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Comparative Analysis of Dew Point Evaporative Cooling with and without Solar Power Integration

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Abstract:
The objective of this study is to examine the operational efficiency of a heat exchanger system when subjected to different dry bulb temperatures of incoming air. Additionally, the study aims to compare the system performance when solar power is integrated for the blower and pump, as opposed to operating without solar power integration. The main aim of this study is to evaluate the influence of renewable energy sources on the efficiency of the system. The experimental findings demonstrate that the efficiency of systems incorporating solar power integration differs by a maximum of 9% when compared to systems without solar power integration, while operating under identical conditions. Moreover, these variations have discernible impacts on wet bulb temperatures and dew points, albeit in a nuanced manner. The incorporation of solar energy into a system has a negligible impact on the relative humidity of the air that is discharged from the heat exchanger. The deployment of solar electricity, meanwhile, offers benefits in terms of sustainability, cost savings, and environmental friendliness. The findings underscore the potential advantages of using solar energy into heat exchange systems, with a particular focus on enhancing performance, reducing costs, and promoting environmental sustainability.

Keywords: Heat exchanger, Solar power integration, System performance, Renewable energy,

1. Introduction

Cold storage facilities are commonly used to provide the low temperatures and high humidity needed to increase the storage life of fruits and vegetables. Traditional storage solutions, such as wooden or bamboo huts near homes or factories, continue to be widely used despite their inefficiency. Mechanical refrigeration in standard cold storage facilities is also notoriously inefficient, not to mention expensive, and often even impossible in regions with spotty or no access to reliable electrical service. The use of evaporative cooling principles to create low-cost, low-energy, environmentally friendly cool chambers has proven crucial in meeting these issues. The relative humidity in these chambers is kept about 90% and the temperature is kept 10-15 degrees Celsius below the ambient level using only locally available materials. Using these innovations, farmers in outlying and difficult-to-reach locations can benefit from reduced losses and on-farm storage options that boost the value chain. Traditional cold storages are still too expensive and impractical for most farmers, especially those in remote locations with limited access to electricity, despite the development of cool chamber technology. A major barrier to the broad use of conventional refrigeration systems is their high-power requirements. This highlights the importance of developing low-cost and energy-efficient cooling options suited to rural areas.

In the past few years, significant progress has been achieved with the development of experimental and computational models to study the mixed processes of heat and mass transfer that take place in the liquid desiccant solution (also

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abbreviated as LDS) dehumidification processes. These models have been created to investigate the mixed heat and mass transfer processes that are engaged in the LDS dehumidification/regeneration processes. These models were built in order to investigate the coupled mechanisms of heat transfer and mass transfer that are at work in the LDS dehumidification/regeneration processes. These models have been constructed in order to investigate the mixed heat transfer and mass transfer processes that take place in the LDS dehumidification/regeneration processes. Dew-point evaporative cooling (DPEC) is widely acknowledged as an effective heat and mass transfer mechanism, providing a practical means of conserving energy on either the demand or supply side of power grids. DPEC, first proposed as the M-Cycle idea by Maisotsenko et al., in 1976 [Dizaji et al., 2018], has changed through time to accommodate the development of new evaporative cooler designs. Direct evaporative cooling (DEC), indirect evaporative cooling (IEC), and dew-point evaporative cooling (DPEC) are the three main types of evaporative coolers. Direct evaporative cooling (DEC) is still the most popular method, as it involves exposing the supply airflow to water in order to cool it via moisture absorption along the iso-enthalpy line. Recent years have seen a significant increase in the number of studies focusing on dew-point evaporative cooling (DPEC).

2. Literature Review

Researchers have paid a lot of attention to how the flow channel structure and operational conditions affect the performance of dew-point evaporative coolers. Early dew-point evaporative cooler designs often made use of rectangular channels (Wicker K., 2003). Liu et al. (2019) examined the design and cooling rate of the cooler, and they found that using corrugated plates instead of flat ones increased efficiency by 10%. Through the use of a counterflow design and finned channels, Lee and Lee (2013) were able to increase the heat transfer characteristics and overall component performance of their regenerative evaporative cooler.

Dew-point evaporative coolers' cooling effectiveness is also affected by channel length, width, height, and air entrance. The efficiency of the cooling system often degrades with both the channel's height and its length. When the channel height was decreased to less than 3 mm, the effectiveness of DPEC was found to be essentially stable, whereas the effectiveness of the dew point rose with dimensionless channel length (Zhao et al., 2008). The performance of indirect evaporative coolers (IECs) was enhanced after researchers Al-zubaydi et al. (2019) examined several water spray configurations and proposed a water spraying approach. The thermal performance of DPIECs was studied by Jia et al. (2019), who found that nylon fiber filling improved device performance in comparison to other materials used for the wet surface. Experiments measuring the capillary rise of water were performed by Duan (2011) on a variety of materials that could be used as heat and mass exchangers. Dew-point evaporative cooler performance was studied by Baakeem et al. (2021), who compared six configurations with a counter-flow arrangement and found that the triangle geometry with a 60° angle was the most effective. Researchers have shown that include fins in the design of dew-point evaporative coolers increases the heat/mass transfer area, hence increasing the coolers' efficiency.

