Experimental analysis of dewpoint indirect evaporative cooler operating with solar panel

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ABSTRACT

M-cycle (Maisotsenko cycle) based indirect evaporative cooling system can significantly enhance the natural ecosystem. The operating cost of dewpoint indirect evaporative cooler (Dewpoint-IEC) is low for space air cooling systems. Dewpoint-IEC is inexpensive, energy efficient, and ecological friendly. This study illustrates the experimental evaluation of Dewpoint-IEC working with varying operating conditions. The system designed for up to 1 Ton cooling capacity of the system which has coefficient of performance and energy efficiency ratio up to 6 and 20. The experimentation of Dewpoint-IEC is investigated in terms of the relative humidity and ambient temperature. The results indicate that the effectiveness of the Dewpoint-IEC system is increased with decrease the relative humidity and increase the ambient air temperature. The highest experimental values of wet bulb and dewpoint effectiveness of the system is 1.11 and 0.76. The maximum resulting values of EER, COP, and cooling capacity is 19, 6.1, and 3.3 kW, respectively. Based on experimental results, the system is a feasible option in hot summer days. Moreover, the power consumption of the Dewpoint-IEC is 70 W which can be achieved by combining the system with solar panels. So, current

research also shows that Dewpoint-IEC integrated with solar panel recommends off-grid solution as well.

Keywords: Maisotsenko-cycle; Indirect evaporative cooler; Thermal effectiveness; Energy efficiency ratio; Solar energy.

INTRODUCTION

Energy is a prime commodity for an amiable life. Developed countries have many energy resources which are providing the signify life worth of its civilian. The energy demand is increasing due to the rapidly growth of population throughout the world. Heating, ventilation, and air conditioning systems (HVAC) meet up essential conditions for space cooling by adjusting the humidity, cleanliness, and temperature (Avallone & Iii, 1997). The essential purpose of HVAC systems is to provide human comfort zone under steady-state conditions of atmospheric temperature ranges (Gagge et al., 1967).

M-cycle is an energy efficient cooling technique, which is going popular throughout the world. This system does not required any type of refrigerant which is producing greenhouse gas, so this system is an ecological friendly (Maisotsenko & Gillan, 2003). This cooling technique is used to decrease the incoming ambient air temperature nearer to the dewpoint temperature of the incoming air. (Alonso et al., 1998). It saves up to 80% energy than other conventional cooling systems. The procedure involves the air pre-cooled according to the indirect evaporator principle, which then causes it to cool down (Finocchiaro et al., 2012).

Muzaffar Ali et al. performed an experimental study on Dewpoint-IEC using fins in dry channels, finding that it was more efficient than traditional indirect evaporative cooling system (IECs). The results showed a dewpoint and wet bulb effectiveness are 0.93 and 1.43. (Ali et al., 2021). Shahram et al. studied a simulated model of M-cycle evaporative cooling system on TRNSYS software and predicted the highest COP of 0.728 (Delfani & Karami, 2020). Duan et al. performed a simulation on counterflow HMX based on M-cycle and achieved wet bulb effectiveness of 1.4. The results showed that it was more efficient than IECs (Duan, 2011). Rubeena et al. studied the holistic integration of counter flow Dewpoint-IEC with solar assisted

desiccant cooling system and observed that maximum values of COP was 0.85 (Kousar et al., 2021).

Press, Dove et al. studied the effectiveness and energy saving potential of IECs and found that it saved energy consumption up to 80% (Press, 2015). Zanchini et al. investigated the M-cycle evaporative cooling system integrated with refrigeration cycle to reduce power consumption up to 38% for an office building (Zanchini & Naldi, 2019). Hassan studied four dissimilar configurations for the indirect evaporative cooler which were parallel flow, counter flow, combined flow, and one regenerative flow. He found the wet-bulb efficiencies as 1.09, 1.26, 1.31, and 1.16 for each system respectively (Hasan, 2012). Kashif et al. performed the experimentation of indirect evaporative cooler in Pakistan. This study was also conducted to compare the M-cycle based indirect evaporative cooler with other types of evaporative coolers (Kashif et al., 2017).

In view of the above literature review, it can be noted that Dewpoint-IEC is viable for use in dry and hot climatic conditions with effective energy savings than other conventional cooling systems. Few studies have been performed for the systems integrated with photovoltaic solar panels to achieve the required power consumption of the system, as referred to in the current research work. Moreover, a detailed experimental analysis is presented involving a varied operating conditions like RH, process air temperature at a fixed values of water temperature and air velocity. Furthermore, a considerable study is presented in view of the effectiveness of wet bulb and dewpoint, cooling capacity, COP, and EER.

SYSTEM DESCRIPTION

Heat exchanger (HMX) of Dewpoint-IEC has crossflow channels arrangement in which dry channels are covered with alternative wet channels. These wet and dry channels are made with polypropylene (PP) sheets and fiber cloth which are attached with the help of a cementex bond. Plastics dividers are also attached with PP sheets and fiber cloth with the help of a bond. The dividers are joined on both sides of the PP sheets. Schematic diagrams of wet and dry channels

are presented in Figure 1. Moreover, the design specifications of Dewpoint-IEC are given in Table 1.

