https://doi.org/10.17221/41/2021-RAE

Development and evaluation of a low-cost evaporative cooling system for agricultural product storage

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Citation: Kapilan N., Patil V.K. (2023): Development and evaluation a low-cost evaporative cooling system for agricultural product storage. Res. Agr. Eng., 69: 48–53.

Abstract: Agricultural products are highly perishable and, hence, we need to preserve these products after harvest. India is an agricultural country and, thus, the post-harvest storage of perishable agricultural products is important to reduce the gap between the demand and supply. Cold storage technologies have been developed and are used in India; however, these technologies are not popular in rural and remote areas due to the higher initial cost and the electrical energy requirement. Therefore, a number of low-cost technologies have been developed and, among these technologies, the evaporative cooling technology is gaining in popularity due to its simple design and lower initial cost. In this work, we have developed and tested a solar photovoltaic (PV) powered evaporative cooling system and used coconut coir as the cooling medium and compared the results with celdex pad. From this work, we observed that this system is an economical and efficient in reducing the temperature and increasing the relative humidity for the storage of agricultural products.

Keywords: agricultural products; evaporative system; performance; preservation; renewable energy

The increase in the world population and industrialisation have increased the energy consumption which has directly and indirectly increased the fossil fuel consumption. The increase in the fossil fuel consumption has caused environmental degradation and, hence, it has been suggested to use an environmentally friendly cooling system (Abaranji et al. 2020). A compressor-based cooling system, such as air conditioners, consumes higher energy as compared to a non-compressor-based cooling system. The non-compressor-based system, such as an evaporative cooling system (ECS), causes lower environmental degradation having a satisfactory cooling performance (Wijaksana et al. 2020). An efficient water spray system improves the cooling effect and enhances the efficiency of the ECS. A significant number of experimental and numerical works have been carried out to enhance the performance of the ECS (Zhou et al. 2017). Different types of cooling pad designs have been developed and it has been suggested that the honeycomb design is better than the other designs (Bishoyi and Sudhakar 2017). The ECS can be used for various industrial and residential applications (Kabeel and Bassouni 2017).

As per a report, India is the second largest producer of fruits and vegetables in the world and also accounts for 15% of the world's production of vegetables. The wastage of fresh horticultural products in India is about 18%. This is due to poor post-harvest management practices. Hence, there is great potential in processing fruits and vegetables in India (National Bank for Rural Agriculture and Rural Development 2014). A system to preserve fresh fruits and vegetables was developed, which consists of a pyramidal

Supported by Vision Group on Science and Technology, India, Project No. GRD228.

https://doi.org/10.17221/41/2021-RAE

shaped frame internally insulated with polystyrene foam, a suction fan, a water pump and a cooling pad that is made from Jute. It is reported that this ECS has significant potential in helping with the short-term preservation of vegetables (Mogaji and Fapetu 2011).

An ECS was developed and tested for the preservation of Irish potato for 14 weeks. It has been reported that a metal-in-block structure is better than a pot-in-pot structure (Okunade and Ibrahim 2011). The improvements in materials used in absorbent pads and ceramic pads enhance the performance of the ECS. It has been suggested that experiments may be conducted to identify more locally available materials that can be used as absorbents (Liberty et al. 2013). It has been reported that the pH and the total soluble solids of tomatoes stored with an ECS were good and suitable for the short-term preservation of tomatoes (Deoraj et al. 2015). The integration of an ECS with good sanitation facilities will increase the quality and freshness of the stored products for a shorter period (Ndukwu and Manuwa 2015). There are few challenges and several opportunitiesin marketing ECSs in some developing countries (Ndukwu and Manuwa 2014). A solar powered ECS was developed with aluminium sheets and a jute pad, and it reported that this system enhanced the shelf-life of tomatoes for an additional 5 days with minor changes in firmness, weight, colour and rotting, as compared to tomatoes stored in normal atmospheric conditions (Zakari et al. 2016).

