

Indirect Evaporative Cooling Applications: A Review

Avinash Pandey¹ Dr. P.K .Jhinge²

¹M.E Student ²Principal

^{1,2}Jabalpur engineering College, Jabalpur

Abstract— The evaporative air cooler is theoretically investigated in this paper. The novel dew point evaporative air cooler, based on counter-flow closed loop configuration, is able to cool air to temperature ambient wet bulb temperature and approaching dew-point temperature. A computational model on heat exchanger for the cooler has been developed. Employing the validated model, we studied the heat exchanger performance due to effect of (i) varying channel dimensions; (ii) employing room return air as the working fluid. Using these means, we have demonstrated improved performance of the dew-point cooler enabling it to achieve higher efficiencies.

Key words: Indirect evaporative cooling, Heat and mass transfer, Numerical simulation, Air conditioning.

I. INTRODUCTION

Evaporative cooling, a potential alternative to the mechanical vapor compression system, has gained growing attention for use in air conditioning. Evaporative cooling is a cost saving and environmentally-friendly method because the working fluid are water and air. Two basic type of conventional evaporative cooling system for air conditioning are direct evaporative cooling system and indirect evaporative cooling system. In a direct evaporative cooling system, the air has a direct contact with water so that the product air can be cooled and humidified simultaneously due to water evaporation. In an indirect evaporative cooling system, which usually has some type of heat exchanger, the air can be cooled without absolute humidity change since the product air is kept separate from evaporation process (1, 2). Compared with the mechanical vapor compression system which currently dominates the air conditioning market, the evaporative cooling system has following advantages (3-7): (i) extensive savings on energy and cost; (ii) reduction in peak power demand; (iii) no CFCs uses;(iv) reduction in pollution emission; and (v) easy integration with built-up-system. However, conventional evaporative cooling system has several limitations: (1) increase in air humidity in direct evaporative cooling system resulting in air conditioning that are uncomfortable for human; (2) low cooling effectiveness of indirect evaporative cooling system[8]; and (3) temperature of the eventual cooled air is limited by the wet bulb temperature. In order to overcome these drawbacks of conventional evaporative cooling system, researchers have investigated possible methods to modify the configuration of cooler so that the outlet air temperature can be reduced to below its wet-bulb temperature and approaching to its dew-point temperature(9,10).

II. LITERATURE REVIEW

The following papers have been studied and referred on the work done:

A. Aftab Ahmad, Shafiqur Rehman, Luai M. Al-Hadhrami(2013)

The study investigated the performance of a 5-ton capacity indirect evaporative cooler under controlled environmental conditions (43.9°C dry bulb temperature and 19.9% relative humidity) but for different air flow rates (631 to 2388 m³/h). The experimental results showed that the intake air energy efficiency ratio of the cooler varied from 7.1 to 55.1 depending on test condition and air flow rate. The power consumption of indirect evaporative cooler was found to vary from 68.3 to 746 watts. Water consumption was found to vary between 0.0160 and 0.0598 m³/h. At full fan speed, an average of 58.7% of total water consumed by indirect evaporative cooler was evaporated. The results indicated that intake air energy efficiency ratio was directly proportional to the wet-bulb depression. The study also showed that indirect evaporative cooler is suitable for hot and dry climatic conditions.

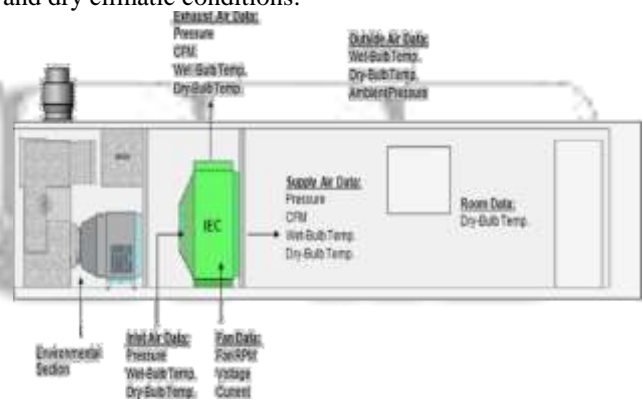


Fig.1: Schematic Diagram of the IEC Testing Chamber.