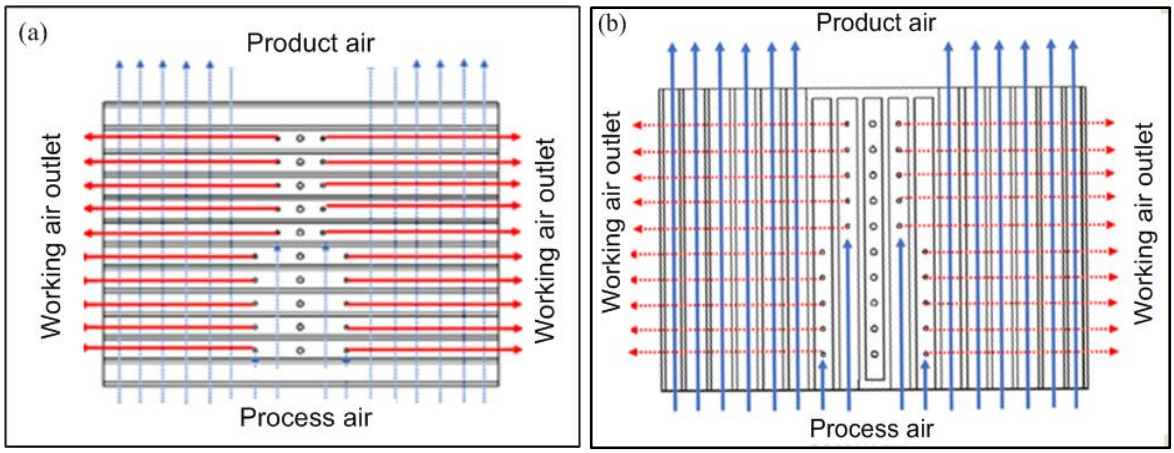


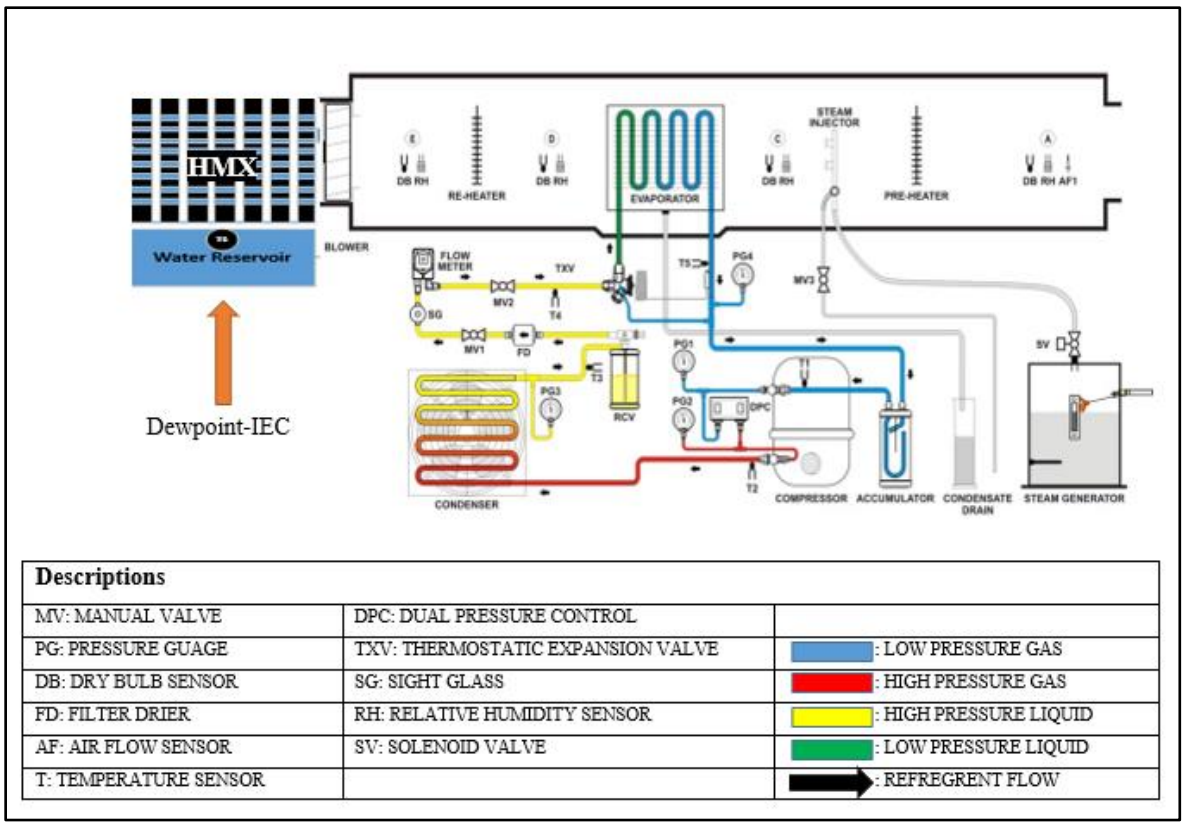
Figure 1. Schematic of dewpoint indirect evaporative cooler; (a) wet channel (b) dry channel

Table 1. Design specifications of Dewpoint-IEC

Parameter	**Value**	**Parameter**	**Value**
HMX width	300 mm	Fiber cloth thickness	0.1 mm
HMX length	420 mm	Hole diameter	6 mm
HMX height	152 mm	No. of holes in a channel	20
Height of channel	4 mm	Holes diameter for air	4 mm
Width of channel	21.4 mm	Total dry channels	18
Type of channel	Rectangular	Total wet channels	19
Polypropylene thickness	0.08 mm	Product to working air ratio	40-60%

Air conditioning laboratory unit (ACLU) is used to testify the Dewpoint-IEC. ACLU is an autonomous training system for the experimentation on cooling, refrigerating, air handling, heating, humidifying, and de-humidifying system. It is designed to creating various conditions and environments like air temperature and relative humidity (RH). It is also controlling the airflow for certain processing as cooling, pre-heating, re-heating, humidifying, and de-humidifying. So, HMX is coupling with air conditioning laboratory unit for experimentation

of the system. The schematic diagram of the Dewpoint-IEC with air conditioning laboratory unit as shown in Figure 2.



