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Performance Evaluation of Mist Spray Direct Evaporative Cooler through Experimentation

A. M. Deshmukh, S. N. Sapali
(Department of Mechanical Engineering, College of Engineering Pune, India)
(Mechanical Engineering Department, M.E.S. College of Engineering, Pune University, Pune, India)

Abstract:*In residential building, the comfort cooling system likethe air conditioning system is one of the major energy consuming appliances. Evaporative cooling systems are predominantly preferred as asubstitute to air conditioning systems sacrificing comfort to a certain level.The performance of a Mist Spray Direct Evaporative Cooler (MSDEC) is evaluated basically on four parameters viz. reduction in air temperature, saturation efficiency, cooling capacity, and noise level. This research article focuses on the development of MSDEC, its performance evaluation and comparison with the Conventional Evaporative Cooler with Honeycomb Pad Arrangement (CECHPA) under the same test conditions. Results indicate the performance of MSDEC is improved significantly in respect of drop in temperature, saturation efficiency and enhanced cooling capacity with a considerable saving in energy input, reduction in water consumption and noise level. The unit is almost free from fungus and mosquitoes as it requires no water storage.*

Keywords: *Mist nozzle, Evaporative cooling, Spinning disc*

I. Introduction

NOMENCLATURE

MSDEC	mist spray direct evaporative cooler
CECHPA	conventional evaporative cooler with the honeycomb pad arrangement
DBT	dry bulb temperature (^oC)
WBT	wet bulb temperature (^oC)
$\dot{m}$	mass flow rate (kg/s)
$C_{p\ air}$	specific heat of moist air (kJ/kg K)
T_1	DBT of inlet air in (^oC)
T_2	DBT of outlet air in (^oC)
T_3	WBT of inlet air in (^oC)
RH	relative humidity (%)
Q	cooling capacity (kW)
η	saturation efficiency (%)
ω	inlet air specific humidity in (kg/kg of dry air)
p_v	partial pressure of water vapor (kPa)
p_s	partial pressure at a saturated temperature of DBT (kPa)

INTRODUCTION

The contributions made by the researchers in the area of a MSDEC is discussed in the following text with the perspective of the understanding drop in temperature, saturation efficiency, cooling capacity, energy consumption, and noise level. The saturation efficiency of a MSDEC is the ratio of actual reduction in air temperature to the maximum possible reduction in air temperature. The cooling capacity of the cooler is nothing but the quantity of air cooled through the cooler which is the product of mass flow rate of air, specific heat of moist air and drop in temperature. It is nothing but the rate of heat removed from the air measured in kW. The noise level is measured by the sound meter. Igor et al. [1] have analyzed a numerical model having compact metallic air/water interface direct evaporative cooler to predict the outlet air temperature. The experimental results are compared with predicted results and observed with 1.33% maximum error. J.M. Wu et al. [2] have proposed a simplified correlation to find the cooling efficiency theoretically by investigating the exchange of energy and concentration among the air stream and water mist particles.Chenguang Sheng et al. [3] developed a practical relationship to analyze the performance of outlet frontal air velocity and cooling effect. The results indicate that the cooling efficiency is in proportion with the frontal air velocity. EI-Sayed G Khater [4] have developed a mathematical model of heat and mass transfer balance of an evaporative cooling pad to optimize the performance affecting parameters, also this model predicts the outlet air properties for different operating conditions. B. Riangvilaikul, et al. [5] havesimulated the heat and mass transfer process for the dew point evaporative cooling system. Kang Zhou [6] has performed the calculation to find evaporation rate of swamp coolers mostly used in arid regions and the mist spray evaporative cooler and remarked as the mist spray evaporative cooling is more efficient and effective in water and energy use. Chakrabarti et al.[7] have provided a one-dimensional model mass and energy balance to predict the effect of various parameters as feeding water temperature, air flow rate, and air humidity ratio on air temperature inside the air washer heat exchanger. CraigFarnham et al. [8] have experimentally investigated the cooling effect produced by the oscillating mist fan in a large indoor space and recorded the drop in temperature by 0.2 to 2.5 K with 5% rise in local humidity. Akintunji et al. [09] have studied the theoretical model of feasibility index to evaluate the month wise potential of the evaporative cooler in Niamey, Niger Republic. The feasibility index depends on the difference between the wet bulb temperature and the wet bulb depression (the difference between the DBT and WBT) and it helps to decide whether evaporative cooling gives the comfort cooling or not. Kachhwaha et al.[10] have developaed a two dimensional numerical model for predicting the heat and mass transfer in a mist spray of water and the air stream moving in the parallel direction in the duct. The conservation of mass, momentum,and energy equations are simulated for water and air. The literature review it is observed that by using the rotary disc and low-pressure mist nozzle combination is used for mist generation for evaporative cooling is not yet reported. The objective of the current research is to develop a MSDEC by using a rotary disc and low-pressure mist nozzle. Further, this research focuses on the experimental analysis of a MSDEC for a drop in temperature, saturation efficiency, cooling capacity, energy saving, reduction in noise level, and maintain the hygienic conditions.

