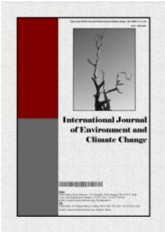

International Journal of Environment and Climate Change

12(10): 494-503, 2022; Article no.IJECC.86980
ISSN: 2581-8627
(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)

Environment Friendly Indirect-direct Type Evaporative Cooling Technology: A Review

K. V. Vala [a*]

[a] *College of Food Processing Technology and Bio-Energy, Anand Agricultural University, Anand, 388110, Gujarat, India.*

Author's contribution

The sole author designed, analyzed, interpreted and prepared the manuscript.

Article Information

DOI: 10.9734/IJECC/2022/v12i1030823

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/86980

Review Article

Received 05 March 2022
Accepted 10 May 2022
Published 18 May 2022

ABSTRACT

This paper reports a review based study into the two stage indirect- direct evaporative cooling technology, which is referred as two-stage evaporative cooling (TSEC) system. The direct-type (evaporative) cooling system is widely using natural cooling technology for storage of agricultural produce particularly fruits and vegetables because of its simplicity, eco-friendly and low-cost. But EC system is environment based and got the limitation that cooling of air can be done up to wet bulb temperature. To overcome this and owing to the continuous progress in cooling technology innovations are done by combining other indirect methods with direct type evaporative cooling system. Such system is known as two stage evaporative cooling, includes indirect and direct type cooling system. The indirect cooling has potential to be an alternative to conventional mechanical vapour compression refrigeration system to take up the air conditioning duty. Indirect cooling system is mostly heat exchanger(s) whereas direct cooling is wet pad type system. Combination of these two systems has obtained significantly enhanced cooling performance, with near to 90% and high energy efficiency ratio up to 80. The experimental and research work done on the indirect and direct cooling technology on the basis of their design, structural, type of indirect cooler, materials of construction, pad materials, effectiveness and energy saving have been reviewed and presented. This review paper explains the working principles of two-stage evaporative cooling systems and its performance assessed. This system is energy efficient, environment friendly and having potential for cooling and storage of fruits and vegetables in countries where hot and dry weather prevails for most of the part.

**Corresponding author: E-mail: kvvala@aau.in;*

Keywords: Evaporative cooling; heat-exchanger; two-stage EC system (TSEC); indirect cooling (IDC); direct evaporative cooling (DEC).

1. INTRODUCTION

Fruits and vegetables contain high percentage of water; carry out their physiological function of respiration to their environment after harvest & storage which lead to their rapid deterioration under conditions of high temperature and low humidity. As a result, heavy losses are encountered in freshly harvested fruits and vegetables. Thelack of sufficient cool storage space at farm level and refrigerated storage at market level further enhances loss of fruits and vegetables [1].

Several factors are responsible for the losses. One of the major problems is the non-availability of the suitable low cost efficient cooling system. Evaporative cooling is the most efficient method for cooling in dry and hot conditions. It has been proved as an effective method of storage of fruits and vegetables [2-6]. The favourable environment for storage of fruits and vegetables is low temperature and high humidity. "Refrigeration system decreases both temperature and humidity while evaporative cooling system decreases less temperature and increases humidity, which is more suitable for agriculture produce" [7]. That is reasonably possible to achieve by two-stage evaporative cooling with comparatively low investment and less energy input.

Two principal methods of evaporative cooling are; direct cooling and indirect cooling. Direct and indirect processes can also be combined. In direct method of evaporative cooling outside unsaturated air is allowed to pass through wet pad, due to evaporation of water air gets cooled and humidified. Whereas, in indirect method of evaporative cooling air is cooled as it flows outside the tubes of the heat exchanger in which cold water circulates. This indirect cooling process takes place at a constant absolute humidity. The effectiveness of either of these methods is below one. The efficiency of direct cooling (EC) is up to 90% with good quality rigid pad media (Dash et al., 2018), [8,9,10], while efficiency of indirect cooling is in the range of 60-70% [11]. The direct evaporative cooling has got the limitation for drop in temperature, i.e. the maximum up to the wet bulb temperature of ambient air. It may be overcome with the two-stage indirect-direct evaporative cooling.