Descriptions		
MV: MANUAL VALVE	DPC: DUAL PRESSURE CONTROL	
PG: PRESSURE GUAGE	TXV: THERMOSTATIC EXPANSION VALVE	: LOW PRESSURE GAS
DB: DRY BULB SENSOR	SG: SIGHT GLASS	: HIGH PRESSURE GAS
FD: FILTER DRIER	RH: RELATIVE HUMIDITY SENSOR	: HIGH PRESSURE LIQUID
AF: AIR FLOW SENSOR	SV: SOLENOID VALVE	: LOW PRESSURE LIQUID
T: TEMPERATURE SENSOR		: REFREGRENT FLOW

Figure 2. Schematic of Dewpoint-IEC with air conditioning laboratory unit

The dewpoint indirect evaporative cooler consists of HMX, axial fan, pump, and solar panel system. HMX is the key part of the system which is consisting of polypropylene-based 37 channels. Dewpoint-IEC is integrated with PV solar panel system to meet the power requirements. The required electricity of the dewpoint-IEC system is 70 W which is achieved by using the 100 W photovoltaic solar panels. The schematic diagram of the Dewpoint-IEC combined with the photovoltaic solar panel system as shown in Figure 3.

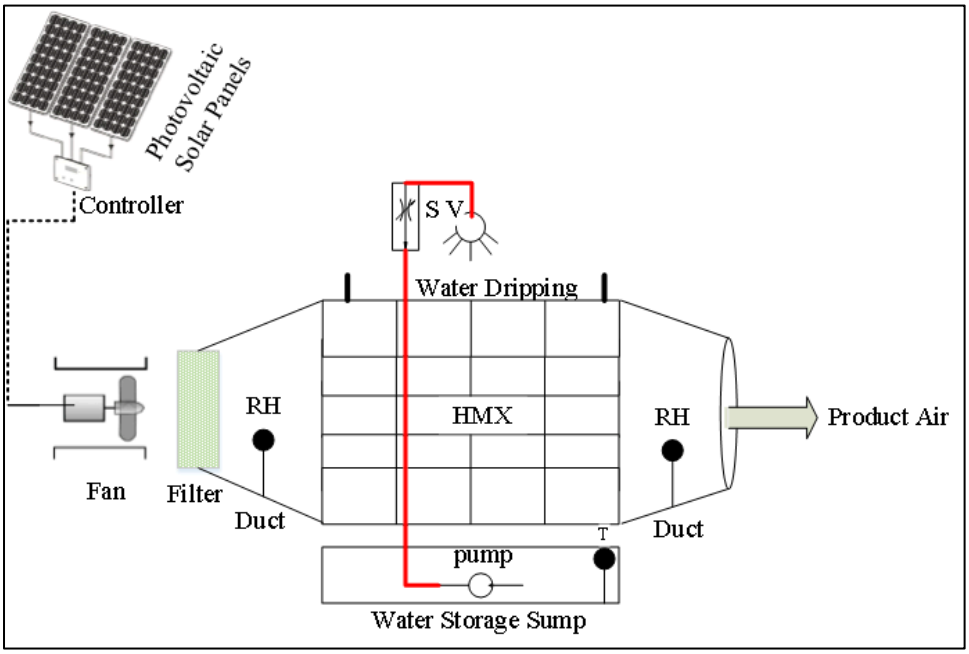


Figure 3. Schematic of Dewpoint-IEC integrated with solar panel system

MANUFACTURING OF HMX

In the current study, HMX is the main part of the system which consists of alternative wet and dry channels arrangement. In dry channels, PP sheets are prepared with length and width of 300 mm and 420 mm. Plastics dividers with the width and height of 4 mm and length of 420 mm is joined on one side of PP sheets with the help of waterproof cementex bond. The distance between each divider is 21.4 mm. The holes of 6 mm are created in between the PP sheets which are delivered water in wet channels. On both sides of water holes, 4 mm holes are created in four sub-channels. These sub-channels are blocked on output side of channels. So, the working air is flown in wet channels through these holes for evaporation as shown in Figure 4.

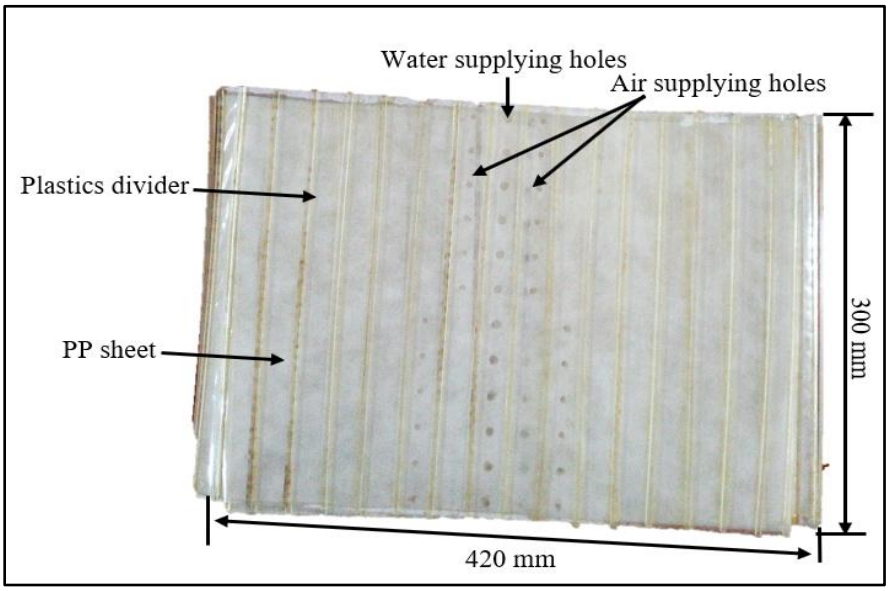


Figure 4. Dry channel of the HMX

In wet channels, fiber cloth is attached on opposite side of PP sheets. Plastics dividers with the width and height of 4 mm and length of 300 mm is joined on fiber side of PP sheets with the help of waterproof cementex bond. The distance between each divider is 21.4 mm. The holes of 6 mm are also created in between the polypropylene sheets which are supply water in wet channels. On both sides of water holes, 4 mm holes are created in four sub-channels. So, the working air is moved in wet channels through these holes as shown in Figure 5.

