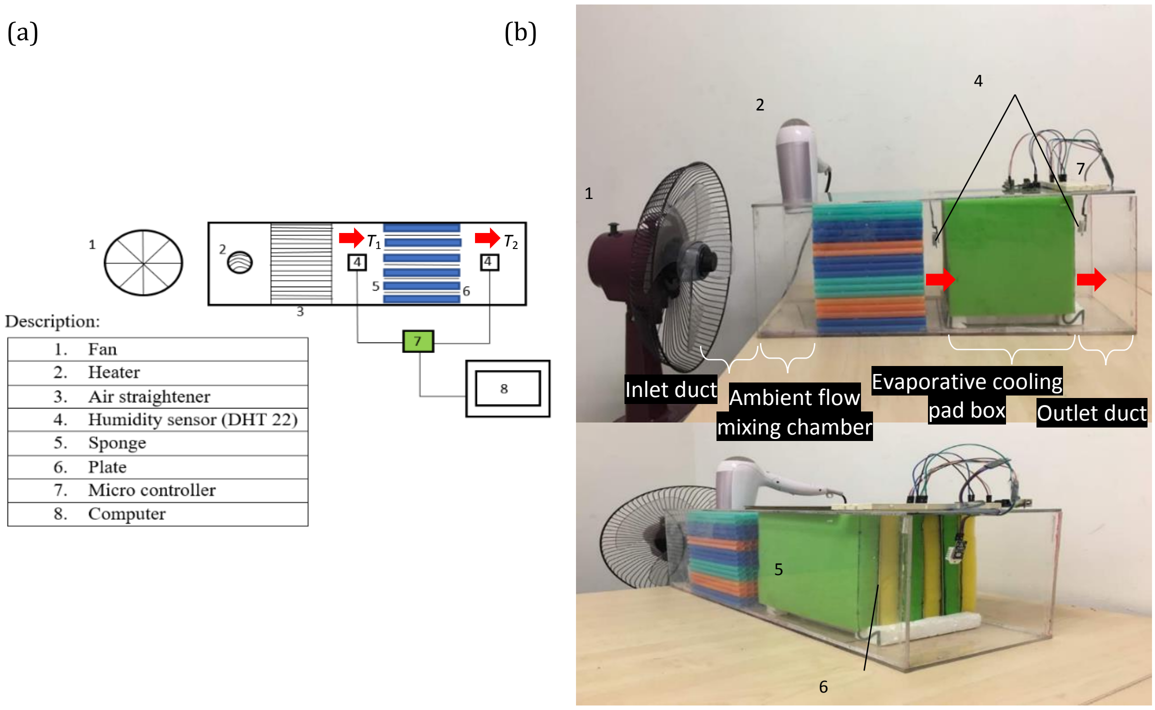

Figure 1: (a) Schematic view and (b) actual view of experimental setup.

Table 1: Property of metal plate.

Material	Thermal Conductivity [W/m-C]	Density [kg/m^3]	Specific Heat [J/kg-°C]
Aluminium (Al6061)	167.0	2.71 × 10^3	1.256 × 10^3
Brass (Yellow)	119.0	8.8 × 10^3	380.0

Table 2: Experimental condition and parameter.

Experimental condition	
Air flow	0.7 m/s
Wet-bulb temperature	20.1 °C
Room temperature	25 – 27 °C
Experimental parameter	
Fin-like shape area	(Pad A) 38025 mm^2 (Pad B) 47775 mm^2 (Pad C) 57525 mm^2
Plate material	Brass (Yellow), Aluminium (Al6061)

RESULTS AND DICUSSIONS

Temperature reduction

The results of temperature reduction under different fin-like shape area and plate material are shown in **Fig. (2)** and **Fig. (3)**, respectively. As can be seen, the maximum temperature reduction was reached after 300 s the heating air was introduced. The dry bulb temperature in the outlet was found not more than 4 °C and lower than that of upstream in the cooling pad. The temperature reduction for each cooling pad invariant with time after 200 s. This trend confirms that evaporation process occurred at the cooling package until that time, showing that there was no more reduction of downstream air. Furthermore, a closer look to both figures revealed several negative value results at the initial stage of cooling process upon existence of plate to the cooling pad. Such value indicates that in the initial stage, the hot and dry air from inlet duct has directly passed to the outlet duct without completely undergoing evaporation process in the cooling pad.

Moreover, a similar gradual increasing trend of temperature reduction for pad A and B was found as shown in **Fig. (2)**. For pad C, a rapid increase was found up until 140 s. This proved that that the time rate of temperature reduction change for pad C is greater than that of pad A and B. The time rate of temperature reduction was influenced by the initial temperature reduction but not on its final values. Although cooling pad C had 1 °C lower initial temperature reduction, rapid temperature reduction change yielded greater final values than pad B. This implies the intersection of response of temperature reduction at approximately 140 s due to a sluggish change of the cooling property using cooling pad B when the initial value was high. These observations suggest that reducing the fin-like shape area attenuate the energy regain in the cooled mainflow.