1.1 Indirect-direct Evaporative Cooling System

Two-stage indirect-direct evaporative cooling system combines indirect evaporative cooling unit in first-stage with direct evaporative cooling unit in second-stage. In this two-stage evaporative cooling system, ambient air is passed over a heat exchangercooling unit (first-stage) with circulating water coming out from the direct evaporative cooling unit [12-14]. The heat exchange process in heat exchanger (indirect EC system) reduces the dry bulb temperature of the air stream without changing its humidity [15-17]. Thereafter, this air stream is introduced into the second stage i.e. direct evaporative cooling system. In the second stage, the pre-cooled air passes through a water-soaked pad. As a result, the air temperature approaches the wet bulb temperature of the pre-cooled air. This temperature is lower than the wet bulb temperature of the ambient air [18-20]. The two-stage evaporative cooling provides air that is cooler than either a direct or indirect single-stage system can provide individually. "The coefficient of performance of the two-stage evaporative cooling system is at least 20% greater than those achieved when employing either the indirect evaporative cooling or direct evaporative cooling system alone" [21]. The cooling capacity of the two-stage evaporative cooling system is higher than that of the single stage evaporative cooling systems. The schematic arrangement of all components is shown in Fig. 1.

In recent trends, it was noticed that the IDC systems are always in combined operation with other cooling measures and commonly used operational modes are (1) IDC/DEC system; (2) IDC/DEC/mechanical vapour compression refrigeration system; (3) IDC/desiccant system; (4) IDC/chilled water system; (5) IDC/heat pipe system. Out of all above addressed effort for lowering the temperature, only combination of IDC and DEC are reviewed here. Less work on TSEC system has been done and published. Therefore an attempt has been made to review critically, all published literature as ready reference for future onward work.

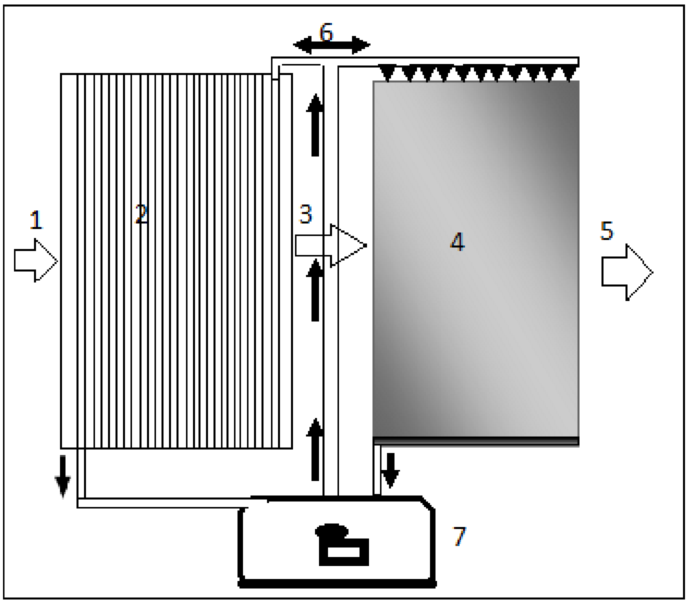

Fig. 1. Schematic arrangement of Indirect-direct evaporative cooling system

1. Ambient air inlet 4. Direct EC unit 7. Water tank & pump
2. Indirect cooling unit 5. Cooled air out
3. Primary cooled air 6. Water distribution pipe

2. REVIEW OF LITERATURE

"Different researchers have made efforts to improve the performance of evaporative cooling system by change in design, process and materials" [22]. "Many scientists have pointed out that in the region where wet bulb temperature is low; two stage evaporative cooling system, which combines indirect and direct evaporative cooling offers energy and cost saving potential with comfort conditions similar to refrigerated systems" [23,24,25,26]. "The cooling effectiveness of indirect evaporative cooling system is generally low, around 40-60% compared to direct evaporative cooling" [27]. The published information on all the above was reviewed and briefly presented here.