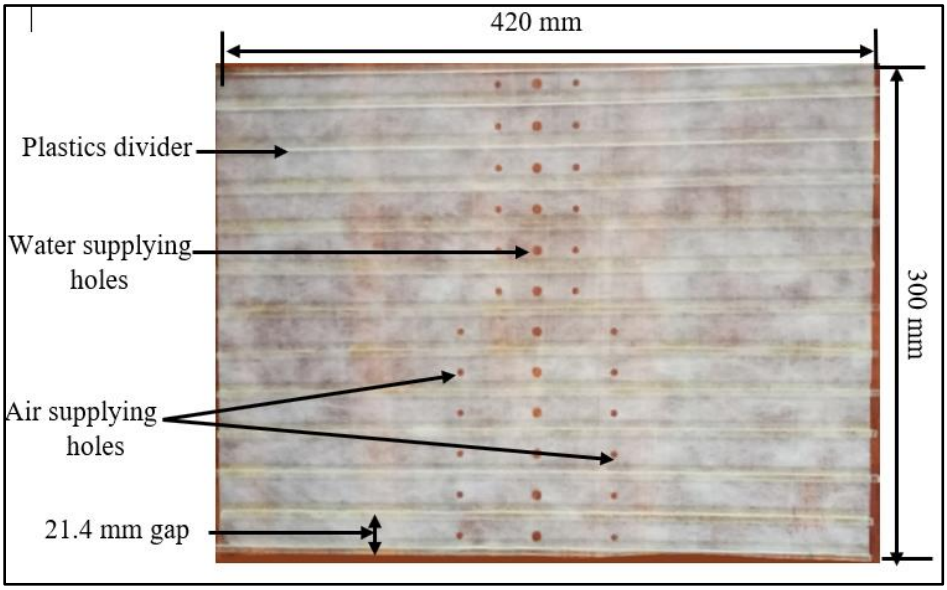


Figure 5. Wet channel of the HMX

Compact heat and mass exchanger is fabricated with inexpensive hygienic materials. HMX is made with 19 wet channels and 18 dry channels which has crossflow arrangements as shown in Figure 6.



Figure 6. Front view of compact HMX

EXPERIMENTAL SETUP

Using Air conditioning laboratory unit, having set required values of temperature and humidity. Dewpoint-IEC is evaluated under a wide range of temperatures which is varied from 33-49 ^{0}C while the other parameters like velocity (6.1 m/s) and water temperature (20 ^{0}C) are fixed. Although another parameter is relative humidity which is varied from 13-20% of dry air during the experimentation. Process air is supplied in dry channels which are being divided into two passages, one is working air and the other is product air. Product air is the useful conditioned air that is being used for desired goals. In addition, process air is moving through blocked dry channels and being forwarded into wet channels via holes along dry channels. This working air is exhausted into atmosphere after engrossing heat and water droplets due to evaporation in wet channels. Dewpoint-IEC is coupled at the outlet of the air conditioning laboratory unit as shown in Figure 7.