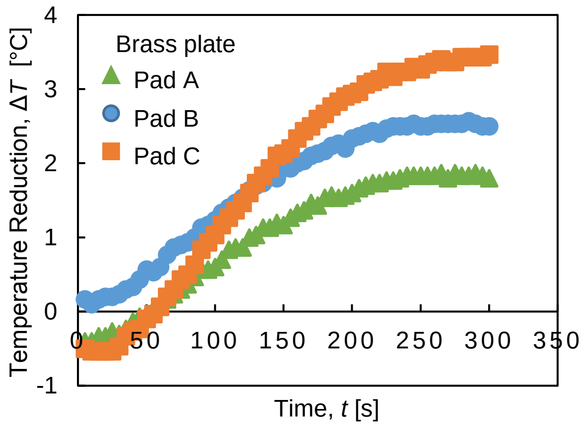

Figure 2: Temperature reduction under different fin-like shape area of metal plate.

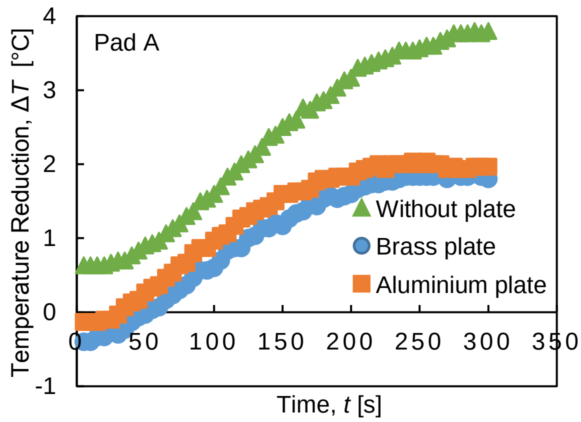

Figure 3: Temperature reduction under different material of metal plate.

In **Fig. (3)**, temperature reduction histories for cooling pad A with brass and aluminium plate were compared with base pad without plate attachment. It can be observed in the figure that temperature reduction begins with slow increase, followed by a moderate change, and then back to slow increase in the property. The aluminium plates improve the rate of evaporative cooling and higher temperature reduction than that can be produced by the brass plate. The base cooling pad produces maximum final temperature reduction slightly below 4 °C and hence superior than those with plate attachments. Here, a number of observations that need a fair interpretations. The initial temperature of air at downstream of the cooling pad may be higher than that of the upstream. It is suggested that the temperature of air mixture leaving the ambient mixing duct is not homogenous. It is also suggested that the sensible heat of mainflow was transferred to the water content in the cooling pad and thus used for evaporative cooling but loss to the plate. This eventually gave rise to low cooling effect for cooling pad with plate attachment.

Humidity increase

The results of humidity increase under different fin-like shape area and plate material are shown in **Fig. (4)** and **Fig. (5)**, respectively. As can be seen, changing the fin-like shape area and material of plate gave the humidity increase up until 18% to 21%. This was an expected trend for a DEC system where the cooled main flow regain the latent heat of the vaporised water as mentioned earlier. In **Fig. (4)**, rapid and slow increase for pad A and C was found respectively in the beginning, where the value started at as low as 5%. Both pads then showed a similar rapid change which followed by a slow change nearly in the end of time. On the other hand, the middle value of fin-like shape area by using pad B gave 5% larger of starting value, but with far more slower time rate than that of pad A and C. Moreover, the humidity increase was found as independent with the fin-like shape area up until 200 s, where temperature reduction was found invariant with time as mentioned before. It is suggested that raising amount of moisture content is influenced by the fin-like shape area, only after the absence of temperature reduction in the downstream air.

Initial humidity increase under different plate material as shown in **Fig. (5)** also revealed nearly the same starting value of humidity increase for pad A with brass and aluminium plate attachment. However, the time rate for pad A without plate attachment showed the similar trend with using brass plate, although the starting value was found 4 % lower than that of brass plate. Here, the latent heat that loss to the plate as mentioned before plays the role for the raising moisture content in using the plate. It is fairly proved by observing the trend for plate with higher thermal efficiency i.e. aluminium. The aluminum plate is believed to absorb larger sensible heat than that of brass plate.

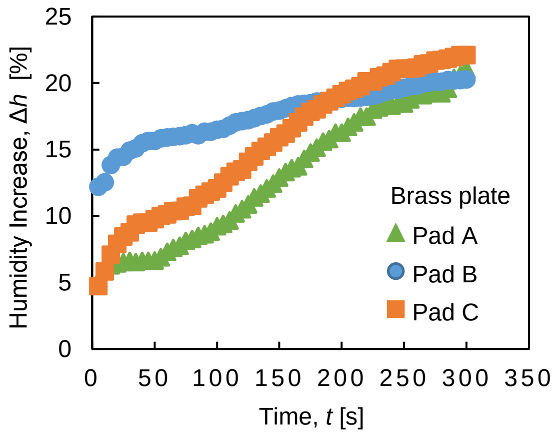

Figure 4: Humidity increase under different fin-like shape.