Source	Output
Sadgir and Ghuge, 2016	They developed an in-house two stage indirect direct evaporative cooling system by using plate heat exchanger in indirect section and filled with cooling pads (corrugated cellulose) to increase the water holding capacity of indirect section and reported that an optimum velocity of 1.5 m/s of secondary air offered the maximum cooling in direct section. They also reported that indirect-direct evaporative cooling system gave best performance for hot and dry climate region in India.
Jain and Hindoliya, 2012	They design and developed a regenerative type direct-indirect evaporative cooling system by placing direct evaporative cooling in first stage and indirect evaporative cooling in downstream and reported that this type of two-stage arrangement is more advantageous for providing thermal comfort in residential and commercial buildings.
Kulkarni and Rajput, 2011	They design and developed, a direct evaporative cooling system, an indirect evaporative cooling system and indirect-direct system (IEC/DEC) i.e. two-stage evaporative cooling system by placing indirect evaporative cooling in first stage followed by direct evaporative cooling in second stage and reported that two-stage evaporative cooling system is found more suitable among all climatic conditions of 39^0c – 46^0c and 37 – 46% RH.
Hui and Cheung, 2009	They designed two-stage indirect-direct evaporative cooling system and

Source	Output
	evaluated its performance in hot and humid climate. Reported that two-stage indirect direct evaporative cooling systems could have good potential to cool outdoor air and energy performance than single-stage evaporative cooling systems. They also reported that the efficiency of the evaporative cooling system depends on system configuration, component design and control strategies.
Rick Philips, 2009	Evaluated the two-stage evaporative cooling system by placing direct and indirect cooling components alternatively and reported that, by keeping the fan upstream side followed by indirect evaporative cooling unit, direct evaporative cooling unit, there is enough space for uniform air velocity to attain good performance results as compared to supply fan placed downstream of the cooling components, placing indirect evaporative cooling downstream of the direct evaporative cooling.
Jain, 2007	Developed and evaluated a two-stage indirect-direct evaporative cooling system and reported that the effectiveness of the two-stage evaporative cooling was found to be 1.1-1.2 over single evaporative cooling system. Results show that two-stage evaporative cooling system could drop temperature up to wet bulb depression of ambient air and provided 90% relative humidity.
Ei-dessouky et. al., 2004	Designed and developed a two-stage indirect-direct evaporative cooling system. The system formed of an indirect evaporative cooling unit followed by a direct evaporative cooling unit and reported that high efficiency are obtained irrespective of the high intake air temperature.
Al-juwayhel et. al., 2004	Designed a single-stage direct evaporative cooling, single-stage indirect evaporative cooling, two-stage indirect direct evaporative cooling and three-stage system of evaporative cooling and mechanical vapour compression. Reported that the two-stage indirect direct configuration achieved the best value of energy efficient ratio, followed by the direct evaporative cooling, three-stage evaporative cooling and indirect evaporative cooling.
Dutta et. al., 1987	For assessment of two-stage indirect direct evaporative system appropriate computer programs were prepared using Fortran iv. They designed; fabricated and tested 8.5 ton indirect-direct evaporative cooling system and compared its performance with a computer prediction, reported that this system has scope for use in India.

2.1 Design and Development of IDC and DEC System

Scientists designed, fabricated, developed and assessed two stage evaporative cooling system; either indirect direct type EC or direct indirect type EC and evaluated individually as well as combined (Sadgir and Ghuge, 2016), [28,8,29,30,31,32,33,34]. They also evaluated the two-stage evaporative cooling system by placing direct and indirect cooling components alternatively with supply fan at upstream side and back side [30]. It was observed/reported that indirect-direct type arrangement of two stage evaporative cooling having supply fan at upstream side performed well as compared to other arrangements. The efficiency of the two stage evaporative cooling system depends on system configuration, component design and control strategies.

2.2 Structural Details of IDC-DEC

Many researchers designed and developed various sizes indirect and direct cooling system (Sadgir and Ghuge, 2016, Kongre et. al., 2015, Reddy et. Al., 2012, Al-juwayhel et. al., 2004, Datta et al, 1987). Proper and effective size of indirect and direct evaporative cooling system resulted in better performance with higher effectiveness. Also selection of proper indirect cooling method plays important role in higher drop of temperature making it suitable for storage of fruits and vegetables [31]. The experimental and theoretical analysis of paper results show that the TSEC system not only has favorable application prospect in the dry region, but also has application in the low/medium humidity areas.