ECSs are used in poultry farms to reduce the impact of higher temperatures on the chickens' health (Çayli et al. 2021). ECSs are used in cooling of greenhouses during hot summers (Misra and Ghosh 2018). The energy consumed by the ECS is very low when compared to a conventional cooling system. Also, the operating cost of the ECS is very low (Lal Basediya et al. 2013). Environmentally friendly materials can be used for the fabrication of the cooling pad to reduce its impact on the environment. The use of locally available materials for the fabrication of a cooling pad will reduce the dependency on foreign countries and will reduce the cost of the ECS (Laknizi et al. 2019). In recent years, ECSs have been integrated with solar energy conversion systems to reduce the need of a conventional energy source (Sultan et al. 2018).

From the literature review, it was observed that locally available materials can be used as the cooling medium in an ECS. Hence, in this work, coconut coir was used as the cooling pad material as it is easily available in rural and remote areas of India. Since the electrical energy is not continuously available in villages and remote areas, we used a solar photovoltaic (PV) system to supply the electrical power required to drive the ECS. The objectives of this work are to develop and evaluate the performance of the solar PV powered ECS and to use coconut coir as a substitute for the celdex pad.

MATERIAL AND METHODS

A direct ECS was developed and which was driven by a 1.5 kW solar PV system. A solar inverter was used to convert the direct current (DC) output from the solar photovoltaic panels to an alternative current (AC) output and which was then supplied to the ECS. A pyranometer was used to measure the solar radiation. Coconut coir was used as cooling pad instead of the commercially available celdex pad. The fan speed was variable and the dry bulb temperature, wet bulb temperature, air velocity and pressure drop were measured. In this work, the independent variable is the fan speed and the dependent variables are the temperature, power and efficiency. The experiments were conducted three times and the average value is considered for the analysis. Figure 1 shows

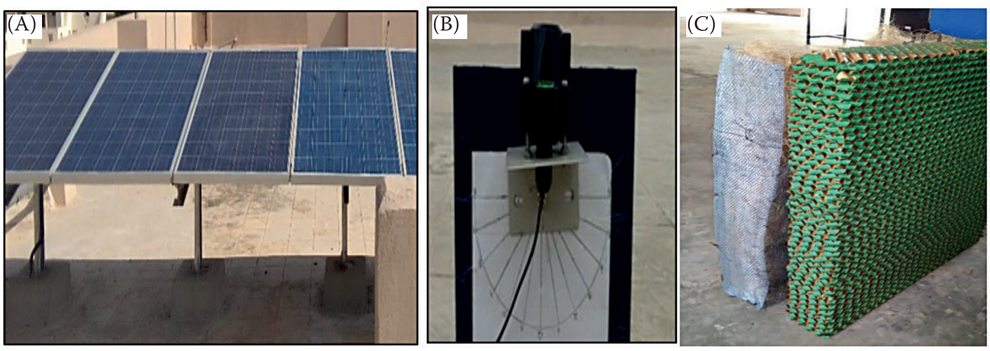

Figure 1. (A) Solar photovoltaic panels, (B) pyranometer, (C) coconut coir and celdex pads

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Figure 2. Evaporative cooling system (ECS) experimental set up

the solar PV system, coconut coir and celdex pads and pyranometer.

Experimental set up. The ECS experimental set up was proposed and is shown in Figure 2. It consists of a rectangular wind tunnel, an axial fan fixed at the tunnel inlet and an evaporative pad is kept close to the inlet of the tunnel where the air should strike the evaporative pad. The fan used in this work is a variable speed fan and its speed was measured using a non-contacting tachometer (Precise, India). The wet bulb and dry bulb temperatures of the air were measured by using a sling psychrometer (Bellstone, India). An energy meter was used for the measurement of the power consumed by the fan. A digital anemometer (Adept, India) was used for the measurement of the air velocity. A small overhead tank was placed above the evaporative pad, to supply water to the ECS. A series of nozzles were provided above the cooling pad, to spray water in the form of tiny droplets onto the evaporative pad. A U-Tube water manometer (Enviro Tech Industrial Products, India) was used in this work to measure the pressure drop across the evaporative pads.