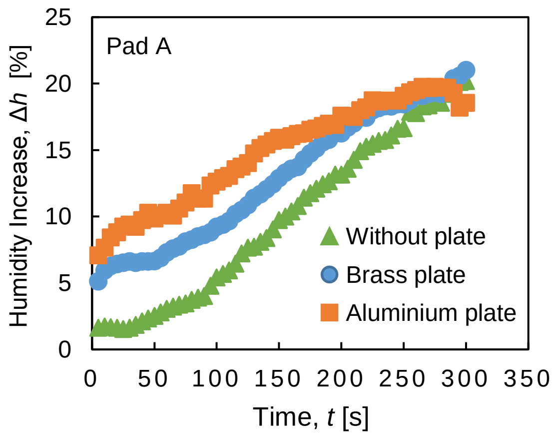

Figure 5: Humidity increase under different material of metal plate.

Cooling efficiency

The results of cooling efficiency under different fin-like shape area and plate material are shown in **Fig. (6)** and **Fig. (7)**, respectively. It was seen in **Fig. (6)** that moderate contact area i.e. pad B using brass plate material can still contribute nearly 50 % of cooling efficiency despite having little degradation over time. Pad C produced better performance than that of pad B since it can maintain the efficiency after reaching nearly same peak value of efficiency. Pad A with even smaller contact area also preserved the efficiency despite having lowest contact area on the mainflow. It is suggested here that rather than increasing the efficiency in the beginning of cooling process, it is most beneficial to increase the contact area on the mainflow for preserving the cooling efficiency over the time-run.

In **Fig. (7)**, it was seen that providing aluminium plate to the wet pad not only keep the same trend of efficiency change till the end of time, but also can maintain the cooling efficiency like the base pad without metal plate. Furthermore, base pad was seen to give greatest efficiency, followed by brass and aluminium plate in the pad. This strengthen the fact that the sensible heat had loss to the plate upon temperature falling as mentioned earlier. Here, the DEC design must be fairly upgraded to divert this heat from going to the metal plate.

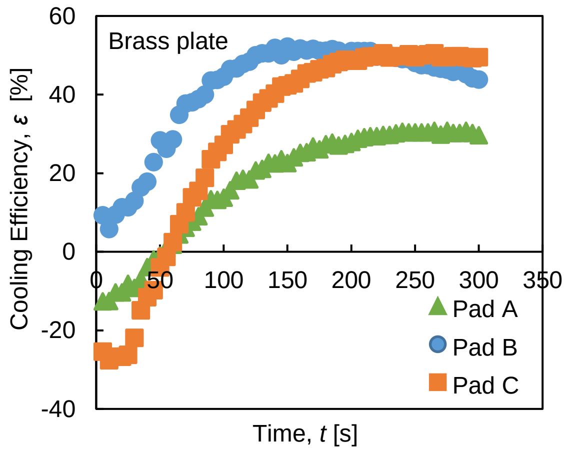

Figure 6: Cooling efficiency under different fin-like shape.

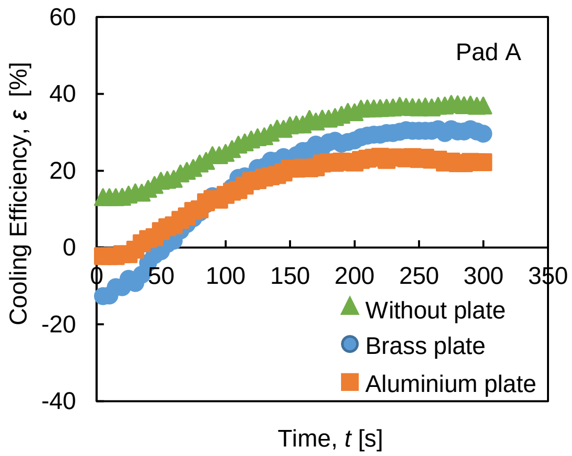

Figure 7: Cooling efficiency under different material of metal plate.

CONCLUSIONS

This article is intended to stablish potential of wet pad prototype for a laboratory scale DEC system. The objective of the investigation is to experimentally inspect the functional relationship between cooling performances and the wet pad properties that influenced by the heat transfer mechanisms of metal plate.

The contact area and thermal property of plate were varied to investigate their effects to the temperature reduction, humidity increase and cooling efficiency. Several points were concluded as following:

1. Reducing contact area of metal plate on the mainflow weaken the energy regain in the cooled mainflow and thus reduce the temperature reduction.
2. Raising amount of moisture content is influenced by the contact area on the mainflow, only after the absence of temperature reduction in the downstream air. The larger the contact area, the larger the humidity increase. Since the latent heat tends to loss into the metal plate and thus plays the role for increment of moisture content, the larger the thermal property of plate, the greater the humidity increase.
3. Efficiency increases nearly 50 % despite poor influence of metal property and contact area on mainflow properties. Increasing contact area of metal plate plays a major role to preserve the cooling efficiency. Since, base pad without metal plate shows superior performance than that of with metal plate due to the loss sensible heat, DEC system must be designed with consideration of providing more homogenous air mixture and preventing the loss sensible heat.

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