Source	Size	Output
Sadgir and Ghuge, 2016	Dimensions of indirect cooler : 0.35x0.35x0.32mm	They designed, developed and evaluated in-house two stage indirect direct evaporative cooling system and reported maximum temperature drop of 21.7°c and maximum effectiveness of 92.5%.
Kongre et. al., 2015	Dimensions of direct cooler: 406x368x660mm Dimensions of indirect cooler : 8x10x4mm	They have designed two-stage cooler cum cold storage and analyzed its performance in laboratory. Reported drop in temperature from 36^0c to 23^0c in 195 min (2h 15min). Result shows that two-stage evaporative cooler provides overall good environment to store the perishable food and vegetables, also this can be better solution against costly air conditioners.
Reddy et. al., 2012	Dimensions of direct cooler: 3700x2750x3200mm dimensions of indirect cooler: 350x350x250mm	For experimental evaluation, constructed a closed chamber using particle board, glass, brick and plywood for experiment and designed small indirect evaporative cooler using plastic drinking straws (4mm dia). The results show that for a given inlet conditions and for given length of the tubes the optimum diameter of the tube 2mm gives better cooling.
Al-juwayhel et. al., 2004	Dimensions of direct cooler: 790x810x20mm Dimensions of indirect cooler: 810x120x125mm	They reported that two-stage indirect direct evaporative cooler shown higher effectiveness value varying between 0.76 and 1.14 than the single-stage evaporative cooling systems.
Datta et. al., 1987	Dimensions of direct cooler: 1000x1000x1000m Dimensions of indirect cooler: 1000x1000x150mm	They fabricated indirect-direct evaporative cooling system and tested and compared its performance with a computer prediction. They reported that this system has scope for use in India and this system also applicable in all zones where the wet bulb temperatures are below 24-26°c for most of the hot season.

2.3 Types of Pad Materials and Heat Exchanger

Types of heat exchanger and pad material are important components of TSEC system. There is a lot of research studying the characteristics and performance of various types of heat exchangers with alternative shapes and different cooling media/pads, namely; plate type, cross flow type for he and corrugated cellulose pad, aspen pad, glassdek, perspex for EC (Sadgir and Ghuge, 2016), [35], (Mohammed A.K., 2013), Jain and Hindoliya, [28], Reddy et al., 2012, [36], Kulkarni and Rajput, 2011). Materials used for making the heat exchanger elements (plate/tube) includes fibre sheet with single side water proofing, aluminium plate/tube with single side wet wicked setting (grooved, meshed, toughed etc.), and ceramic plate/tube with single side water proofing. The type of material used for construction of heat exchanger and cooling pads used in evaporative cooling system far most important as far as drop in temperature is concerned.

Source	Parameters	Output
Sadgir and Ghuge, 2016	Pad material: corrugated cellulose (50, 100 & 150 mm thick) Type of heat exchanger: aluminium plate heat exchanger (nos. Of plates:14, & spacing: 2 cm)	They design, developed and evaluated two stage indirect direct evaporative cooling system and reported efficiency of the indirect section increased from 18.76 to 32% with maximum temperature drop of 3.35° at 1.5 m/s secondary air velocity. They also reported that thicker pad performed better in direct section with temperature drop from

Source	Parameters	Output
		10.5 to 12.50°c. Overall maximum temperature drop of 21.7°c and maximum effectiveness of 92.5% was reported.
Kongre et. al., 2015	Pad material: aspen pad (30mm thick) Type of heat exchanger: copper tube(10mm dia., 30ft long)	They reported that the two-stage evaporative cooler provided overall good performance and drop in temperature was observed from 36°c to 23°c.
Mohammed A.K., 2013	Pad thickness: 15 cm	Designed, constructed and tested a two-stage evaporative cooling experimental set up consisting of an indirect evaporative cooling stage followed by a direct evaporative cooling stage. Reported that this system can provide comfort conditions during the whole of hot season and can works well in the desert like environments, alone or as a supplement to a chiller or direct expansion refrigeration system.
Jain and Hindoliya, 2012	Pad material: aspen wood Type of heat exchanger: aluminium tube (7mm dia.)	A commercially available direct type evaporative cooler was evaluated by adding a heat exchanger (indirect evaporative cooler) and reported improvement in coefficient of performance 20-25% with heat exchanger than direct evaporative cooler.
Reddy et al., 2012	Pad material: perspex sheet (12mm thick) Type of heat exchanger: drinking plastic straws (4mm dia.)	Experiments were conducted to evaluate the performance of the cooler under different ambient conditions (for different inlet temperatures ranging from 25°c to 45°c. The results show that less relative humidity, low velocity of comfort air and an increase in the inlet temperature of comfort air gives higher cooling effect.
Sodha and Somwanchi, 2012	Pad material: glasdek, (100mm thick)	They have evaluated a model for the validation of the water temperature along direction of flow in an evaporating pad and reported a new concept of using the tank water for cooling to extraneous objects. The steady state temperature of water in the tank is reached from 33°c to 23°c near to wet bulb temperature in a time of the order of one hour or less.