When the fan was switched on, room air was supplied to the evaporative cooler tunnel. The water was supplied from the overhead tank to the cooling pad through the nozzle arranged on the top of the pads. When the water flows down the surface of the coconut coir, part of the water is evaporated by the warm air that passes through the pad. The temperature of the air is reduced and its humidity simultaneously increases due to the water evaporation. After conducting experiments with the celdex pad, it was replaced with the coconut coir and the experiments were conducted as discussed previously.

RESULTS AND DISCUSSION

The solar radiation study was carried out from 8:30 am to 3:30 pm using the pyranometer and the data were stored in the data logger. Figure 3 shows the results of the readings recorded by the pyranometer. The average solar radiation flux was 912 W·m^{-2} and the maximum solar radiation was recorded in the afternoon. The cloud movement affects the solar radiation and, hence, there are fluctuations in the readings.

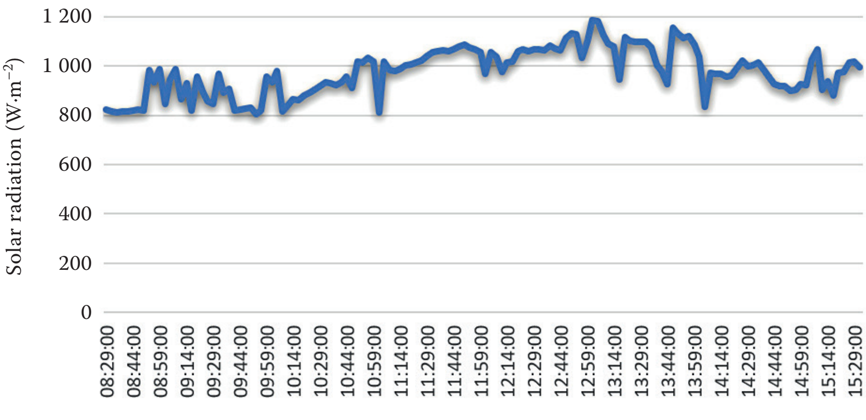

Figure 3. Solar radiation versus time

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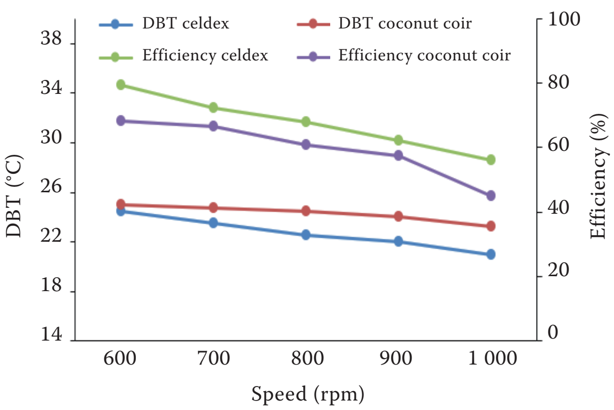

Figure 4. Speed versus the dry bulb temperature (DBT) and efficiency

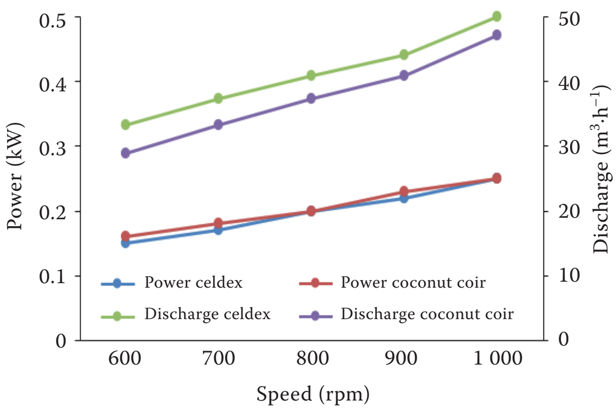

Figure 5. Speed versus the power consumption and discharge

The power produced by the solar PV panel depends upon the solar radiation.

