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INVESTIGATION ON EFFECT THERMO-PHYSICAL PROPERTIES OF EVAPORATIVE COOLER MATERIALS ON TEMPERATURE DISTRIBUTION AND FOOD QUALITY

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Abstract- *Advancement in evaporative cooler based storage system can contribute to food waste reduction with minimum energy consumption. Efficient evaporative cooler for high humid and temperature zone still need a significant amount of research. In this study, the performance of a direct and two indirect evaporative coolers have been compared with the investigation of temperature distribution inside the storage chamber. Prediction of the maximum evaporative cooling effect is calculated theoretically and compared with experimental results. Quality of stored food has been analyzed in terms of appearance. The theoretical value of surface temperature closely matches with experimental values of the evaporative coolers. Remarkable discrepancy in quality is found for the foods that are stored in different evaporative cooler.*

Keywords: Food storage, Evaporative cooler, porous material, Temperature distribution, Food quality.

1 INTRODUCTION

Currently, one-third of produced food is wasted annually due to a lack of proper processing and preservation. This loss is even more significant in developing countries, amounting to 30–40% of seasonal fruit and vegetables. On the other hand, according to the UN food agency, every day 18,000 children die of hunger and malnutrition, and 850 million people go to bed every night with empty stomachs. Like other developing countries, Bangladesh encounters a significant amount of seasonal fruits and vegetables due to the shortage of appropriate preservation system [1]. Moreover, the existing cold storage is used only for paddy, wheat, and potato preservation [2]. Most of the seasonal fruits and vegetables are not preserved to extend their shelf life. Among different available technologies, cold storage is mainly equipped with a mechanical refrigeration system that consumes significant amount of electrical energy and puts pressure on the national grid. These systems despite its technological edge are mostly depended on non-renewable source of energy, which is a significant drawback for developing, and least developed nation with dire crisis of energy. [3-5].

Notwithstanding, mechanical refrigeration is energy-intensive and costly includes high initial investment, cannot be quickly and easily installed, requires a continuous supply of power, high operational cost, and cannot be built in remote range and not eco-accommodating as well. Given these reasons, this strategy is not broadly utilized as a part of numerous tropical and sub-tropical nations, where refrigeration is required most [6-9]. This strategy is not likewise reasonable to farmers, retailers and wholesalers [10]. Evaporative cooling-based storage system can play an important role to overcome the storage-related problems. Evaporative cooling storage structure (ECSS) is a twofold divider structure having space between the dividers which is loaded with permeable water engrossing materials called pad [4, 11, 12]. These pads are kept continually wet by applying water. At the point when unsaturated air goes through a wet pad, exchange of mass and warmth happens, and the energy for the evaporation process comes from the air stream. Evaporative cooling is an adiabatic procedure happening at consistent enthalpy. As evaporative cooler is not a new concept, there are numerous successful research outcomes reported in literature [8, 13-16]. There are two broad types of evaporative cooler depending on the retrieving of cooling effect from the cooling pad to the storage chamber. Direct evaporative cooler allows the cooled moist air to the storage chamber; whereas, indirect evaporative does not permit air to do so. Most of the direct evaporative cooler is made of porous materials such as brick, sand, mud while the indirect evaporative cooler is mainly made from metallic body. There is inadequate comparative study that deals with temperature distribution and quality of direct and indirect evaporative cooler. In this work, temperature distribution in direct and indirect evaporative cooler has been investigated along with assessing quality of stored foods.

Moreover, theoretical value of maximum surface temperature of the evaporative cooler is calculated and compared with experimental values. The research work is quite relevant in the context of Bangladesh. This research work is highly promising in diminishing the dependency on conventional electricity supply, reducing environmental pollution as well as mitigating food lost.

2 MATERIALS AND METHODS

2.1 Theoretical temperature

The theoretical surface temperature can be solved theoretical using the proper formulation of simulations heat and mass transfer. Assuming, sensible heat from surrounding is transferred to sample trough convective mode that is used for phase change of liquid water. Radiation and conduction can be neglected due to their insignificant contribution to heat transfer. The following equation shows the mentioned energy conversion.

$$Q_{convection}=\dot{m}_v h_{fg} \quad (1)$$

Where, $\dot{m}_v$ is the rate of evaporation and $\dot{h}_{fg}$ is the latent heat of vaporisation of water at the surface temperature By simplification, the following relationship of surface temperature can be derived:

$$T_s = T_\infty = \frac{h_{fg}}{C_p Le^{\frac{2}{3}}} \frac{M_v}{M} \frac{P_{v,s}-P_{v,\infty}}{P} \quad (2)$$

2.2 Experimental Setup

The investigation is carried out in Rajshahi, Bangladesh, which has a hot and humid climate. From all three chambers, data were taken at an hour interval from 8 a.m. to 5 p.m. for six consecutive days.