2.4 Effectiveness of the ID-DECsystem

In theory, the efficiency of either of the indirect-type or direct-type cooling system is less than 100 per cent, this is because, and both the system can cool entering air up to its wet bulb temperature only. But the overall effectiveness can be achieved more than 100 per cent, when direct and indirect are combined and works as a single unit. The overall performance of indirect-direct evaporative cooling system evaluated by researchers in different climates and seasons are reviewed hereunder;

Mohammed, 2013, has designed, constructed and tested a two-stage evaporative cooling experimental set up consisting of an indirect evaporative coolingstage followed by a direct evaporative cooling stage and reported that effectiveness of two-stage indirect direct evaporative cooling unit, under various outdoor conditions varies in the range of 90-110%, whileindirect evaporative coolingstage was observed in the range of 55-65%.

Abbouda and Almuhanna [37], have designed, constructed and tested a two-stage evaporative cooling system consisting of a direct evaporative cooling and indirect evaporative cooling. They reported that the overall effectiveness of the combining cooling system was more than 100% (102.8%). They also reported that in re-circulating type evaporative cooling system with cross-fluted cellulose pad, the collected water in sump reaches equal to the dew point temperature of the entering air after steady state condition has reached. This system is environmentally clean & energy efficient, and can be used in various climatic conditions.

Kulkarni and Rajput [22], have fabricated and tested two-stage indirect direct evaporative coolerhaving wet surface plate heat exchanger type indirect stage with three different shapes and three different cooling materials. They reported that saturation efficiency of direct evaporative cooling varies in the range of 98.3% to 71.9%, for indirect evaporative cooling 83.3% to 37.2%. Overall efficiency varies in the range of 119.5% to 74.3%. Cooling capacity for combined mode ranged between 4679 and 43771 kJ/h for different combinations. They also reported that the cooling efficiency can be improved by adding an indirect stage before the direct stage and the dry bulb temperature of incoming air can be reduced below its wet bulb temperature. Rectangular shape gave higher efficiency. Results show that the two-stage evaporative cooling system will be suitable for climatic conditions of 39°c-46^{0}c dry bulb temperature and 37%-46 % relative humidity.

Gomez et al., [38], explained the phenomena of mixed evaporative cooling systems with indirect system with tubular heat exchanger and plate heat-exchanger and reported that when dry outside air is allowed to pass from indirect evaporative cooling and this out coming air from indirect evaporative cooling is allowed to pass from direct evaporative cooling, that results, decreases in temperature and also increases the air humidity. Modern designs of these systems used plastics tube that resisted corrosion better.

Heidarinejad et al. [39], experimentally investigated "the cooling performance of indirect-direct evaporative cooling system in various simulated climatic conditions. They used plastic wet surface heat exchanger as an indirect evaporative cooling unit and 15 cm thick cellulose pad for a direct evaporative cooling unit. They obtained an effectiveness of indirect evaporative cooling unit in the range of 55%-61% and effectiveness of indirect direct evaporative cooling unit in the range of 108%-111%. Such system is found to be better for the hot and humid climates. They also reported 55% more water consumption than direct evaporative cooling unit and 33% of mechanical cooling systems".

Hui and Cheng, [29], have assessed the performance of two-stage evaporative cooling systems in hot and humid climate and reported that the cooling efficiency of the standalone indirect evaporative cooling and direct evaporative cooling units are lower than one, but that of the combined two-stage evaporative cooling system may be greater than one.