The dry bulb temperature (DBT) is the temperature recorded by thermometer at the outlet of the ECS. It affects the cooling and performance of the ECS. Figure 4 shows the effect of the fan speed on the outlet DBT with the celdex and coconut coir as the cooling pad medium of the solar powered ECS. From the figure, it can be observed that the DBT decreases gradually with an increase in the fan speed. This is due to the higher fan speed which increases the air circulation and water evaporation. The air supply flow rate affects the evaporation and cooling performance (Wang et al. 2018). The celdex pad results in a lower DBT compared to the coconut coir due to the better surface design which causes better interaction between the water and air. This results in better evaporation, which enhances the cooling and causes a lower DBT. This behaviour is similar to the work carried out with a gunny sack as a cooling pad (Wijaksana et al. 2018). The maximum reduction in the DBT obtained with luffa cylindrica fibres as the cooling media in an indirect ECS was about 16 °C (Potra et al. 2021).

Figure 4 also shows the effect of the fan speed on the saturation efficiency of the solar PV powered ECS with the coconut coir and celdex cooling pads. The saturation efficiency of the ECS decreases with an increase in the fan speed due to the increase in the cooling effect. This is due to the slower air velocity which causes a greater evaporation rate as the air passes over it. This results in better evaporative rates as the air takes more time to travel through the pad (Kesavan 2018; Velasco-Gómez et al. 2020). The celdex cooling pad provides higher efficiency (Franco et al. 2011; Tejero-González and Franco-Salas 2021) compared to the coconut coir at all the fan speeds due to the better contact area provided by the celdex pad between the air and water (Vala et al. 2016).

The effect of the fan speed on the power consumption of the fan with the celdex and coconut coir cooling pads is shown in Figure 5. From the figure, it can be observed that the power consumption of the fan increases with an increase in the fan speed. From the figure, it can be observed that the power consumption

Table 1. Effect of the speed on the dry bulb temperature (DBT), discharge, power and efficiency (with the celdex pad)

Speed (rpm)	DBT (°C)			Discharge ($m^3 \cdot s^{-1}$)			Power (kW)			Efficiency (%)		
	min	max	mean	min	max	mean	min	max	mean	min	max	mean
600	24	25	24.7 (0.58)	32.4	33.8	33.3 (0.76)	0.14	0.16	0.15 (0.02)	55	56	55.67 (0.58)
700	23	24	23.7 (0.58)	37.1	37.4	37.2 (0.17)	0.16	0.18	0.17 (0.01)	61	63	62 (1.00)
800	22	23	22.7 (0.58)	40.1	40.89	40.63 (0.45)	0.19	0.22	0.21 (0.02)	67	69	68 (1.00)
900	22	22	22.0 (0.00)	43.5	45.0	44.5 (0.87)	0.21	0.25	0.22 (0.02)	72	73	72.3 (0.58)
1 000	20	21	20.7 (0.58)	49.5	49.9	49.77 (0.23)	0.24	0.27	0.25 (0.02)	78	80	79 (1.00)

Numbers in parentheses represent the standard deviation

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Table 2. Effect of the speed on the dry bulb temperature (DBT), discharge, power and efficiency (with the coconut coir pad)

Speed (rpm)	DBT (°C)			Discharge ($m^3 \cdot s^{-1}$)			Power (kW)			Efficiency (%)		
	min	max	mean	min	max	mean	min	max	mean	min	max	mean
600	25	25	25 (0.00)	28.1	29.9	28.7 (1.04)	0.14	0.16	0.15 (0.01)	44	45	44.67 (0.58)
700	24	25	25 (0.58)	33.0	34.2	33.4 (0.69)	0.17	0.18	0.17 (0.01)	57	58	57.3 (0.58)
800	24	25	24 (0.58)	37.01	37.45	37.3 (0.25)	0.19	0.21	0.20 (0.01)	59	61	60.0 (1.00)
900	23	25	24 (1.00)	40.2	40.95	40.72 (0.48)	0.22	0.23	0.23 (0.01)	65	66	65.67 (0.58)
1 000	23	23	23 (0.00)	46.8	47.3	47.13 (0.29)	0.24	0.26	0.25 (0.01)	68	69	68.3 (0.58)

Numbers in parentheses represent the standard deviation

of the coconut coir is higher than the celdex pad. The resistance offered by the coconut coir to the flowing air is higher than the celdex pad and, hence, requires higher power consumption at all the fan speeds. However, the difference in the power consumption between the celdex and coconut coir is small.