CECHPA made from cellulose material in order to get a large surface area per unit volume. The honeycomb pad arrangement has a great effect on the water absorption and evaporation process, but it has certain limitations as these honeycomb pad arrangement restricts air flow and increases the pressure drop. To maintain the required air delivery, the only alternative left is to increase the fan speed which leads to an increase in power consumption. To get an efficient cooling, a proper water distribution system on the cooling pad is also required which needs a small pump. Cooling pads are not durable and need frequent cleaning and also its cost is very high. To overcome these limitations, authors have replaced the honeycomb pad arrangement by a mist nozzle, hence the obstacles to the air flow is removed, so no need to increase the fan speed to maintain the required air delivery which saves the energy consumption. The air to water contact surface area is enhanced by generating a fine mist by using the mist nozzle which works on low pressure and a spinning disc. No additional input energy is required to the nozzle and the spinning disc to generate the fine mist which leads towards the energy saving and noise control. Due to more contact surface area, evaporation rate increase which leads to a maximum drop in air temperature and increases the saturation efficiency and cooling power.

II. Mist Nozzle

The nozzle comprises a nozzle body, a swirling element called microturbine, an orifice; which are designed, manufactured and tested. A swirling element isfixed in the nozzlebody in order to give a spinning effect to the water. Orifice disc helps to speed up water flow through the nozzle. Because of this nozzle assembly, water pressure reduces which is sufficient to generate mist water particles. Due to good machining properties, mist nozzle is developed from the brass. Fig. 1 shows a photograph of such a mist nozzle.

Fig. 1: Photograph of a Mist nozzle

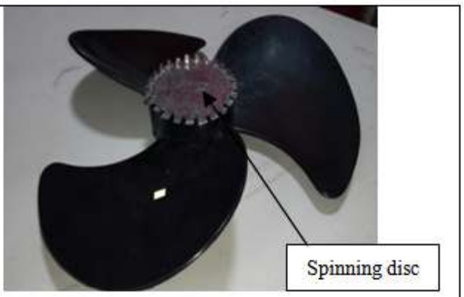

Fig. 2: Spinning disc

The assembly of the mist nozzle is inserted into the suitable diameter PVC pipe. The city tap water pressure in the range of 4 to 8 bar is sufficient to generate mist spray of the water.

III. Development Of Rotating Disc

The rotatingdisc promotes to create a fine mist available from the nozzle. In MSDEC, the rotating disc is one of the major components used, which is connected to the hub of the fan blade as shown in Fig. 2. Rotating disc has extended surfaces along its circumference which promotes shearing of water into fine particles and enhances the surface area of water for evaporation. The salient feature of this rotating disc is that it does not require additionalenergy for its rotation as it is fixed to the hub of the fan blade.