Rick Philips [30], has analyzed an evaporative cooling air handling unit using chilled-water (re-circulated water) coil in conjunction with direct evaporative cooling and reported that using direct evaporative cooling in conjunction with an indirect cooling coil, results in 100% cooling efficiency with indirect cooling coil placed upstream of the direct evaporative cooling.

Jain [31], has developed and tested "a two-stage evaporative cooler to improve the efficiency by using wooden shave as the packing material and reported that effectiveness ranged from 1.1 to 1.2 and this system could achieve favourable temperature and relative humidity conditions for storage of tomatoes for 14 days. Such a cooler could provide necessary comfort even though outside humidity is higher. The two-stage evaporative cooler is found to provide 20 % better cooling when compared to single stage cooler".

Ei-dessouky et al., [32], carried out theoretical and experimental study on "small-scale evaporative cooling unit using structured packing material of high-density polythene with wetted surface area of 420 m^2/m^3. They have also carried out the performance analysis of two-stage evaporative coolers. The efficiency of indirect evaporative cooling and direct evaporative cooling units when operated individually were found to be 20-40% and 63-93% respectively, whereas the efficiency of two - stage indirect direct evaporative cooling varied over a range of 90-120%".

Bourhan et Al., [21], reported that "the coefficient of performance of the combined two-stage evaporative cooling system was at least 20% greater than those achieved when employing either the indirect evaporative cooling or direct evaporative cooling system alone".

El-dessouky et. al., 1996, evaluated the concept of pre-cooling the air before direct evaporative cooling without using cooling tower i.e. two-stage indirect-direct evaporative cooling system and observed that effectiveness increased with packing thickness and flow rate of water to indirect-direct evaporative cooling.

Datta et. Al. [34], have experimentally studied "an 8.5 ton indirect-direct evaporative cooling system and reported that such a system provides a relief cooling rather than comfort cooling. The room could be maintained at 4-5 ºc above the inlet wet bulb temperature using such a cooler".

2.5 Energy Saving and Environment Friendly

In comparison with mechanical vapour compression systems, two-stage evaporative cooling system uses water as working fluid instead of cfcs, require less power and simple manufacturing technology. This system does not use any synthetic refrigerant thereby it is environmentally clean and energy efficient system. The published research work is reviewed here;

Mohammed, 2013, found that more than 60% power saving could be obtained by two-stage indirect direct evaporative cooling system in comparison with mechanical vapour compression systems with just 55% increase in water consumption with respect to direct evaporative cooling systems. He also reported that direct evaporative cooling systems provide comfort in a wide range of hot season; indirect direct evaporative cooling systems can provide higher level of comfort condition by obtaining lower dry bulb temperature and wet bulb temperature.

Patil et al., [40], explained the concept of various ways to attain cooling by using indirect evaporative cooling and its combination with direct evaporative cooling i.e. mixed evaporative cooling systems and reported that mixed evaporative cooling system is more effective in dry and hot climate and can be applied in whatever climate. Mixed evaporative cooling system is energy efficient and environmentally clean.

Rick Philips [31], has analyzed an evaporative cooling air handling unit using cooling coil in conjunction with direct evaporative cooling. He explained the arrangement of cooling components in different sequences and examined its effect on energy saving and reported that using direct evaporative cooling in conjunction with indirect evaporative cooling, results in 35% energy saving and sequence (arrangement) of supply fan, upstream of the cooling components with cooling coil is placed upstream of the direct evaporative cooling, less energy is consumed.

Maheshwari et al, [27], compared the power requirement of an indirect evaporative cooling unit with conventional packaged air conditioner. They concluded that the best performance of indirect evaporative cooling unit coincides with the hour of maximum cooling capacity and peak power demand of conventional unit and it offers maximum reduction in cooling capacity and peak power demand.

El-dessouky et. al., 2000, have developed a membrane air dryer and coupled with conventional direct indirect evaporative cooler and reported that when such system is combined with mechanical vapour compression system to achieve to perfect thermal conditions, about 50% savings in electricity are obtained.

Datta et al. [26], found that most zones of India Suitable for evaporative cooling system, where the wet bulb temperature is usually below 25^{o}C and reported that potential energy savings envisaged by replacing conventional refrigerated systems by evaporative system is $\approx 75\%$.

