Review of Direct Evaporative Cooling System With Its Applications

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Abstract-- Evaporative cooling is an energy efficient and environmentally friendly air conditioning technology. Direct evaporative cooling systems is a technology which involves adiabatic humidification and cooling of air with supplementary heat exchange facilities to lower final air temperature and try to reduce relative humidity. This concept is enhanced in all engineering fields due to its characteristics of zero pollution, energy efficiency, simplicity and good indoor air quality. This cooling effect has been used on various scales from small space cooling to large industrial applications. An extensive literature review has been conducted. The review covers direct evaporative cooling design criteria, applications, advantages and disadvantages. Experimental and theoretical research works on feasibility studies, performance test and optimization as well as heat and mass transfer analysis are reviewed in detail.

Keywords: Evaporative cooling, Design, Applications, Performance test, Optimization, Humidity, Air Conditioning

INTRODUCTION

Evaporative cooling is the process by which the temperature of a substance is reduced due to the cooling effect from the evaporation of water. The conversion of sensible heat to latent heat causes a decrease in the ambient temperature as water is evaporated providing useful cooling. Effective cooling can be accomplished by simply wetting a surface and allowing the water to evaporative. Evaporative cooling occurs when air, that is not too humid, passes over a wet surface; the faster the rate of evaporation the greater the cooling.[1]When considering water evaporating into air, the wet-bulb temperature, as compared to the air's dry-bulb temperature, is a measure of the potential for evaporative cooling. The greater the difference between the two temperatures, greater the evaporative cooling effect. Evaporative coolers provide cool air by forcing hot dry air over a wetted pad. The water in the pad evaporates, removing heat from the air while adding moisture. When water evaporates it draws energy from its surroundings which produce a considerable cooling effect. In the extreme case of air that is totally saturated with water, no evaporation can take place and no cooling occurs [2].

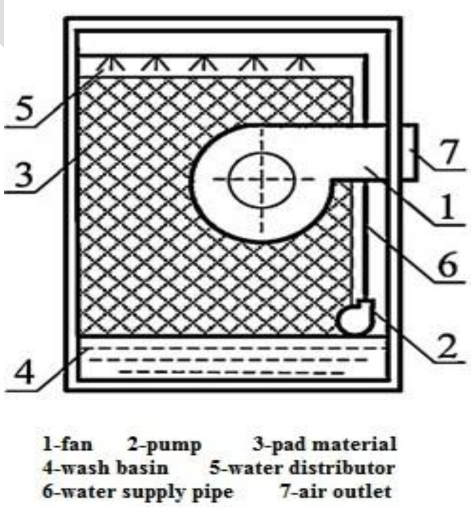

Fig.1. Schematics of a drip-type DEC.[8]

Generally, an evaporative cooling structure is made of a porous material that is fed with water. Hot dry air is drawn over the material. The water evaporates into the air raising its humidity and at the same time reducing the temperature of the air [3].The fundamental governing process of evaporative cooling is heat and mass transfer due to the evaporation of water. This process is based on the conversion of sensible heat into latent heat. Sensible heat is heat associated with a change in temperature. While changes in sensible heat affect temperature, it does not change the physical state of water. Conversely, latent heat transfer only changes the physical state of a substance by evaporation or condensation [4].As water evaporates, it changes from liquid to vapour. This change of phase requires latent heat to be absorbed from the surrounding air and the remaining liquid water. As a result, the air temperature decreases and the relative humidity increases. The maximum cooling that can be achieved is a reduction in air temperature to the wet-bulb temperature (WBT) at which point the air would be completely saturated [1,5].

This system is the oldest and the simplest type of evaporative cooling in which the outdoor air is brought into direct contact with water, i.e. cooling the air by converting sensible heat to latent heat. Ingenious techniques were used by ancient civilizations some of it by using earthenware jar water contained, wetted pads/canvas located in the passages of the air [6].The most commonly used direct evaporative coolers are essentially metal cubes or plastic boxes with large flat vertical air filters, called "pads", in their walls. Consisting of wettable porous material, the pads are kept moist by the water dripped continuously onto their upper edges. The process air is drawn by motorized fans within the coolers. After being cooled and humidified in the channels between the pads, the air leaves the cooler as "washed air" for cooling use. Many coolers use two-speed or three-speed fans, so the users can modulate the leaving air states as needed.[7]Fig. 1 is the schematic diagram of a drip-type DEC. Water is sprayed at the top edges of the pads and distributed further by gravity and capillarity. The falling water is recirculated from the water basin by the water pump. In DEC, the process air contacts directly with the sprayed water and hence is cooled and humidified simultaneously by the evaporation of water.[8]

This paper aims to review direct evaporative cooling technologies that could potentially provide sufficient cooling comfort, reduce environmental impact and lower energy consumption in buildings. Experimental and theoretical research works on feasibility studies, performance test and optimization as well as heat and mass transfer analysis are reviewed in detail. The review covers direct evaporative cooling design criteria, applications, advantages and disadvantages.