The air discharge through the ECS affects the performance of the ECS (Laknizi et al. 2019). Figure 5 also shows the effect of the fan speed on the air discharge in the solar powered ECS with the celdex and coconut coir as the pad cooling media. From Figure 5, it can be observed that the discharge of the ECS increases with an increase in the fan speed. This is due to the increase in the fan speed which increases the quantity of the air supplied to the ECS. It can also be observed from figure that the celdex pad provides a higher discharge compared to the coconut coir. This is due to the unique design of the celdex pad which offers less resistance to the air movement of. The difference in the discharge between celdex and coconut coir is small at higher speeds.

Tables 1 and 2 show the independent and dependent values at different values with the celdex and coconut coir pads, respectively. From the tables, it can be observed that the standard deviation value is very low and is insignificant.

CONCLUSION

The demand for the preservation of vegetables and fruits is high in the summer due to the higher solar radiation and higher ambient air temperature. Solar energy can be utilised to drive the ECS in order to reduce the dependence on conventional electrical energy. This type of system will be useful in rural and remote areas. In this work, an ECS was successfully developed and tested with coconut coir as the cooling medium. From the experimental results, it can be observed that the fan speed significantly affects the performance of the ECS. It can also be observed that the performance of the ECS with coconut coir is comparable to the celdex cooling pad. From this work, we can conclude that the low-cost and easily available coconut coir can be used as a renewable and sustainable alternative to the celdex pad which is used in ECSs. A solar PV powered ECS is suitable for the short-term preservation of agricultural products in remote and rural areas.

Acknowledgement: We thank Mr. M. Naveen, the laboratory assistant, for his help in the experimental work.

REFERENCES

Abaranji S., Panchabikesan K., Ramalingam V. (2020): Experimental investigation of a direct evaporative cooling system for year-round thermal management with solar assisted dryer. International Journal of Photoenergy, 20: 6698904.

Bishoyi D., Sudhakar K. (2017): Experimental performance of a direct evaporative cooler in composite climate of India. Energy and Buildings, 153: 190–200.

Çayli A., Akyüz A., Üstün S., Yeter B. (2021): Efficiency of two different types of evaporative cooling systems in broiler houses in Eastern Mediterranean climate conditions. Thermal Science and Engineering Progress, 22: 100844.

Deoraj S., Ekwue E.I., Birch R. (2015): An evaporative cooler for the storage of fresh fruits and vegetables. The West Indian Journal of Engineering, 38: 86–95.

Franco A., Valera D.L., Peña A., Pérez A.M. (2011): Aerodynamic analysis and CFD simulation of several cellulose evaporative cooling pads used in Mediterranean greenhouses. Computers and Electronics in Agriculture, 76: 218–230.

Kabeel A.E., Bassuoni M.M. (2017): A simplified experimentally tested theoretical model to reduce water consumption

https://doi.org/10.17221/41/2021-RAE

of a direct evaporative cooler for dry climates. International Journal of Refrigeration, 82: 487–494.

Kesavan M. (2018): Performance evaluation of evaporative cooler using luffa fiber materials. International journal of Engineering Research and Technology, 7: 193–196.

Laknizi A., Abdellah A.B., Faqir M., Essadiqi E., Dhimdi S. (2019): Performance characterization of a direct evaporative cooling pad based on pottery material. International Journal of Sustainable Engineering, 14: 46–56.

Lal Basediya A., Samuel D.V., Beera V. (2013): Evaporative cooling system for storage of fruits and vegetables – A review. Journal of Food Science Technology, 50: 429–442.