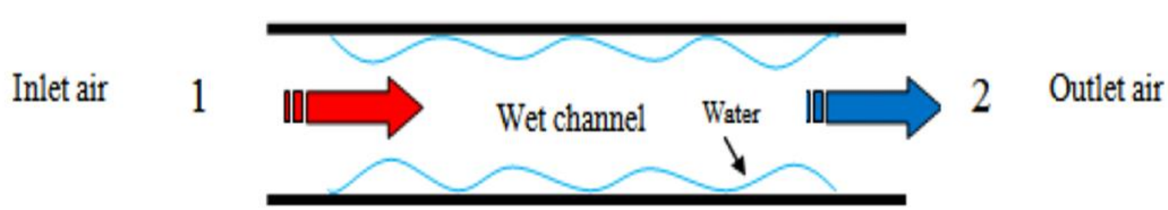
Condensation of water vapor from the product air was studied experimentally in a cross-flow indirect evaporative cooler by Meng et al. (2018). Outlet and main air temperature, wet bulb-effectiveness, water consumption rate, heat transfer rate, and condensation rate were among the many significant parameters revealed after analyzing the device's performance for different input airflow parameters. Non-condensation, partial condensation, and complete condensation were found to be the three possible states of the exchanger's condensation. Curtain fabric and raw cotton fabric were both tested as filler materials for an evaporative cooler by Niyomvas et al. (2013). Their research showed that some fabrics made it possible to obtain lower supply air temperatures. For the purpose of direct evaporative cooling, Al-Sulaiman (2002) examined the efficiency of three natural fibers (palm fibers, jute, and luffa) and compared them to that of a commercial wetted pad. Cooling efficiency, material performance (sale deposits), and cooling efficiency deterioration were all considered, with jute showing the highest cooling efficiency and luffa the lowest. The research indicated that luffa and jute (after surface treatment to increase mold resistance) could be used as viable alternatives to traditional cotton wet pads. In an experimental evaluation of an indirect evaporative cooling system, Sun et al. (2020) examined the impacts of nozzle type and spray technique. The spiral type nozzle was determined to be more applicable, and the intermittent spray approach was suggested for enhanced performance. To prevent the growth of germs and save operational expenses, Shahzad et al. (2021) presented a novel design that did away with hydrophilic surfaces within the system. Coefficient of performance (COP) values as high as 45% and 80% efficacy were observed in the experiments. A unique dew point cooler with a super-performance hydrophilic material layer, complex heat exchanger structure, and intermittent water supply system was experimentally investigated by Xu et al. (2017). The device's efficiency was measured and compared to that of a standard commercial dew point air cooler (M30) in a number of controlled laboratory environments. For the same inlet airflow conditions, the new prototype demonstrated lower product air temperatures, greater COP values, and enhanced wet-bulb and dew-point effectiveness.

The purpose of study in this paper is to utilize the advantage of evaporative cooling is to reduce the temperature of air without addition of moisture existed for some time. The primary objective of this study is to conduct a comparative analysis of the performance of the system, both with and without the incorporation of solar power for the operation of the blower and pump. This analysis will provide valuable insights into the advantages of utilizing renewable energy sources in improving the overall efficiency of the heat exchange system.

3. Experimental test set up and Methodology:

3.1 Experimental test set up

In order to put an environmentally friendly evaporative cooling system through its paces, you will require a number of components, such as a heat exchanger, a blower, a place with refrigeration, and a pump. The heat exchanger, which is responsible for transferring heat from the air outside the building to the water that is utilized in the cooling system, is often installed on the building's roof or in close proximity to the area that is cooled. The blower is attached to the heat exchanger and is driven by electricity. Its purpose is to circulate air through the heat exchanger and the space that is being chilled. The space that needs to be chilled is referred to as the refrigerated space, and it may be a room, a building, or an outdoor area. At the very bottom of the reservoir a pump is placed. This pump, which is driven by an electrical current, is responsible for transferring water from the reservoir to the heat exchanger.