DESIGN CRITERIA

The main parameter considered when evaluating the performance of direct evaporative coolers is the Saturation Effectiveness (ε_s), which can be defined as [9]

$$\varepsilon_s = T_{11} - T_{12} / T_{11} - T_{h11} \quad \text{...........(1)}$$

where
ε is the saturation effectiveness,
T_{11} is the outdoor air temperature,
T_{12} is the supply air temperature and
T_{h11} is the outdoor air wet bulb temperature.
The value of the Saturation Effectiveness depends on the following factors:

1- Air velocity through the cooler: For a specific cooler, with a particular area and water flow, an increment in the velocity would result in:

- A higher air volume flow.
- A higher effect of evaporative cooling, which can be calculated as:

$$Q = m_a Cp_a (T_{11} - T_{12}) = v.S\rho Cp_a (T_{11} - T_{12}) \quad \text{...........(2)}$$

Where,
Q is the sensible heat (W),
v is the air velocity (m/s),
S is the area section (m^2) and
ρ is the density(kg_{da}/m^3).
In the majority of the direct evaporative coolers, velocity must not exceed 3m/s to prevent generation aerosols. In other case it would be necessary to dispose a drift eliminator, which increases slightly the pressure drop.

2- Relation water/air (M_w/M_a): This is the relation between the mass flow of atomized water and air flow. A high value shows a higher contact area between air and water and thus higher ε_s.

3- Configuration of the humid surface: A humidifier that provides a higher area and time of contact between air and water permits obtaining higher values of εs.

In these systems water recirculation is generally used to save water and improve economic results. The recirculated water temperature is close to the wet bulb air temperature. Given that air comes into direct contact with the atomized water, this process permits cleaning the air by removing particles of dust into it. However, if there are great amounts of dust or particles into the air, an additional filter should be used to prevent the fouling of the humidifier and the nozzles. [10]

RESEARCH AND APPLICATIONS

Theoretical analysis on evaporative cooling is essential for revealing the heat and mass transfer laws in evaporative cooling process as well as for predicting the process outputs under various working conditions. A number of studies were conducted on numerical simulation of heat and mass transfer of DEC. [8] Zhang and Chen analyzed the heat and mass transport processes in DEC and developed a simplified physical model for the DEC, in which the process air was forced to flow over a wet plate with simultaneous heat and mass transfer [11].Qiang et al. [12] established a neutral network model to predict the air handling performance of DEC under various working conditions. The direct cooling technology using water evaporation is widely used for environmental control in agricultural buildings. Zhang [13] studied the heat and mass transfer characteristics of a wet pad cooling device by assuming complete evaporation of the spraying water. By analogous analysis of the heat and mass transfer processes in DEC and cooling tower, Du et al. [14] obtained the cooling efficiency formula of DEC as a function of the pad thickness, heat transfer coefficient, face velocity and specific pad surface. A mathematical model of DEC and its associated boundary conditions were established and the distributions of the velocity and humidity were calculated by the SIMPLER method [15].

He et al. studied film media used for evaporative pre-cooling of air. The cooling efficiencies of the cellulose media 43% to 90% while PVC media are 8% to 65%.[16] Lee and Lee has been fabricated a regenerative evaporative cooler and tested. To improve the cooling performance, the water flow rate needs to be minimized as far as the 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 well below the inlet wet-bulb temperature of 23.7 °C.[17] Xuan et al. first introduced the working principles and thermodynamic characteristics of different types of evaporative cooling, including direct, indirect and semi-indirect evaporative cooling.[8] Fouda and Melikyanadiscussed heat and mass transfer, process in direct evaporative cooler. The predicted results show validity of simple mathematical model to design the direct evaporative cooler, and that the direct evaporative cooler with high performance pad material may be well applied for air conditioning systems.[18] Kulkarni and Rajput made a theoretical performance analysis of direct evaporative cooling. The results of the analysis showed that the aspen fiber material had the highest efficiency while the rigid cellulose material had the lowest efficiency.[19]