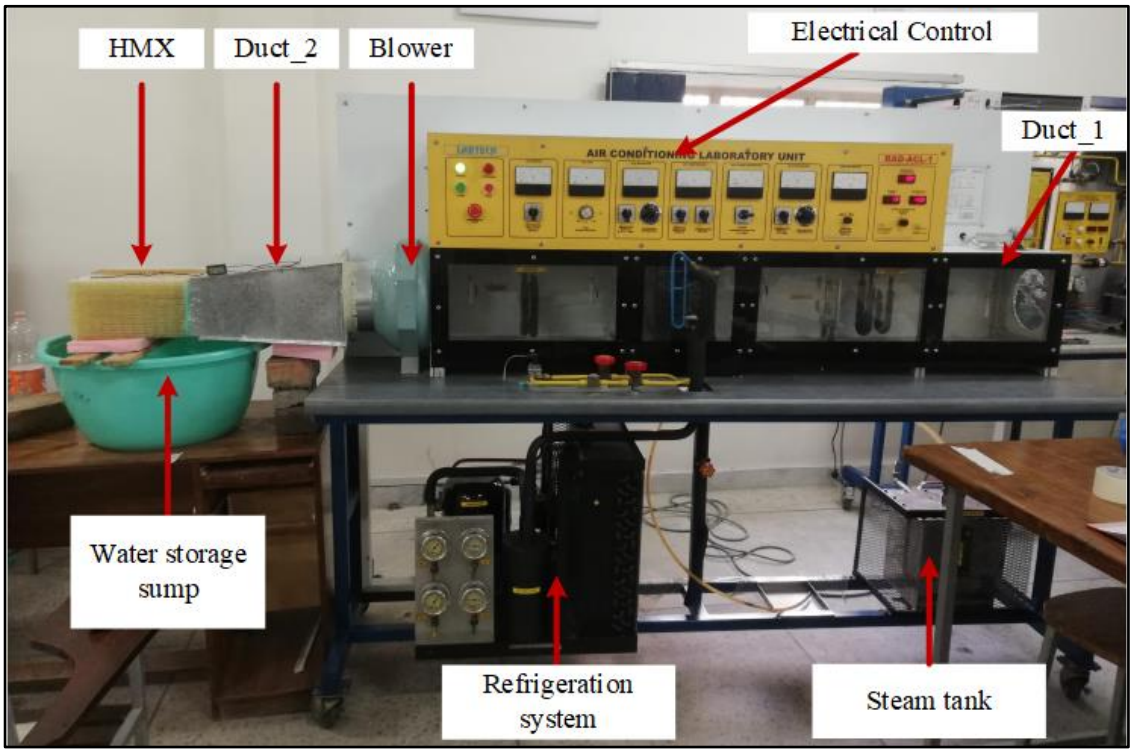


Figure 7. Experimental setup of Dewpoint-IEC with air conditioning laboratory unit

Dewpoint-IEC is also integrated with photovoltaic solar panel to fulfill the required power of the system. Dewpoint-IEC system consists of HMX, water pump, and axial fan which has a total power consumption of 70 W as shown in Figure 8. The power consumption for the axial fan and water pump are easily achieved by installing the 100 W PV solar panel setup.

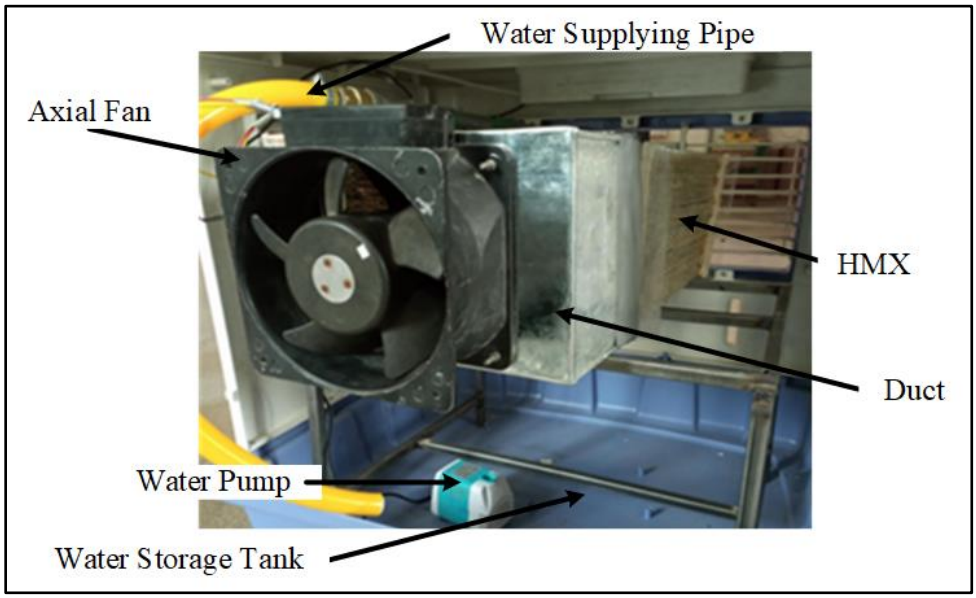


Figure 8. Experimental setup of Dewpoint-IEC integrated with PV solar panel

PERFORMANCE INDICATORS

In dry channels, the temperature drop of the product air is the key parameter of Dewpoint-IEC. So, temperature difference is measured by getting the difference of ambient temperature (T_a) and product air temperature (T_p).

$$\Delta T = (T_a - T_p) \tag{1}$$

While cooling capacity (CC) shows the ability of the system to handling the cooling load. It is calculated by the temperature difference product and mass flow rate of air ($\dot{m}$). Where, C_p is the specific heat at constant pressure.

$$CC = \dot{m} C_p (T_a - T_p) \tag{2}$$

Wet bulb effectiveness (ε_{wb}) of the system indicates up to what extent cooling effect is produced relative to wet bulb temperature of incoming process air. Similarly, dewpoint effectiveness (ε_{dp}) shows that to which extent cooling is achieved relative to the dewpoint of incoming air. The effectiveness of the system is calculated by using relations 3 and 4, respectively.

$$\epsilon_{wb} = \frac{\Delta T}{\Delta T_{wetbulb}} = \frac{T_a - T_p}{T_a - T_{wetbulb}} \tag{3}$$

$$\epsilon_{dp} = \frac{\Delta T}{\Delta T_{dewpoint}} = \frac{T_a - T_p}{T_a - T_{dewpoint}} \tag{4}$$

Coefficient of performance (COP) is the ratio of cooling capacity (W) and the power consumption (W) of the system. It is measured from the given Equation 5.

$$COP = \frac{CC}{\dot{W}_e} \tag{5}$$

The efficiency of Dewpoint-IEC is determined by the energy efficiency ratio (EER). It is measured by multiplying the 3.142 with COP of the system.

$$EER = 3.142 * COP \tag{6}$$

RESULTS AND DISCUSSION

In this research, an extensive experimental evaluation of dewpoint indirect evaporative cooler is performed. Initially, the experimentation of Dewpoint-IEC is performed under controlled conditions which is created by using the ACLU. The system is operated at constant air flow with different controlled ambient conditions.

Temperature Difference

Process air temperature is one of the key parameters. It is observed that the temperature drop of process air rises by rising the ambient temperature (T_a) at fixed values of velocity (V) and water temperature (T_w). The reason is that process air holds more water vapors at higher ambient temperature and lower RH as shown in Figure 9.

