

Development and Experimental Evaluation of Indirect Evaporative Cooling System Employing a Psychrometric Energy Core System

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ABSTRACT: This paper presents results of an experiment conducted to investigate the performance and development of an indirect evaporative cooling system employing a Psychrometric Energy Core (PEC) unit under control operation conditions. Components of a 2 kW PEC system was designed and evaluated, and the outcome of these tests is used to optimise the final design of the cooling system. Results of the test have shown that the performance of the system can be maximised by optimizing the PEC pads wetting rate and the air flow rate through the core. Based on the preliminary results the system design was optimised. The performance of the optimised system in terms of cooling capacity was improved by about 80% compared to the original system, and COP of 33 was achieved.

Key words: Psychrometric Energy Core, indirect evaporative cooling, pads wetting.

1.0 Introduction

Evaporative coolers lower the temperature of air by using the latent heat of evaporation of the working fluid. In this process a warm dry air is changed to a cool moist air by using the heat in the air to evaporate the water. These systems operate very well in dry climates, but the drawback is that, the supply air humidity increases significantly. In direct evaporative cooling systems the relative humidity of the supply air may vary in the range of 70% to 90% [1].

To provide a comfort cold air supply, an indirect evaporation could be used. In an indirect evaporative air cooler, the primary air is passed over a dry side of a plate and secondary or working air is passed over the opposite wet side of a plate. The wet side absorbs heat from the dry side and causes the water to evaporate, thus removing its

latent heat and as a result the air on the dry side is cooled (see Fig. 1).

The temperature on the dry side of the plate travels in counter flow to the air on the wet side, and ideally the product air temperature on the dry side of the plate could reach the wet bulb temperature of the incoming air [4].

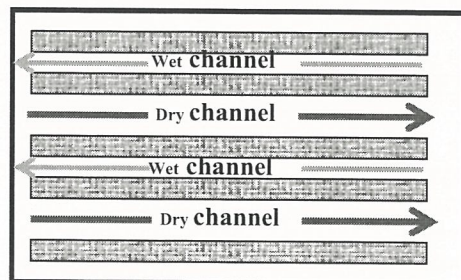


Figure 1: Indirect evaporative cooling arrangement

For many years indirect evaporative cooler have been used with little success. Because of the poor heat transfer rates, commercialized unit have not been able to produce a cooling capacity that justifies the excessive material and manufacturing costs [2].

The cycle of psychometric energy core (PEC) uses the same wet side and dry side of a plate as described above, but employed a special geometry to direct the airflow within the PEC core in vertical and horizontal channels. Therefore, the cooling temperature is not limited to the wet bulb temperature of the incoming air. The core allows any liquid or vapour to be cooled below the wet bulb and toward the dew point temperature of the incoming working air. The cycle has been realized in a uniquely designed plate wetting and channel system which achieves optimum cooling temperatures within few degrees of the dew point for the product air [3]. In addition, the working air is saturated with high enthalpy, accounting for the sensible heat loss in the product air.

In this way the unsaturated inlet air is divided into two streams at two states, a low- temperature, low-enthalpy state, and a high-temperature, high-enthalpy state. The low-temperature, low-enthalpy air passes through the horizontal channels (supply channels), while the high-temperature, high-enthalpy air diverges and exits through the vertical channels (exhaust channels).

2.0 The psychometric energy core system

The PEC cooling is a means of air temperature reduction and operates on the principle that water absorbs heat from the surrounding air while it evaporates. The psychometric energy is the energy produced during the specific process of interaction between air and a hygroscopic solution such as water [3]. The PEC is made of a special paper (pads) that absorb and hold moisture

and these are separated by thin plastic sheets (Fig. 2). The pads are arranged in a special way, so that the inlet air is divided into two streams within the core, horizontal channels through the core and vertical channels emerging from a certain number of the horizontal channels (Fig 3). Water is sprayed over the pads along the vertical channels using a circulating pump allocated at the base of the core casing. Water droplets passing through the vertical channels soak the pads and trickles through them to be collected at the bottom of the casing.

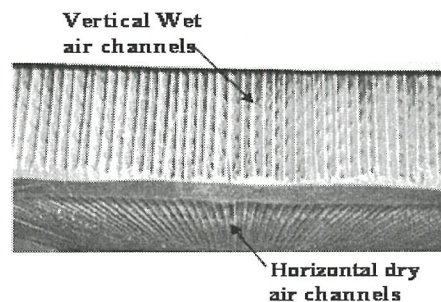


Figure 2: Structure of PEC Core showing the Wet (Exhaust air) and the dry (Supply air) channels.