Liberty J.T., Ugwuishiwu B.O., Pukuma S.A., Odo C.E. (2013): Principles and application of evaporative cooling systems for fruits and vegetables preservation. International Journal of Current Engineering and Technology, 3: 1000–1006.

Misra D., Ghosh S. (2018): Evaporative cooling technologies for greenhouses: A comprehensive review. Agricultural Engineering International, 20: 1–15.

Mogaji T.S., Fapetu O.P. (2011): Development of an evaporative cooling system for the preservation of fresh vegetables. African Journal of Food Science 5: 255–266.

National Bank for Rural Agriculture and Rural Development (2014): Model Project Report on Fruit and Vegetable Processing Unit National Bank for Agriculture and Rural Development. Available at https://agricoop.nic.in/

Ndukwu M.C., Manuwa S.I. (2014): Review of research and application of evaporative cooling in preservation of fresh agricultural produce. International Journal of Agricultural and Biological Engineering, 7: 85–101.

Ndukwu M.C., Manuwa S.I. (2015): Impact of evaporative cooling preservation on the shelf life of fruits and vegetable in South Western Nigeria. Research in Agricultural Engineering, 61: 122–128.

Okunade S.O., Ibrahim M.H. (2011): Assessment of the evaporative cooling system (ECS) for storage of Irish potato. Production Agriculture and Technology Journal (PAT), 7: 74–83.

Putra N., Sofia E., Gunawan A. (2021): Evaluation of indirect evaporative cooling performance integrated with finned heat pipe and luffa cylindrica fiber as cooling/wet media. Journal of Advanced Research in Experimental Fluid Mechanics and Heat Transfer, 3: 16–25.

Sultan M., Miyazaki T., Mahmood M.H., Khan Z.M. (2018): Solar assisted evaporative cooling based passive air-conditioning system for agricultural and livestock applications. Journal of Engineering Science and Technology, 13: 693–703.

Tejero-González A., Franco-Salas F. (2021): Optimal operation of evaporative cooling pads: A review. Renewable and Sustainable Energy Reviews, 151: 111632.

Vala K.V., Kumpavat M.T., Nema A. (2016): Comparative performance evaluation of evaporative cooling local pad materials with commercial pads. International Journal of Engineering Trends and Technology, 39: 198–203.

Velasco-Gómez E., Tejero-Gonzále A., Jorge-Rico J., Rey-Martínez F.J. (2020): Experimental investigation of the potential of a new fabric-based evaporative cooling pad. Sustainability, 12: 7070.

Wang Y., Huang X., Li L. (2018): Comparative study of the cross-flow heat and mass exchangers for indirect evaporative cooling using numerical methods. Energies, 11: 1–14.

Wijaksana H., Winaya N.S., Sucipta M., Ghurri A., Suarnadwipa N. (2018): The investigation on cooling capacity and CELdek material pad classification of evaporative cooling pad system using different pad material with water temperature and water discharge variations. AIP Conference Proceedings, 1983: 020019.

Wijaksana H., Winaya N.S., Sucipta M., Ghurri A. (2020): An overview of different indirect and semi-indirect evaporative cooling system for study potency of nanopore skinless bamboo as an evaporative cooling new porous material. Journal of Advanced Research in Fluid Mechanics and Thermal Sciences, 76: 109–116.

Zakari M.D., Abubakar Y.S., Muhammad Y.B., Shanono N.J., Nasidi N.M., Abubakar M.S., Muhammad A.I., Lawan I., Ahmad R.K. (2016): Design and construction of an evaporative cooling system for the storage of fresh tomato. ARPN Journal of Engineering and Applied Sciences, 11: 2340–2348.

Zhou N., Chen F., Cao Y., Chen M., Wang Y. (2017): Experimental investigation on the performance of a water spray cooling system. Applied Thermal Engineering, 112: 1117–1128.

Received: May 10, 2021
Accepted: April 21, 2022
Published online: December 21, 2022