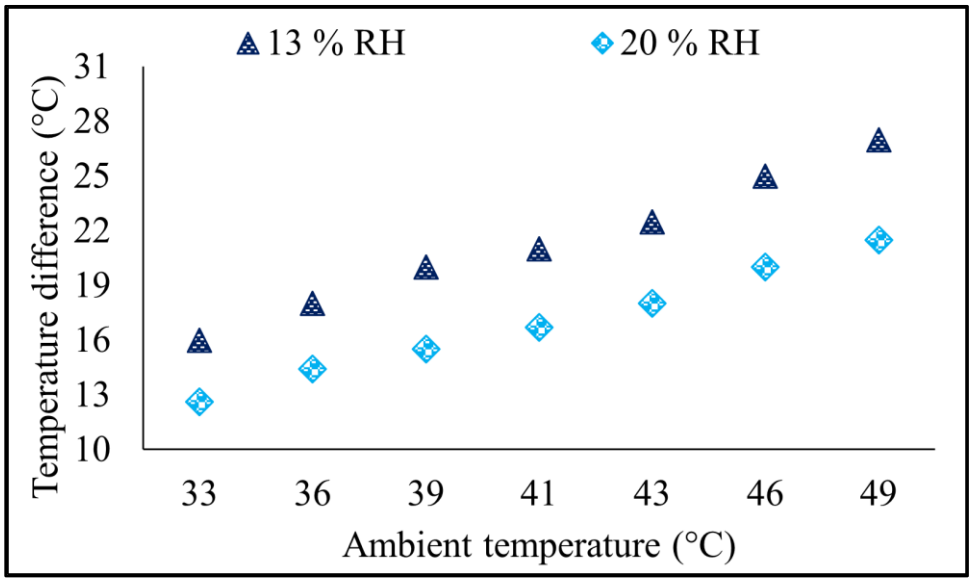


Figure 9. Temperature drops in dry channels at V=6.1m/s and T_w = 20 ^{0}C

Dewpoint Effectiveness

Dewpoint effectiveness is measured at different values of ambient air temperatures. It is observed that increasing the ambient air temperature and decreasing the relative humidity are more tendency to cause evaporation. Hence, the highest dewpoint effectiveness of the system is achieved at 49 ^{0}C temperature and 13% RH as shown in Figure 10.

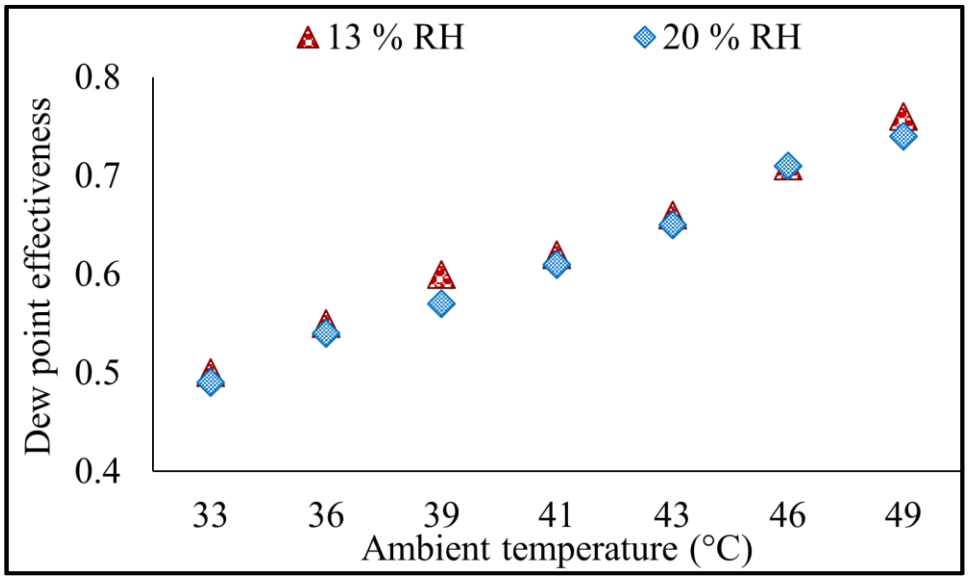


Figure 10. Dewpoint effectiveness at V=6.1m/s & T_w = 20 ^{0}C

Wet Bulb Effectiveness

Wet bulb effectiveness is also measured at various values of ambient air temperatures. It is also noticed that the wet bulb effectiveness increases with increasing the ambient temperature and decreasing RH of the air. Thus, the highest wet bulb effectiveness is achieved at 49 ^{0}C temperature and 13 % RH as shown in Figure 11.

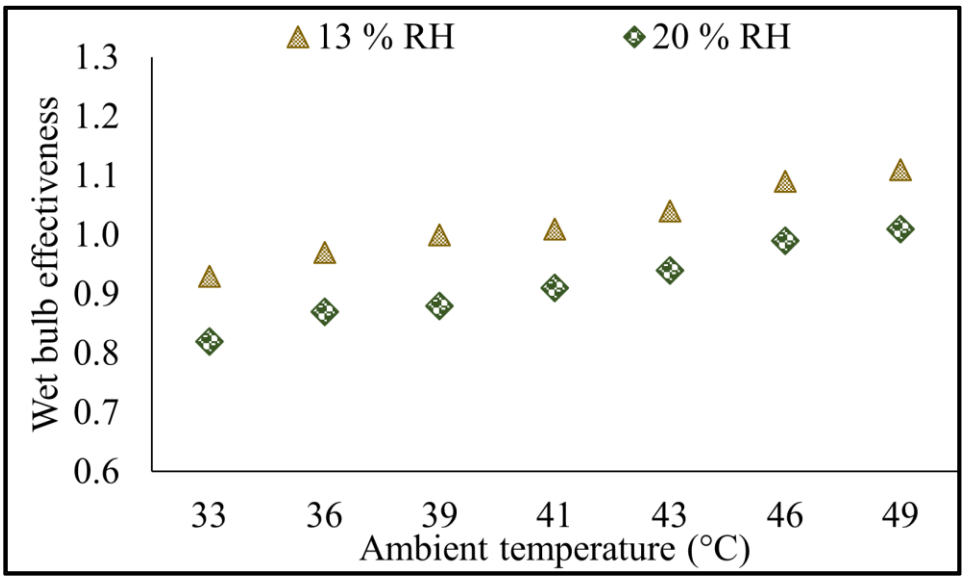


Figure 11. Wet bulb effectiveness at V=6.1 m/s and T_w = 20 ^{0}C

Cooling Capacity

CC of the system is calculated by using equation 2 with varying the ambient air temperature and it is compared at RH=13% and 20%. It is observed that raising the ambient air temperature