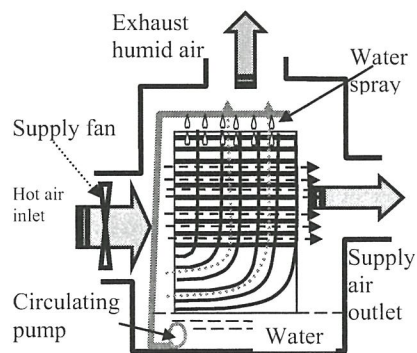


Figure 3: Schematic showing the PEC core unit operation

3.0 Experimental setup of the first prototype:

The first prototype PEC cooling system consists of five major parts: housing made of fibreglass sheet, a dc motor driven air supply fan, a water-moistened Psychrometric Energy Core (PEC), a dc motor driven water pump and water distribution pipes.

The circulating pump sprays water onto the PEC, wetting the pads. The fan draws fresh warm air from the ambient into the PEC housing unit. The inlet air is divided into vertical and horizontal channels as shown in Fig 3. Heat is transferred from the dry surface of the pads to the wet surface by direct conduction. This causes the evaporation of the water from the wet surface releasing its latent heat of vaporisation. The water vapour is dragged by the passing air in the vertical channels to the exhaust exit. The dry cold air passes through the horizontal channels to the supply air outlet.

The system is fabricated as shown in Fig 3. The tests were carried out for the PEC cooling unit and the cooling capacity of the system is assessed by measuring the temperature, relative humidity and air flow rate at inlet, and outlets ports at steady state conditions. The inlet parameters were controlled using an environmental chamber which allows control of the room temperature and relative humidity.

3.1 Results of test of the first prototype

The tests were carried out with environmental chambers temperature set at 25°C, 30°C, 35°C and 40°C and relative humidity (RH) 40%. The cooling capacity of the PEC is estimated using the following equation:

$$Q_c = m(h_{in} - h_{out})$$

Where; Q_c is the cooling capacity (kW), m is the mass flow of the supply air outlet (kg/s), h_{in} is the enthalpy at inlet (kJ/kg), h_{out} is the enthalpy at outlet (kJ/kg).

Values of air enthalpy at inlet and outlet of the PEC is estimated using the Psychrometric chart and EES software at the various temperatures and relative humidity values obtained from the test measurements. The results of the cooling capacity of the PEC unit at varying chamber temperatures and relative humidity 40% are presented in Fig 4.

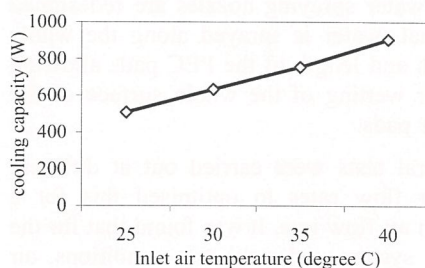


Figure 4: Variation of the cooling capacity with ambient temperature for the first PEC cooling prototype.

4.0 Optimisation of the PEC unit

The results obtained from the test of the original prototype of 2 kW unit have shown that the performance of the system is very low. At 25°C ambient condition the system produces only one quarter of its cooling capacity. This has increased to 900 Watts at 40°C (just under half of the rated capacity). Investigations to the design have highlighted a number of reasons for this low performance. Among these is the geometry of the PEC core housing, which blocks the air flow. Most of the air recirculates inside the PEC housing with very little leaving at the supply air outlet. Also, there was a gap between the fan blades and the casing causing some air to escape as a result. Another factor is the ratio of the water flow

to the air flow rates. If too much water is sprayed on the surface of the pads, this affects the rate of evaporation and hence the heat removal from the pads. If water supply is not sufficient, the rate of evaporation also decreases and hence the heat removal rate.

The physical geometry of the PEC housing was refined to exclude corner from the air flow passage throughout the PEC casing, and the gap between the fan blades and the PEC housing was also adjusted to prevent air escape at the inlet. These two modifications have improved the air flow rate significantly, and the energy consumption of the fan was also reduced. The water spraying nozzles are redesigned so that, water is sprayed along the whole width and length of the PEC pads allowing better wetting of the whole surface of the paper pads.

Several tests were carried out at different water flow rates to optimise this for a given air flow rate. It was found that for the 2kW system under the test conditions, air flow 4.4 m/s and water flow rate 11 l/min give the best cooling capacity. The system is then tested under these conditions and the results are presented in the next section.