a) Working principle of direct evaporative cooling

b) Actual photograph of the experimental test set up

Fig 1: Experimental test set up used for the research work

The supply air enters the evaporative cooling system in the axial direction at a temperature of 30 degrees Celsius when the blower speed is at its maximum of 1300 revolutions per minute. The supply air exits the casing in the axial direction after traveling through the wet and dry channels. The supply air is cooled by the aluminum sheets in the dry channel before it is delivered to the desired region, and the working air absorbs heat from the supply air by evaporating water from the hessian sheets in the wet channel. The water that is provided to the wet channel is recirculated with the assistance of a pump, and during this process, the latent heat of evaporation is absorbed from the material that is surrounding the wet channel. At the highest blower speed, both the supply air and the working air are determined to have a temperature of 28 degrees Celsius. Despite the fact that the indirect evaporative cooling process can only achieve a temperature drop that is as great as the wet bulb temperature of the surrounding air, the evaporative heat exchanger's latent heat transfer and the vaporization process are essential to accomplishing the appropriate level of cooling.

4. Results and Discussion

The present study entails conducting experimental trials to investigate the performance of a heat exchanger system while subjecting it to different dry bulb temperatures of the incoming air. The velocity of the air in the dry channel remains constant at 2.7 m/s, while the performance of the system is evaluated at various velocities in the wet channel, specifically 2.2 m/s, 4.1 m/s, 5.4 m/s, 6.6 m/s, and 8.5 m/s. Throughout these experimental trials, data is collected regarding the outlet temperature of the air as it exits the wet channel, as well as the temperature of the product water at the outlet. Furthermore, the system includes a monitoring mechanism to measure the relative humidity of the air that is discharged. The experiments are carried out at dry bulb temperature of 31ºC. It is worth noting that the circulation components of the system, such as the air blower and water pump, are initially energized by electricity. The primary objective of this study is to conduct a comparative analysis of the performance of the system, both with and without the incorporation of solar power for the operation of the blower and pump. This analysis will provide valuable insights into the advantages of utilizing renewable energy sources in improving the overall efficiency of the heat exchange system. The experimental outcomes for both the solar-powered and non-solar-powered system configurations at dry bulb temperature of 31ºC have been methodically arranged and displayed in Table 1,

Table 1: Experimental trial at DBT = 31°C, RH = 54%, WBT = 23.5°C and DPT = 20.6°C

Mode of Operation	Dry channel velocity (m/s)	Wet channel velocity	Wet channel outlet temperature (Tw 1)	Product water outlet temperature (Tw 2)	Wet bulb effectiveness (ε_W)	Dew point effectiveness (ε_D)
Electric operated	2.7	2.2	27.7	26.2	0.64	0.46
		4.1	26.7	25.8	0.69	0.5
		5.4	25.9	24.3	0.89	0.64
		6.6	25.4	23.9	0.94	0.68
		8.5	25.5	23.6	0.98	0.71
Solar operated	2.7	2.2	27.6	26.6	0.59	0.42
		4.1	27.1	26.3	0.63	0.45
		5.4	26.1	24.3	0.89	0.64
		6.6	25.5	23.8	0.96	0.69
		8.5	25.2	23.7	0.97	0.7

4.1 Wet Bulb Effectiveness (ε_W):

Figures 2 illustrate the variation in wet bulb effectiveness with respect to wet channel velocity for various air dry bulb temperature in systems with and without solar integration. In this experimental study, the wet channel velocity was systematically varied between 2.2 and 8.5m/s. The trends in Figure 2 clearly indicate that wet bulb effectiveness consistently rises with increasing wet channel velocity, regardless of the air's initial dry bulb temperature. This phenomenon is attributable to the enhanced heat transfer capabilities of the wet channel, resulting in lower product water outlet temperatures.

However, for identical wet channel velocities, the effectiveness of wet bulbs appears to diminish as air dry bulb temperatures increase. The value of ε_W values for solar-integrated and non-solar systems is 0.59 to 0.99 for air dry bulb temperatures of 31ºC. Notable is the fact that, under identical operational conditions, the effectiveness of systems with and without solar power integration varies by up to 9%. Intriguingly, the effect of solar power integration on the efficacy of wet bulbs does not follow a consistent pattern, with variations observed in both directions.