Stanley et al, [23] and Navon & Arkin, [25], have pointed out that in the regions where wet bulb temperature is low, two stage evaporative cooling system, which combines indirect and direct evaporative cooling offers energy and cost saving potential.

3. CONCLUSIONS

The indirect- direct type system configuration provides more cooling and the air leaving temperature can be lowered below inlet air wet-bulb temperature with more relative humidity than stand-alone indirect-type or direct-type cooling system. This combined systems is energy efficient, environment friendly and having potential for cooling and storage of fruits and vegetables in country like India where hot and dry weather prevails for most of the part. Also the system is simple in construction and no so costly, so farmers can adopt it for short term storage of fruits and vegetables. This system can also be combined with mechanical refrigeration system to achieve to perfect thermal conditions with savings in electricity.

COMPETING INTERESTS

Author has declared that no competing interests exist.

REFERENCES

1. FAO. Postharvest management of fruits and vegetables in the asia-pacific region. Asian Productivity Organization; 2006. ISBN: 92-833-7051-1.
2. Liberty JT, Okonkwo WI, Echiegu EA. Evaporative cooling: a postharvest technology for fruits and vegetables preservation. International Journal of Scientific and Engineering Research. 2013;4(8):2257-2266.
3. Ready VS, Praveen S, Akakeri JH. Design and performance evaluation of an indirect evaporative air cooler. International Journal on Production and Industrial Engineering. 2012;3(1):17-21.
4. Samira A, Woldetsadik K, Workneh TS. Postharvest quality and shelf life of some hot pepper varieties. Journal of Food Science Technology. 2011;50 (5): 842-855.
5. Sunmonu M, Falua KJ, David AO. Development of a low-cost refrigerator for fruits and vegetables storage. International Journal of Basic and Applied Science. 2014;2(3):85-93.
6. Suryawanshi SH, Unde PA, More HG. Low cost storage of fruits and vegetables. Proceeding xxxix annual convention and symposium of Indian Society of Agricultural Engineers. 2005;9-11: 260-261.
7. Nitipong S, Sukum K. Recycled high-density polyethylene and rice husk as a wetted pad in evaporative cooling system. American Journal of Applied Sciences. 2011;8(2):186-191.
8. Sharma PK, Mansuri SM. Studies on storage of fresh fruits and vegetables in solar powered evaporative cooled storage structure, Agricultural Engineering Today. 2017;41(1):10:18.
9. Warke DA, Deshmukh SJ. Experimental analysis of cellulose cooling pads use in evaporative coolers. International Journal of Energy Sciences and Engineering. 2017;3(4):37-43.
10. Vala KV, Joshi DC. Development of evaporative cooling transportation system for perishable commodities. Journal of Agricultural Engineers. 2010;47(1):27-33.
11. Mohmmad AK. Experimental performance evaluation of two-stage evaporative cooling system. Scholar’s Journal of Engineering and Technology. 2013;1(3):122-127.
12. Chadha KL. Handbook of horticulture. Indian council of agricultural research, New Delhi, PP: 2001:1031.
13. Chakraverty A, Mujumdar AS, Raghvan GS, Ramaswamy HS. Handbook of postharvest technology; cereals, fruits, vegetables, tea and spices. Marcel Dekker, Inc, New York; 2003.
14. Chaudhary ML. Recent developments in reducing postharvest losses in the Asia-pacific region. Paper presented at the seminar on “reduction of post-harvest losses of fruits and vegetables” held during Oct. 5-11, New Delhi; 2004.
15. Ei-dessouky HTA, Al-haddad AA, Juwayhel FI. Thermal and hydraulic performance of a modified two-stage evaporative cooler. Renewable Energy. 1996;7(2):165-176.
16. Ei-dessouky HT, Ettouney HM, Bouhamra WS. A novel air conditioning system: membrane air drying and evaporative cooling. Transaction I Chemical Engineering, 2000;78(7):999-1009.
17. Kumar A, Gupta AK, Ghuman BS, Grover I. Effectiveness of evaporatively cooled stores of various capacities constructed under different ambient conditions. Agricultural engineering today, Indian Society of Agricultural Engineers. 2003;27(2-3):38-48.
18. Adebisi OW, Igbeka JC, Olurin TO. Performance evaluation of absorbent materials in evaporative cooling system for the storage of fruits and vegetables. International Journal of Food Engineering. 2009;5(3):1-14.
19. Arya M, Arya A, Rajput SPS. An environment friendly cooling option. Journal of Environmental Research and Development. 2009;3(4):1254-1261.
20. Basediya AL, Samuel DKV, Beera V. Evaporative cooling system for storage of fruits and vegetables-a review. Journal of Food Science Technology. 2013;50(3):429-442.
21. Bourhan T, Tahat M, Ahmad AL H, Victor AM, Probert D. Thermodynamic behavior of an air conditioning system employing