4.1 Results of tests of the optimised system

Fig. 5 and Fig. 6 present the results obtained following optimisation of the water and air flow rates and the geometrical improvement of the PEC housing. Results in Fig. 5 were those following improvement of the PEC housing geometry alone. At ambient temperature of 40°C and relative humidity 50% a cooling capacity of 1.6 kW was achieved only through proper geometry design. When the water flow rate is optimised and adequate pads surface wetting is achieved, the cooling capacity of the system has improved considerably to 1.94 kW for inlet air temperature 40°C and relative humidity 50% (Fig. 6).

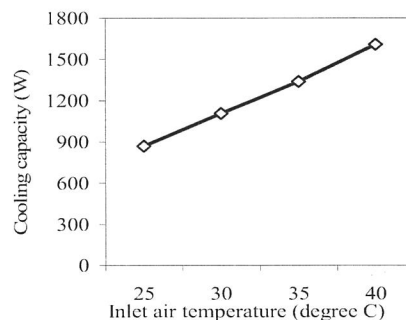


Figure 5: Variation of the cooling capacity with the air temperature for the geometrically optimised system (RH = 50%)

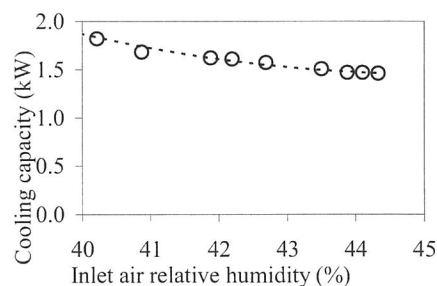


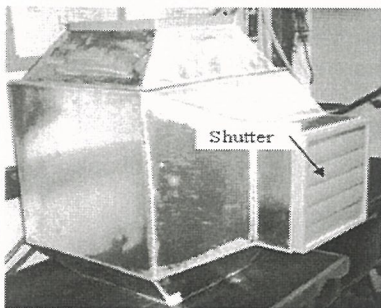
Figure 6: Variation of the cooling capacity with the relative humidity of the inlet air following system geometry and pads wetting improvement

5.0 Design and construction of a demonstration unit

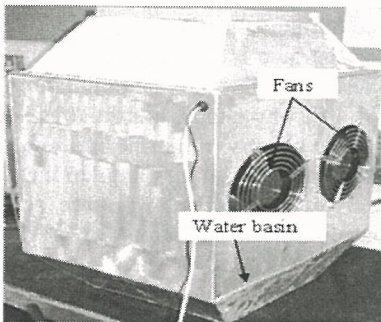
The system has been redesigned taken into account the improvement achieved above. To maintain the appropriate air flow rate two DC fans each 29 watts were used instead of the AC fan (Fig. 7). This enables the system to be operated using solar Photovoltaic power. The casing of the cooler is made using aluminium panels, and is shaped to minimise pressure losses along the air flow path, both for the exhaust air and the supply air as shown in Fig. 7 and

Fig. 8. The thickness of the core is chosen so that water spray covers all the width of the pads using a 15 mm tube as shown in Fig. 8.

The water is circulated using a 15 watt DC motor driven submersible pump located at the base of the system (Fig. 7). Three rows of water spraying holes are made along the water pipe sprayer; one along lower surface and two opposite rows on the sides of the pipe at about approximately 45° from the horizontal. This arrangement enabled water to be sprayed along the overall width of the PEC core and maintaining a uniform wetting surface.



(a) Front of the PEC cooling system



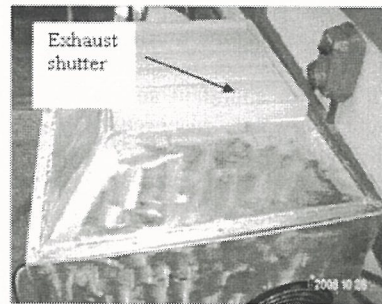
(b) Rear of the PEC cooling system

Figure 7: Photos showing the inlet and the outlet ports of the prototype

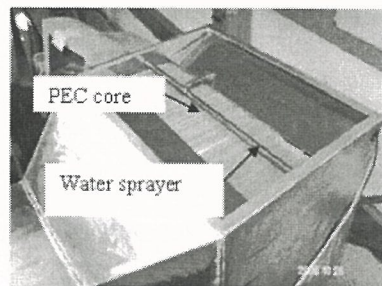
Humidity and temperature sensors were setup to measure the humidity and the

temperature at the inlet, outlet and the exhaust ports. The system was tested under controlled conditions of temperature and relative humidity using the environmental chamber.

Fig. 9 shows the Variation of the inlet and the supply air as obtained from a test run with the chamber relative humidity set at 50%. An average temperature difference of about 7°C was achieved in these tests.



(a) Exhaust shutter



(b) PEC core and water spray

Figure 8: Photos showing the PEC core, the water distribution pipe and the exhaust shutter