IV. The Concept Of Film Evaporation And Drop Evaporation

The rate of evaporation depends upon the surface area of contact between the air stream and water particles or wetted surface area. The honeycomb pads provide film evaporation, as a water film is formed along the surface of the honeycomb pad. And its increased surface area enhances the rate of evaporation. The wetted surface area of the honeycomb pad is equal to $370m^2/m^3$. In the given experimental setup the total wetted surface area is $3.544\ m^2$ actual photograph of the honeycomb pad is as shown in Fig. 3.The major drawback of this honeycomb pad is its increased surface area creates a pressure drop to the air flow, scaling is deposited on its surface and it affects the evaporation rate of the water. To overcome these issues, authors have replaced the film evaporation process by fine mist generation and such evaporation process significantly increases the rate of evaporation than the film evaporation. Smaller is the droplet size; greater is the rate of evaporation and to achieve the smaller droplet size, a mist spray nozzle,and the spinning disc is used to generate fine mist spray at a very low pressure of water. In fine mist evaporation method, each fine water particle is covered with an air stream to exchange the heat, which helps to enhance the cooling capacity evaporating water particles rapidly.and finally the cooling capacity of the system. The rotating disc and nozzle arrangement in the casing are shown in the (Figure 5). In MSDEC, due to the absence of honeycomb pad, there is no pressure loss of air, no scaling of dust and impurities in the water. The air is freely taken inside by the fan and forced into the casing to mix with the fine water particles gives more cooling effect with less rate of energy consumption.

Fig. 3: DECHPA represents film evaporation

V. Test Facility

The schematic diagram of the test facility is as represented in(Figure 4). The air stream properties liketemperatures, relative humidity and mass flow rate of air are recorded by using sensor band (5) and (6) respectively. Sensor bands are joined to the data acquisitions system to record the observations.

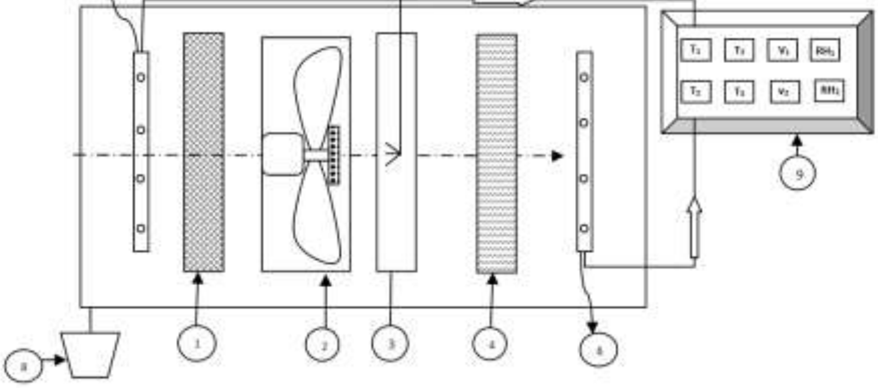

Fig. 4: Schematic diagram of the test facility

1 Air filter
2 Rotating disc and fan blade assembly
3 Mist nozzle
4 Air diverter
5 Sensors band at the inlet section
6 Sensors band at the outlet section
7 Water tray
8 Drain water tray
9 Data acquisition system

The cooling capacity of the MSDEC is depending upon therate of water evaporation. The water evaporation rate in the cooler is a function of air stream properties and the free contact surface between the inlet air stream and mist water particles.In the present work, we have promoted the dropwise evaporation instead of film wise evaporation as used in conventional desert coolers having honeycomb pad as a cooling media as is the only option for improving the cooling capacity of MSDEC. In the developed MSDEC, enhancement in air-water contact surface area is achieved by using specially developed innovative rotating disc and mist nozzle assembly.

Fig.5 Developed MSDEC

Developed MSDEC is shown in Fig.5consists of an axial fan having a blade diameter of 225mm and a having the speed range of 750 rpm to 2200 rpm. MSDEC is having a volume flow rate of 700 cfm. It consumes the maximum power of 87 W. The length, width and height of the MSDEC are 390mm x 390mm x 590mm respectively. The face diameter of the outlet end of MSDEC is 300mm. This system is having a watersupply storage tray of 5-liter capacity. A water storage tray is fitted above the system and mist nozzle is joined to the storage tray through a rigid pipe. A water flow regulating valve is also provided between the storage tray and the nozzle pipe.