In these works, the temperature distribution in two metal-based (indirect) and a mud-based (direct) evaporative cooler has been investigated. A rectangular sheet metal box was made with a volume of 0.0730 m^3. An aluminium pitcher volume of 0.014 m^3 was taken. The four sides of metallic chamber were covered with a cloth, the top ends of which were immersed in water placed in the top tray. For allowing evaporation, the cloth surrounding the metallic chamber was made to remain wet continuously by downward gravitational flow of water. The aluminium pitcher is available, and for its low cost it is available most of the houses. It has high heat conductivity and surface area. Two earthen pot of different sizes were taken. Wet sand is placed between two pots for preparing an environment that is conducible for evaporation. The overall volume of the storage is 0.0062580231 m^3. The metallic system was wrapped with wet cloths.

2.3 Temperature and humidity measurement

Both outside and inner side temperature are measured using Infrared thermal imaging camera (FLIR One, USA). Hygrometer was used for measuring humidity air in the chamber.

2.4 Image Acquisition and analysis

Digital images were obtained by using 8.0 megapixels Samsung camera. These images were stored in the bitmap graphic format. ImageJ software was employed to analyses digital images in the RGB (Red – Green – Blue) colour. RGB-triplets for every pixel in the image represent the intensities of RGB colours in the range from 0 to 255.The hue angle and colour change were determined with color analysis. The hue angle value defines whether the object is red, orange, yellow-green, blue, or violet [17]. Hue angle is determined by:

$$h_0 = \tan^{-1}\left(\frac{\sqrt{3}(G-B)}{2R-G-B}\right) \quad (3)$$

Colour changes in the RGB colour model were defined as:

$$\Delta E_{RGB} = \sqrt{[(\Delta R)^2 + (\Delta G)^2 + (\Delta B)^2]} \quad (4)$$

3 RESULT AND DISCUSSION

3.1 Temperature Distribution

The Theoretical temperature and acquired temperature through evaporation process was well observed. From the steel storage, it is clear that there is a temperature difference between an inside wall and sample vegetables which are shown in Figure 1. The inside temperature is slightly higher than the outside wall temperature of the device.

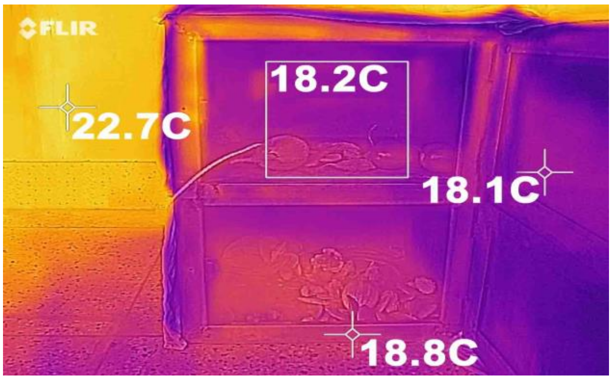

Fig. 1: Temperature distribution in metallic chamber

As the pot in pot storage has no pad material on the outer surface, it showed a random difference in temperature on the inner surface that is shown in Figure 2. The outside surface shows a temperature decrease from the ambient condition, the inside temperature shows a random difference.

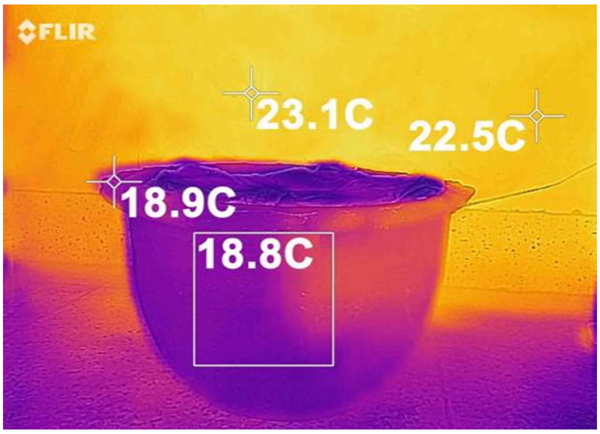

Fig. 2: Temperature distribution in the metallic pot in pot

Like those two devices, aluminium jar shows a significant temperature difference on its outer surface from the ambient condition. However, due to the irregular shape of the device, thermal imaging of the inner surface was not convenient and shown in Figure 3.