Heidarinejad et al. have been discussed, the results of performance analysis of a ground-assisted hybrid evaporative cooling system in Tehran. A Ground Coupled Circuit (GCC) provides the necessary pre-cooling effects, enabling a DEC that cools the air even below its WBT. Simulation results revealed that the combination of GCC and DEC system could provide comfort condition whereas DEC alone did not. This environmentally clean and energy efficient system can be considered as an alternative to the mechanical vapor compression systems. [20] Kachhwaha and Prabhakar presented simple and efficient methodology to design a house hold desert cooler, predict the performance of evaporative medium and determined pad thickness and height for achieving maximum cooling.[21] Dai and Sumathy theoretically investigated a cross-flow direct evaporative cooler, in which the wet durable honeycomb paper constituted as the pad material, and the air channels formed by alternate layers of two kinds of papers with different wave angles were regarded as parallel plate channels with constant spacing. [22]

Basediya et al. reported basic concept and principle, methods of evaporative cooling and their application for the preservation of fruits and vegetables and economy also. Zero energy cooling system could be used effectively for short-duration storage of fruits and vegetables even in hilly region.[2] McKenzie et al investigated the coupling evaporative cooling and decentralized gray water treatment in the residential sector.[23] Chen et al. presented a case study of a two-stage DEC air conditioning application in the northeast Chinese city of Lanz housing simulation. The results showed that the indoor temperature and humidity level can be maintained at design values using such a system. Moreover, the electrical installation power of a two-stage DEC system is only 50.7% of that of conventional central air conditioning systems.[24] The energy saving potentials of using DEC for air precooling in air-cooled water chiller units in 15 typical cities in China were calculated by Jiang and Zhang [25]. The results showed that by using DEC, the COP of the chillers can be enhanced by 15–25% in most of those cities. According to the analysis results of You et al., using DEC in air-cooled chiller units, the energy efficiency ratio (EER) of air-cooled chiller units in Tianjing can be increased by 14% [26].FAO (1983) advocated a low cost storage system based on the principle of evaporative cooling for storage of fruits and vegetables, which is simple, and relatively efficient. The basic principle relies on cooling by evaporation.[27]

The pad characteristics as well as the parameters of the air and the water in DEC significant influence the performance of DEC. Therefore, the measurement and test of the heat and mass transfer processes of various pads under different inlet air parameters attracted a lot of attentions.[28]You and Zhang studied the performances of the stainless steel pad and the perforated aluminum pad by assuming the adiabatic humidifying process [29].The optimum mass flow rate of the air and the water were1.5–3.5 kg m^{-2} s^{-1} and 0.8–1.4 kg m^{-2} s^{-1}, respectively. Moreover, Ge investigated the cooling and dehumidification performances of five types of perforated aluminum pads with different sizes at various circulation water temperature[30]. Yang et al. tested the cooling performance of the aluminum pad with specific surface area under the higher air velocity, the cooling efficiency of the pad tested was about 60% [31]. Zhang and Chen measured the adiabatic humidifying and dehumidifying cooling performances of cellulose pads [32]. The experiment results indicated that the optimum airflow rate. Feng and Liu investigated the heat and mass transfer process of the foam ceramic pad with a specific surface [33].

ADVANTAGES AND DISADVANTAGES

Based on available information of direct evaporative cooling system different advantages and disadvantages can be summarized as follows:

Advantages:

- The main advantages of evaporative coolers are their low cost and high effectiveness.
- Permitting a wide range of applications and versatility in the buildings, dwellings, commercial and industrial sectors.
- Direct evaporative devices act like filters, removing dust particles in air.
- It requires no special skill to operate and therefore is most suitable for rural application.
- It can be made from locally available materials.
- Highly efficient evaporative cooling systems that can reduce energy use by 70%.
- Less expensive to install and operate.
- It can be easily made and maintained.

Disadvantages:

- The water consumption associated to the operation of these systems, which is ascarce resource in dry and hot climates, where these systems best work.
- Evaporative cooling system requires a constant water supply to wet the pads. Therefore, need to be watered daily.
- Space is required at outside the home.
- Water high in mineral content leave mineral deposits on the pads and interior of the cooler gets damaged.[2,10]
- DEC is only suitable for dry and hot climates. In moist conditions, the relative humidity can reach as high as 80%, such a high humidity is not suitable for direct supply into buildings, because it may cause warping, rusting, and mildew of susceptible materials.[34]

CONCLUSION

In this paper a review of direct evaporative cooling technology that could be efficiently applicable in building air-conditioning was carried out. Using water for evaporation as a mean of decreasing air temperature is considerably the most environmentally friendly and effective cooling system. Evaporative cooling differs from common air conditioning and refrigeration technologies in that it can provide effective cooling without the need for an external energy source. If the power consumption can reduce to a moderate level then it will become serviceable in all sorts of requirements. Evaporative cooling is also important to the development of independent temperature and humidity control air conditioning systems. More R&D on potential applications of evaporative cooling systems would be advisable to promote environmentally friendly, energy-efficient, and comfortable air conditioning and, hence, a more sustainable world.

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