5.1. Experimental Procedure

Initially, ambient air stream properties are noted at the inlet section.The airs mass flow rate is regulated by varying fan motor speed through the voltage regulator. Water flow is controlled through a water flow regulating valve, which is located between the water storage tray and nozzle pipe. Drop in temperature of the air is measured keeping the water flow rate constant. Temperature is measured with a digital temperature indicator having the accuracy of (± 0.5^0C). Other parameters like RH, WBT, and air velocity are measured by using an instrument having the facility to measure air velocity, ambient temperature,and humidity. Energy consumption is measured by using a digital energy meter. Performance measuring parameters such as a fall in temperature, saturation efficiency, cooling power, energy consumption, and noise level is measured at different ambient conditions and mass flow rates. Under the same test conditions, the performance analysis of the same size and capacity of CECHPA is carried out. Obtained results are used to carry out the comparative study.

The performance parameters, cooling capacity,and saturation efficiency, of the cooler, are calculated by using the following equations 1 and 2.

Cooling power/capacity, $$Q = \dot{m}\, C_{p\ air}\ (T_1 - T_2) \tag{1}$$

Saturation efficiency, $$\eta = \frac{T_1 - T_2}{T_1 - T_3} \qquad (2)$$

VI. The Goodness Of The Experiment

Saturation efficiency is one of the performance measuring parameters of the MSDEC. It is the function of measurable properties of the air such as temperature, velocity,and the relative humidity. Details of the TESTO 410-2, air velocity with ambient temperature and humidity instrument used for the measuring these properties are as given in Table 1.

Table 1: Technical specifications of the instrument

Instrument make: TESTO		Model: 410-2
Parameter	Range	Accuracy
Temperature	-10 to 50 °C	± 0.5°C
Relative humidity	0 to 100 %	± 2.5 %
Velocity	0.4 to 20 m/s	± 0.4 m/s

The absolute uncertainty i.e. the goodness of the experiment is measured by using the Weakest Link Rule. The absolute uncertainty of the systemis the largest relative uncertainty recorded from all measured relative uncertainties is considered. As shown in Table 2, the largest relative uncertainty is 8.33% for a set of sample observation as given below in Table2.

Table 2: Sample observation to measure the goodness of the experiment

Property of air	Value with absolute uncertainty	Relative uncertainty %
Temperature	(35±0.5) °C	0.5/35 = 0.0142 = 1.42
Relative humidity	(30± 2.5) %	2.5/30 = 0.0833 = **8.33**
Velocity	(5± 0.4) m/s	0.4/5 = 0.08 = 8.00

For the given set of experimental readings, the saturation efficiency is 72% with the uncertainty of 8.33%, it represents the experimental method and setup is in good order and results are as expected.

VII. Experimental Results and discussion

Experimentally the performance evaluation of the MSDEC and CECHPA is carried out. Tests are conducted by changing the mass flow rates of air. The effect of the mass flow rate of air on the drop in temperature of the air is shown in Fig. 6. The drop in temperature of the MSDEC is improved by about 10 to 25% compared to CECHPA. The combined effect of mist nozzle and rotating disc produces fine water particles which are further sheared and are carried through the air stream leading to increased evaporation of water particles. This not only increases the drop in temperature but also improves the cooling effect. This could be mainly attributed to an increased evaporation rate with increasing mass flow rate.