and decreasing RH give higher cooling capacity of the system at fixed values of velocity and water temperature. For the reason that the evaporation tendency of air is increased with rising the ambient air temperature and reducing the RH as shown in Figure 12.

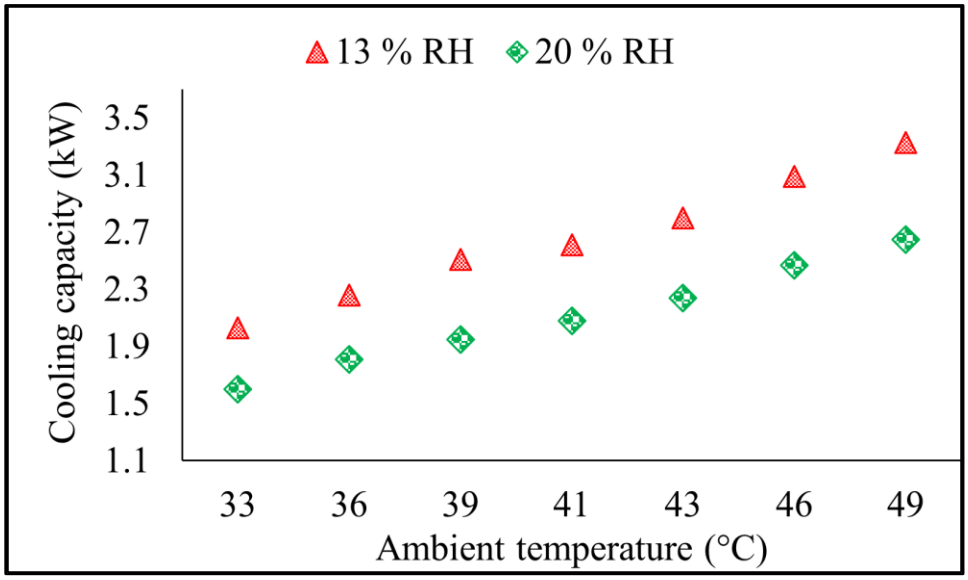


Figure 12. Variation of CC with ambient temperature (T_a) and RH

Coefficient of Performance

COP of the system is also determined by applying equation 5 with varying the ambient air temperature and it is compared at RH=13% and 20%. The maximum value of COP is measured at peak inlet parameters i.e., T_a= 49 ^{0}C, V=6.1 m/s, RH=13%, and T_w=20 ^{0}C. it is observed that increasing the cooling capacity is resulted in the higher value of COP as shown in Figure 13.

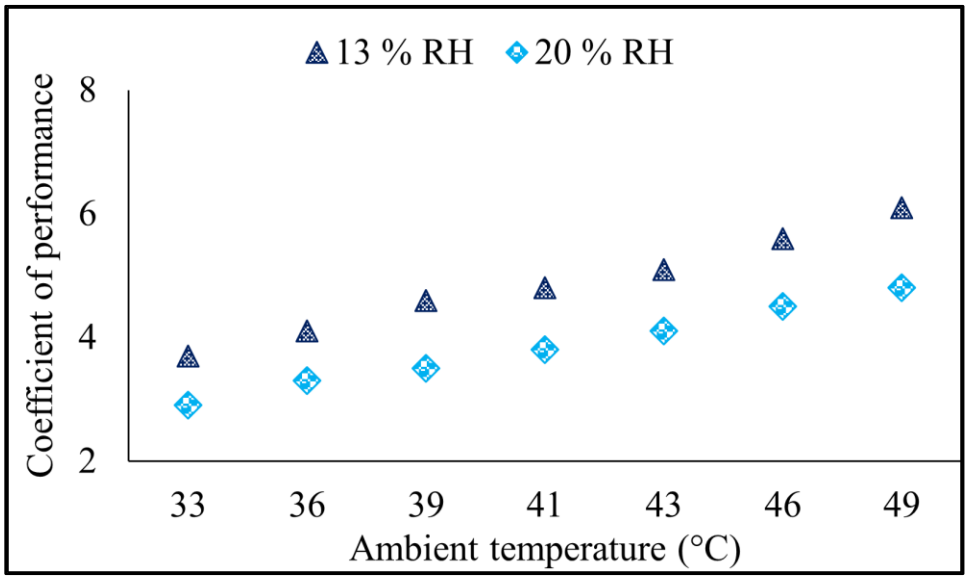


Figure 13. Coefficient of performance (COP) variation regarding to ambient temperature and RH of the air

Energy Efficiency Ratio

Energy efficiency ratio is calculated by using equation 6. It is observed that high COP resulting in high EER. EER is maximum at T_a= 49 ^{0}C, V=6.1 m/s, RH=13%, and T_w=20 ^{0}C as shown in Figure 14. It is found that the energy efficiency ratio rating is higher, the air cooler is more efficient. When Dewpoint-IEC has 12 EER rating is considered a better energy efficiency rating (An & Conditioner, 2006). Hence this system is more efficient.