1) Result

In this paper, the performance of the indirect evaporative cooler was evaluated for different test condition at variable fan speed. It can be concluded from the test results that the indirect evaporative cooler provides low cost evaporative cooling without adding moisture to the air supplied to the conditioned space. The indirect evaporative cooling system can achieve wet bulb effectiveness more than 100% because theoretically the limiting value of supply air temperature to the conditioned space is the dew point temperature of the intake air. The test results indicate that intake air energy efficiency ratio of indirect evaporative cooler is directly proportional to wet-bulb depression. The study shows that the indirect evaporative cooler is mostly suitable for hot and dry climatic conditions. In order to improve the existing system, following recommendations are made and being considered in our future works as well. The existing system requires initial soaping of the heat exchanger units which could be avoided by using different and suitable heat exchanger material. Moreover, the existing system is suitable only for hot and dry climatic conditions. It could also be used in humid condition as well if the inlet air can be

conditioned by suitable air conditioning mechanism such as liquid desiccant system or desiccant wheel.

B. Joohyum Lee, Dea-Young Lee(2013)

A regenerative evaporative cooler has been fabricated and tested for the performance evaluation. The regenerative evaporative cooler is a kind of the indirect evaporative cooler comprised of multiple pairs of dry and wet channels. The air flowing through the dry channels is cooled without any change in the humidity and at the outlet of dry channel a pair of air is redirected to the wet channel where the evaporative cooling take place. The regenerative evaporative cooler fabricated in this study consists of the multiple pairs of finned channels in counter flow arrangement. The fins and heat transfer plates were of aluminum and brazed for good thermal connection. This porous layer coating was applied to the internal surface of wet channel to improve surface wet ability. The regenerative evaporative cooler was placed in climate chamber and tested at various operation conditions. The regenerative evaporative cooler was placed in climate chamber and tested at various operation conditions. The cooling performance is found greatly influenced by the evaporative water flow rate. To improve cooling performance, the evaporative water flow rate needs to be minimized as far as even distribution of the evaporative water is secured. At the inlet condition of 32°C and 50% RH, The outlet temperature was measured at 22°C which is much below the inlet wet-bulb temperature of 23.7°C.



Fig. 2: Schematic of Regenerative Evaporative Cooler.

1) Result

In this study, counter flow fin-inserted regenerative evaporative cooler is fabricated and its cooling performance has been examined experimentally under various operating conditions. Aluminum fin and heat transfer plate are assembled by brazing and porous layer treatment is applied on the wet channel to enhance wet ability. The experimental result is compared with numerical analysis. From the experimental and numerical analysis, following conclusion are obtained.

- (1) It is required to minimize the flow rate of evaporative water within the limit of uniform water distribution in the wet channel because the cooling performance is greatly reduced as the evaporation water flow rate increases.
- (2) The cooling capacity is maximum when the extraction ratio from dry channel to wet channel is 0.3.
- (3) The intake air can be cooled lower than its wet-bulb temperature by regenerative evaporation cooler. The supply air of 22°C is obtained when the intake air condition is 32°C, 50% RH (23.7°C wet-bulb temperature).

- (4) The pressure drop in wet channel stays invariant whether the evaporation water supply or not.

C. Hamid Montazeri, Bert Blocken, Jan L.M. Hensen(2014)

The evaporation of droplets in a turbulent two-phase flow is of importance in many engineering applications. Water droplet evaporation in spray system, for example, is increasingly used in public spaces and near building surfaces to achieve immediate cooling and enhance the thermal comfort in indoor and outdoor environments. The complex two phase flow in such a system is influenced by many parameters such as continuous phase velocity temperature and relative humidity, drop size distribution velocity and temperature of the droplets continuous phase droplet and droplet-droplet interactions. Most of these parameters are not easily varied independently. To gain insight into the performance of the system, however, detailed knowledge of the impact of every parameter is important. Computational fluid Dynamics (CFD) is a useful tool for performing such parametric analyses. To the best of our knowledge, a detailed analysis of the cooling performance of a water spray system under different physical condition has not yet been performed. This paper provides a systematic parametric analysis of the evaporative cooling provided by a water spray system with a hollow cone- nozzle configuration. The analysis is based on grid-sensitivity analysis and validation with wind-tunnel measurements. The impact of several physical parameters is investigated: inlet air temperature, inlet air humidity ratio, inlet air velocity, and inlet water temperature and inlet droplet size distribution. The results show that for a given value of a inlet water temperature (35.2 °C), as the temperature different between the inlet air and inlet water droplets increases from 0 °C to 8°C , the sensible cooling capacity of the system improve by more than 40%. In addition, injecting water droplets with a temperature higher than the dry-bulb temperature of the air can still provide cooling, although the amount of cooling reduces considerably compared to the case with water at lower temperatures.