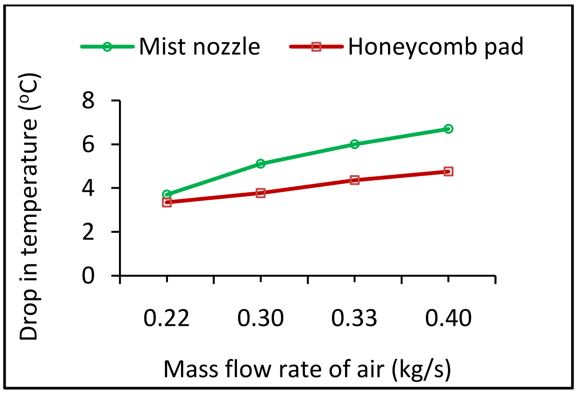

Fig.6. Comparison of the drop in temperature of MSDEC and CECHPA at a differentmass flow rate of air

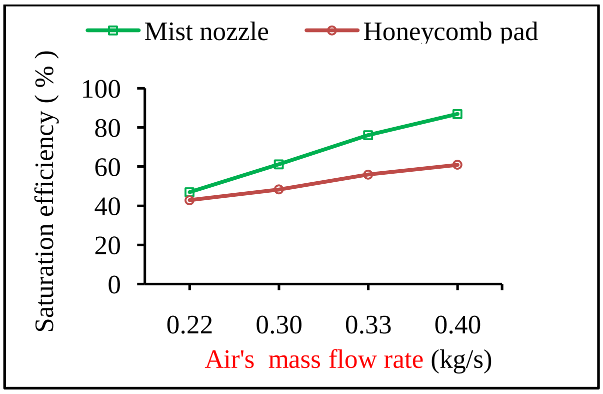

Fig. 7. Comparison of saturation efficiency of MSDEC and CECHPA at a differentmass flow rate of air

As represented in Fig. 7 it is observed that the saturation efficiency of MSDEC is higher in the range of 10 to 40% compared to the CECHPA. Increase in contact surface area between the air and water particles on account of a mist nozzle and rotating disc arrangement is the reason for higher saturation efficiency. Also, the mass flow rate influences the atomization of drops and drop size. The comparison of the cooling capacity of the MSDEC and CECHPA for different mass flow rates of air is presented in Fig. 8. The experimental results show the cooling capacity of a mist spray direct evaporative cooler is in the order of 10 to 40 % higher than that of the CECHPA.

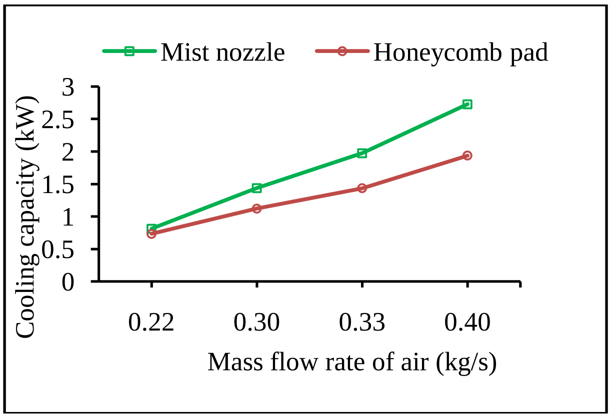

Fig.8. Comparison of the cooling capacity of MSDEC and CECHPA at a various mass flow rate of air

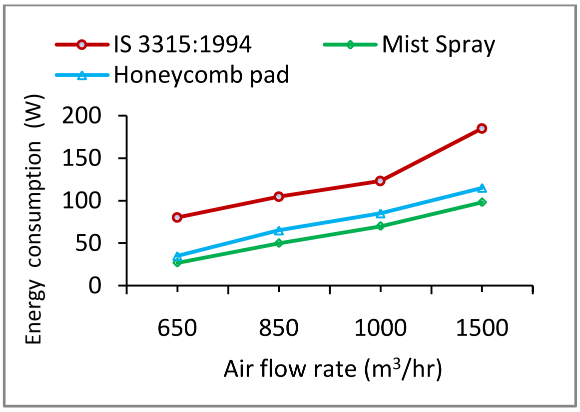

Fig. 9. Comparison of energy consumption of MSDEC, CECHPA and IS 3315:1994 at a various volume flow rate of air

According to IS 3315: (1994) standard, the energy consumption rate of an evaporative cooler should not more than 185 W for 1500 m^3/hr [11]. The developed MSDEC consumes energy at the rate of 84 W for 1500 m^3/hr of air flow and CECHPA consumes energy at the rate of 93 W for the airflow of 1500 m^3/hr. As shown in Fig. 9 the power required for the MSDEC is almost 50 % less than the standard maximum permissible limit and about 10 % less than the rate of energy consumption of CECHPA.