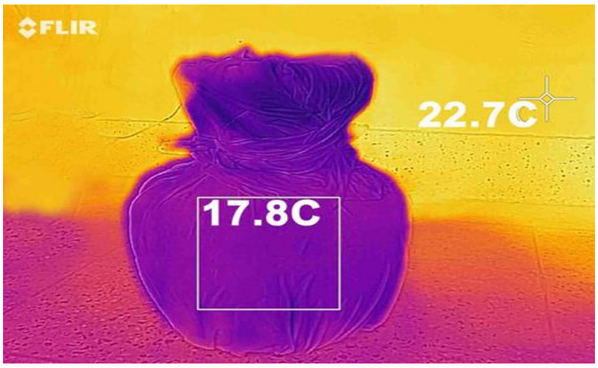

Figure 3: Temperature distribution in metallic Aluminum Jar

3.2 Average Temperature Difference

The average temperature of the evaporative cooler has been calculated mathematically and compared with the experimental value. The comparative values of average surface temperature have been presented in Figure 4 and 5.

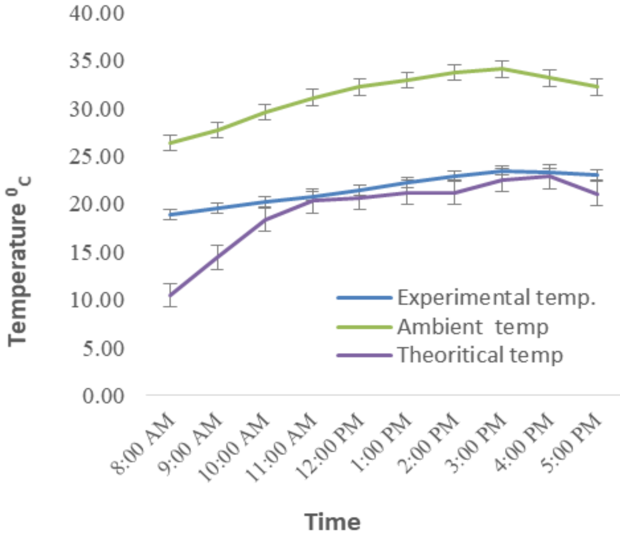

Figure 4: Average theoretical and experimental surface temperature of the aluminium jar

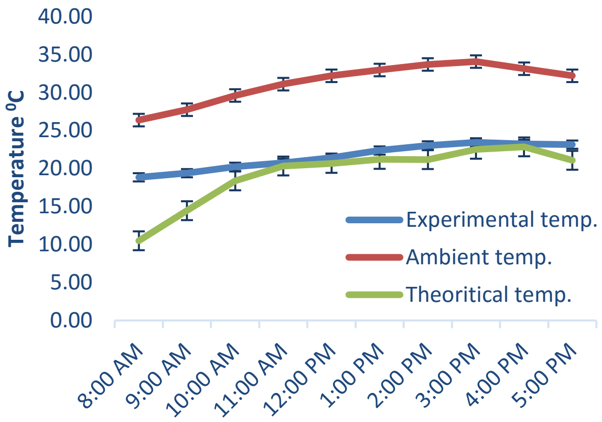

Figure 5: Average theoretical and experimental surface temperature of pot in pot

Metallic body evaporative cooler showed significant temperature difference from the ambient temperature ranging from 7 to 12 °C. Temperature difference is quite convincing as it falls close to theoretical one as shown in figure 4.

Similar trend of average temperature difference found for direct cooler. Theoretical value closely matches with the experimental values in this case as well.

3.3 Colour degradation

It is evident that the colour of food material changes with storage time. The total colour difference was considered as the most sensitive parameter for the measurement of colour. Colour differences and hue angle has been measured for food that was stored in the evaporative storage systems.

Table 1: Total colour degradation of stored food

Day	Ambient	Steel box storage	Pot in pot	Aluminum jar storage
1st day (fresh sample from market)				
7th day				
	h°= 48.05 ΔE= 42.59	h°= 62.21 ΔE= 34.61	h°= 60.65 ΔE= 34.68	h°= 61.57 ΔE= 36.67

The visual appearance, average RGB values along with total colour changes affected by different storage system are presented in Table 1. It is seen that the sample that is kept in ambient condition shows maximum colour degradation. On the other hand, the sample that is stored in the evaporative cooler encountered less colour degradation.

From this visual inspection, it is also apparent that the stored vegetables are still consumable, whereas the vegetables that are kept in ambient conditions are not consumable at all. Eventually, 6 to 4 days more shelf life of bean could be obtained in cold chamber storage as compared to ambient condition storage.

4 CONCLUSION

This research investigates the temperature distribution and quality aspect of direct and indirect evaporative cooler. Significant evaporative cooling temperature depression from the ambient air temperature has been found in all of the three coolers. The theoretical temperature of the surface of the cooler shows a good fit with experimental results. However, the appearance analysis shows the evaporative cooler is suitable only for the short-term preservation of vegetables. From this study, it is confirmed that metallic body evaporative cooling can also offer same cooling effect of the traditional mud-based cooler.

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7 NOMENCLATURE

Symbol	Meaning	Unit
T	Temperature	(K)
P	Pressure	(Pa)
M	Molar Mass	(kg/mol)
Subscript		
v	vapor,	
s	liquid -gas interface	
α	ambient	