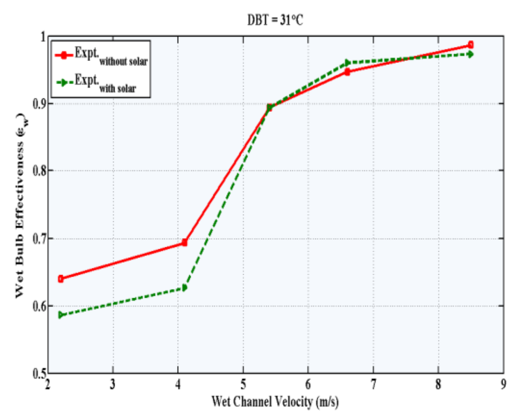


Figure 2: Variation of Wet Bulb Effectiveness with Wet Channel Velocity at DBT 31ºC

4.2 Dry Bulb Effectiveness (ε_D):

Figure 3 provide a clear depiction of the relationship between dew point effectiveness (ε_D) and wet channel velocities in solar-powered and non-solar systems, under dry bulb temperature of 31ºC. Similar to the concept of wet bulb effectiveness (ε_W), the effectiveness of dew point also demonstrates a consistent trend of enhancement as the velocity of the wet channel increases. The observed phenomenon can be ascribed to the enhanced heat transfer capabilities in the wet channel of the heat exchanger, which is a direct result of the amplified air velocity.

Across a range of wet channel velocities ranging from 2.2 m/s to 8.5 m/s, the values of ε_D vary between 0.42 and 0.71 for dry bulb temperatures of 31ºC. These values apply to both solar-integrated and non-solar systems. Interestingly, there is no significant correlation between the utilization of solar power and the variable ε_D. The average percentage deviation in ε_D between solar and non-solar systems typically ranges from 3% to 5%. The findings of this study highlight the intricate connection between the utilization of solar power and the effectiveness of dew point, indicating that the impact of solar power on dew point may differ depending on various operational circumstances.

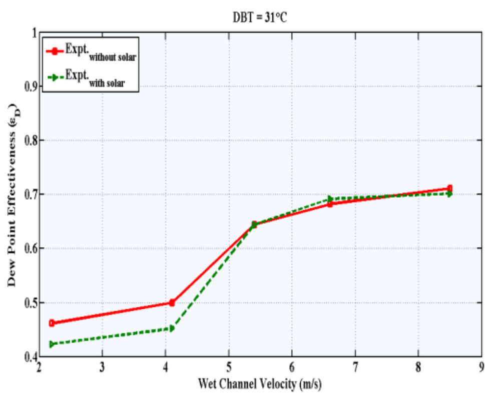


Figure 3: Variation of Dry Bulb Effectiveness with Wet Channel Velocity at DBT 31ºC, (b)

4.4 Power Consumption:

The integration of solar energy for powering the air circulation blower and water circulation pump within the system does not seem to have a discernible influence on key parameters, including wet bulb effectiveness, dew point effectiveness, and relative humidity of the air. In the configuration that does not rely on solar energy, the electrical power is consumed by two components. The blower consumes 30W of power, while the water pump utilizes 20W. It is assumed that both components operate with an efficiency of 70% and 60% respectively. The combined energy consumption amounts to 77 watts. During an 8-hour daily operation, the total amount of electrical energy consumed is equivalent to 0.616 kilowatt-hours (kWh), along with its corresponding cost. On the other hand, the solar-powered system derives advantages from a sustainable and environmentally friendly energy source, thereby obviating the necessity for procuring electrical energy. Over the course of a year consisting of 365 days, with each day having 8 operational hours, the solar system is able to generate significant savings amounting to 224.84 kWh of electrical energy. The utilization of solar power for these components not only leads to a reduction in operational costs but also highlights its environmentally friendly and sustainable characteristics.

5. Conclusion

This study conducted a thorough examination of the operational efficiency of a heat exchanger system when exposed to different dry bulb temperatures of incoming air. The primary objective was to compare the system's performance with and without the incorporation of solar power for the functioning of the blower and pump. A noteworthy finding derived from our experimental investigations is that, when subjected to identical operational conditions, the efficacy of systems incorporating solar power integration displayed a fluctuation of up to 9%. The relationship between the integration of solar power and the effectiveness of wet bulb temperatures exhibited inconsistent patterns, with observed fluctuations in both positive and negative directions.

Additionally, the research findings indicate that there is no statistically significant relationship between the adoption of solar energy and the variable ε_D. The observed average percentage deviation falls within the range of 3% to 5%. This observation underscores the intricate correlation between solar power and dew point, implying that the influence of solar energy on dew point might exhibit variability across diverse operational conditions. The study also revealed that the incorporation of solar energy did not exert a direct impact on the relative humidity of the air discharged from the heat exchanger. The average percentage divergence between the systems utilizing solar energy and those without was determined to be 3.14%.

It is important to highlight that the use of solar power in the operation of the blower and pump within the heat exchanger system presents distinct benefits, such as sustainability and environmental compatibility. This particular form of renewable energy obviates the necessity for conventional sources of electrical energy, hence leading to diminished operational expenditures and emphasizing the environmentally conscious and sustainable attributes of the system.

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