VIII. Conclusions

Comparative performance analysis of a MSDEC and the CECHPA is experimentally carried out. Developed MSDEC shows significant improvement in system performance with a reduction in energy consumption.
With the support of these experimental results, the followingoutcomes are drawn.

- Drop in air temperature obtained with developed MSDEC is 10 to 35 % higher than that of CECHPA.
- Saturation efficiency and cooling capacity of a MSDECis increased in the range of 10 to 40% than the CECHPA due to its higher air to water surface area of contact for a various mass flow rate of air.
- Lower energy consumption by 10 to 20 % at various volume flow rate than that of CECHPA highlights the energy-efficient performance of the MSDEC.
- The noise level of the MSDEC is 62dBA against the sound level of 70dBA of CECHPA, which is about 10% less than the CECHPA.
- The size of the MSDEC for the same volume flow rate of air is 40% smallerthan of CECHPA.

  For the aridregion, this energy efficient system may contribute to resolving the issues existing in CECHPArelated to hygiene, durability,and economy with enhanced comfort cooling.

Conflict of interest The authors declare that there is no conflict of interests regarding the publication of this paper.

References

[1]. Igor Kovacevic, Maarten Sourbron, The numerical model for a direct evaporative cooler, Applied Thermal Engineering, (2016)
[2]. J.M. Wu, X. Huang, H. Zhang, Theoretical analysis on heat and mass transfer in a direct evaporative cooler, Applied Thermal Engineering, Issue 29, (2009) 980-984
[3]. Chenguang Sheng, A. G. Agwu N nanna, Empirical correlation of cooling efficiency and transport phenomena of a direct evaporative cooler, Proceedings of the ASME 2011 International Congress and Exposition IMECE2011, Denver, Colorado, USA
[4]. EI- Sayed G. Khater, Performance of direct evaporative cooling system under Egyptian conditions, Journal of Climatology & Weather Forecasting, Volume 2, Issue 2, (2014)
[5]. B.Riangvilaikul, S. Kumar, An experimental study of a novel dew point evaporative cooling system, Energy and Buildings, 42 (2010) 637-644

[6]. KangZhou,Calculationof Evaporation rate of a droplets cluster and conceptual design of structure utilizing water droplets for evaporation, Hydrol Current Res, volume 5, Issue 3,(2014)177

[7]. S. S. Chakrabarti, L. R. Bhandarkar, AnuragVijawargiya, P. S. R. K. NageshwarRao, A mathematical approach in the formulation of a direct evaporative cooling device, International Journal of Engineering Research & Technology (IJERT) Volume 4, Issue 02, (2015)

[8]. CraigFarnham, Lili Zhang, Jihui Yuan, Kazuo Emura, Ashraful M. Alam and Takeo Mizuno, Measurement of the evaporative cooling effect: oscillating misting fan, Building Research & Information, (2017)

[9]. Lateef L. Akintunji, Ibrahim U. Haruna, Bello S. Momoh, Theoretical evaluation of the potential of evaporative cooling for human comfort using feasibility index (Fi) model, International Journal of Scientific & Technology Research, Volume 3, Issue 3, (2014)

[10]. S. S. Kachhwaha, P. L. Dhar, S. R. Kale, Experimental studies and numerical simulation of evaporative cooling of air with a water spray-I. Horizontal parallel flow, International Journal of Heat and Mass Transfer, Volume 41, Issue no 2, (1998) 447-464

[11]. IS 3315 (1994): Evaporative Air Coolers (desert coolers) [MED 3: Mechanical Engineering]

[12]. ISHRAE Refrigeration Handbook pp 7.1 to 7.6 - 2015