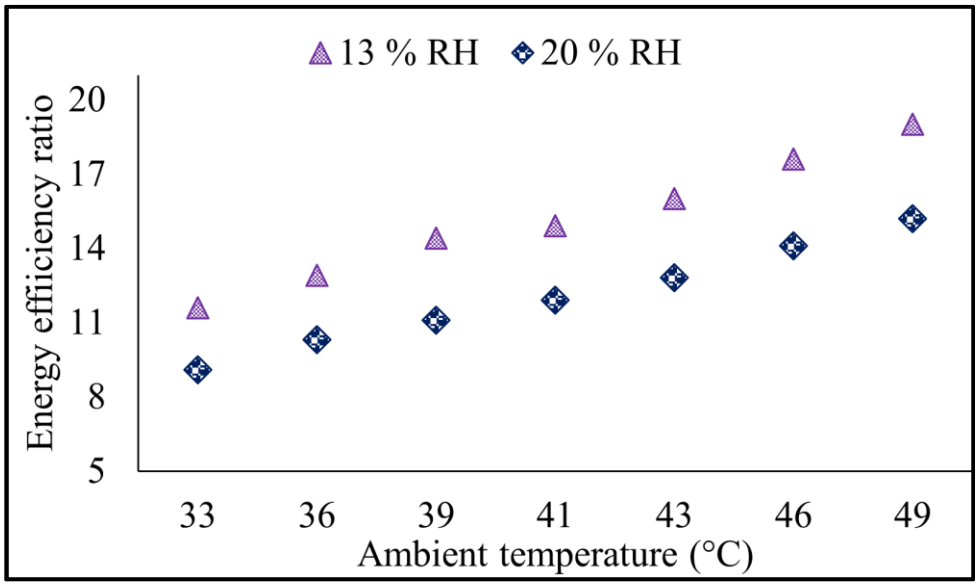


Figure 14. EER of the system

Velocity Distribution

The air velocity distribution through dry and wet channels as shown in Figure 15, which shows that how to process and working air flow in channels. Inlet air with velocity 6.1 m/s is supplied to dry channels of the Dewpoint-IEC which is divided into two passages like process air and working air. In dry channels, 4 sub-channels are blocked at the output side of the system. These blocked sub-channels helped to forward around 30% of inlet air to wet channels.

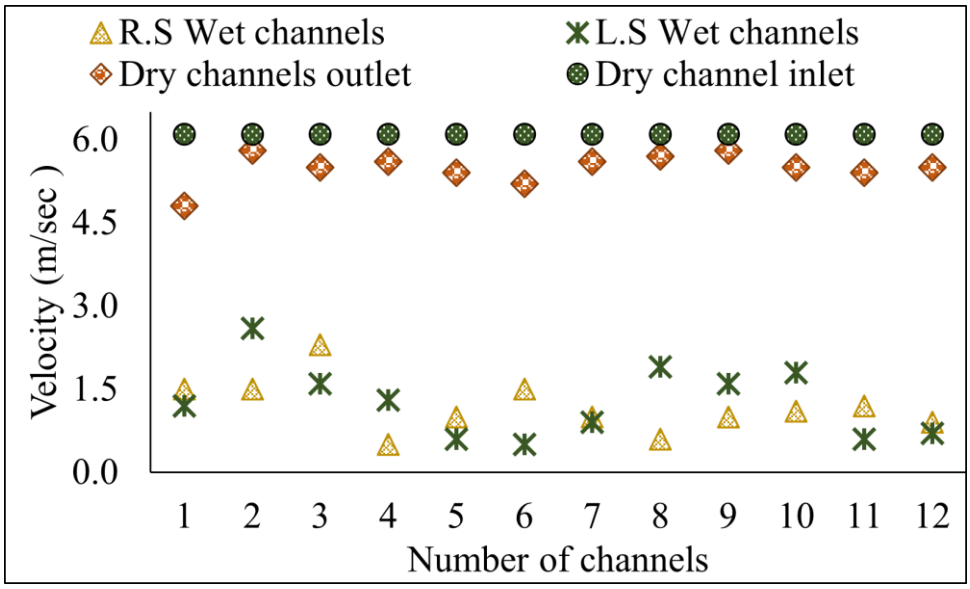


Figure 15. Process air distribution through wet and dry channels

System Comparison

The performance of Dewpoint-IEC is investigated experimentally under different controlled ambient conditions, and it is compared with published numerical study (Anisimov et al., 2014) of crossflow indirect evaporative cooler. It is noted that the measuring wet bulb effectiveness is varied from 0.84-1.15 while in this study, it is varying from 0.82-1.11. Hence, the maximum percentage error is found up to 3.48 %.

CONCLUSIONS

In this research, a thorough experimental investigation is performed. The inlet parameters like air temperature (33-49 ^{0}C) and relative humidity (13% and 20%) are varied under an extensive range of ambient conditions. The comparative investigations are in terms of COP, energy efficiency ratio, the effectiveness of wet bulb, and dry bulb. It is notifying that maximum product air temperature is achieved at T_a=49 ^{0}C, RH=13%, V=6.1 m/s, and T_w=20 ^{0}C. The higher temperature difference results in extreme values of CC, COP, and EER which vary from 1595-3334 W, 2.9-6.1, and 9.1-19, respectively. Another investigation is performed by integrated the Dewpoint-IEC with PV solar panel system. The required electrical energy of the system can be easily achieved by installing the PV solar system. The experimental results depict that Dewpoint-IEC can be energy efficient for cooling purposes. So, the high energy efficiencies of the system make it more feasible as compared to other conventional cooling systems.

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