D. Hsiu-Che Wang, Alexander V. Mamishev(2012)

Electro spray evaporative cooling (ESEC) has been investigated as the potential thermal management solution for future electronics. However, the optimal heat transfer performance of ESEC chamber has not yet been thoroughly examined. This paper investigated optimal heat transfer performance of ESEC chamber with different types. The geometry types affect the ESEC chamber heat transfer performance in different ways. Although increasing the quantity of the micro nozzles and the spacing between them does not improve the steady state heat transfer performance, a higher quantity of micro nozzles with increased spacing noticeably enhances the transient cooling rate. Additionally, certain practical design issues are discussed.

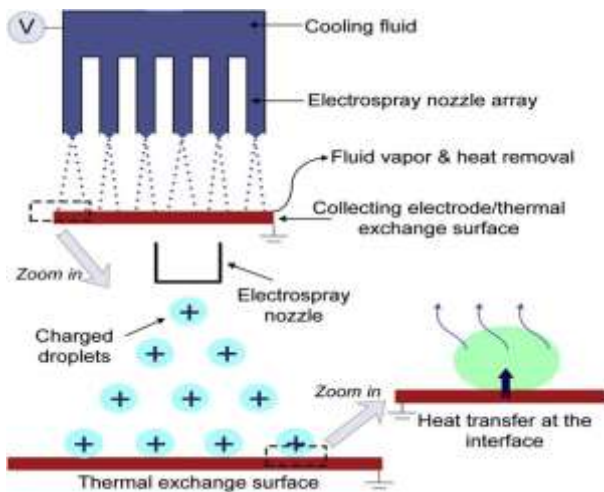


Fig. 3: Schematic Diagram Showing the Operating Principle Behind the ESEC Chamber.

1) Result

The experimental results show that for the same kind of ESEC chamber, the heat transfer performance at different heat fluxes is distinct. At the same heat flux, the enhancement ratio increases when the working fluid flow rate (Weber number) and applied potential (electric Weber number) are increased. The 4-nozzle chamber with 6 mm spacing achieves the maximum enhancement ratio 1.87 among the 8-nozzle chambers. Furthermore, among all ESEC chambers, the maximum enhancement ratio of 1.87 was achieved by 8-nozzle chamber with 5 mm spacing at the lowest heat flux. According to the average thermal resistance, regardless of micro nozzle spacing on the ESEC chamber, higher heat flux results in higher average thermal resistance. The lowest average thermal resistance of 8.5 K/W was achieved by 8-nozzle chamber with 5 mm spacing. The average cooling rate analysis shows that 4-nozzle chamber with 6 mm spacing. The comparison between the maximum achievable enhancement ratio and the maximum cooling rate among ESEC chamber indicates that the average cooling rate is not directly related to the achievable maximum enhancement ratio. Although increasing the spacing and quantity of micro nozzles on the ESEC chamber does not have an obvious improvement on the maximum achievable enhancement ratio and the lowest average thermal resistance, increasing the spacing and quantity of micro nozzles noticeably improves the highest transient cooling rate.

III. CONCLUSION

During studying these paper I was found that effectiveness of heat exchanger for indirect evaporation cooling increased, and further more research have investigated to modify the configuration of the cooler. Recently researchers are working on indirect evaporative cooler to improve its effectiveness so that outlet air temperature can be reduced to below its wet-bulb temperature (the limit of conventional cooling) and approaching its dew-point temperature.

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