combined evaporative water and air coolers. Applied Energy. 2001;70:305-319.
22. Kulkarni RK, Rajput SPS. Performance evaluation of two stage indirect-direct evaporative cooler with alternative shapes and cooling media in direct stage. International Journal of Applied Engineering Research. 2011;1(4):800-812.
23. Stanley AM, Rodrieguezanza GM. Rock bed regeneration as a means of indirect evaporative cooling. Journal of Ashrae transactions-85, 1979;2(4):787-795.
24. Neil Eskara. Indirect-direct evaporative cooling system, ASHRAE transactions. 1980;22(5):22-25.
25. Nanon R, Arkin H. Feasibility of direct-indirect evaporative cooling for residences, based on studies with a desert cooler. Building and Environment. 1994;29(3): 393-399.
26. Datta S, Sahgal PN, Kishore VVN, Dhingra SC. Design and operating characteristics of evaporative cooling systems. International Journal of Refrigeration. 1987;10 (4):205-208.
27. Maheshwari GP, Al-Ragom F, Suri RK. Energy saving potential of an Indirect Evaporative Cooler, Applied Energy. 2001;69(1): 69-76.
28. Jain JK, Hindoliya DA. Development and testing of regenerative evaporative cooler. International Journal of Engineering Trends and Technology. 2012;3(6):694-697.
29. Hui SCM, Cheung WY. Two-stage evaporative cooling systems in hot and humid climate. In proceedings of the Tianjin-Hong Kong symposium, 29-30 Jun, Tianjin, China. 2009:64-76.
30. Rick Philips. Using direct evaporative plus chilled water cooling. Ashrae Journal. 2009:16-19.
31. Jain D. Development and testing of two-stage evaporative cooler. Building and Environment. 2007;42:2549-2554.
32. Ei-dessouky H, Ettouey H, Al-Zeefari A. Performance analysis of two-stage evaporative cooler. Chemical Engineering Journal. 2004;102(3):255-266.
33. Al-juwayhel F, El-dessouky H, Ettouney H, Al-Qattan M. Experimental evaluation of one, two, and three stage evaporative cooling systems. Heat Transfer Engineering. 2004;25(6):72-86.
34. Datta S, Sahgal PN, Subrahmaniyam S, Dhingra SC, Kishore VVN. Design and operation of evaporative cooling systems. Journal of Australian Refrigeration, Air Conditioning and Heating. 1987;41 (2):28-36.
35. Kongre UV, Shirgire ND, Bagade PA, Neware NT. Testing and performance analysis of two stages evaporative cooler cum cold storage. International Journal of Scientific Research and Development. 2015;3(2):711-713.
36. Sodha MS, Somwanchi A. Variation of water temperature along the direction of flow: effect on performance of an evaporator cooler. Journal of fundamentals of renewable energy and applications, I (article idr110301-6 pages). 2012;2:1-6.
37. Abbouda SK, Almuhanna EA. Improvement of evaporative cooling system efficiency in green houses. International Journal of latest Trends Agriculture and Food Science. 2012;2(2):83-89.
38. Gomez EV, Rey Martínez FC, Tejero GA. The phenomenon of evaporative cooling from a humid surface as an alternative method for air-conditioning. International Journal of Energy and Environment. 2010;1(1):69-96.
39. Heidarinejad G, Bozorgmehr M, Delfani S, Esmaeelian J. Experimental investigation of two-stage indirect-direct evaporative cooling system in various climatic conditions. Building and Environment. 2009;44(10): 2073-2079.
40. Patil CR, Hirde KG, PRMIT, Badnera R. The concept of indirect evaporative cooling. International Journal of Engineering Science and Innovative Technology. 2013;2(5):391-396.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/86980