

Integrated Evaporative Cooling System Using Porous Ceramic Evaporators and Thermoelectric Cooling Device

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Abstract: Evaporative cooling using porous ceramic evaporators were experimentally investigated. Encouraging results in terms of temperature reduction and cooling effectiveness were reported. In this work thermoelectric unit was integrated in to the evaporative cooling system containing porous ceramic evaporators. The warm inlet air cooled in the porous ceramics' evaporative cooling chamber was passed over the hot- side fins of the thermoelectric cooling device to act as a better heat sink. This increased the coefficient of performance, (COP) and is a measure of reducing high humidity associated with direct evaporative cooling applications. It also minimises material failure resulting from higher temperature generated at the hot side when a thermoelectric unit is in operation. The system was subjected to various psychometric test conditions consisting of varying the inlet temperatures and relative humidity. Also the power supplies to the thermoelectric unit as well as the exhaust fan were varied. Typical test results showed that the cold side temperature of thermoelectric unit was 5° Celsius lower and the hot side was 10° Celsius lower, respectively when operated on the wet and dry porous ceramics evaporative cooling chamber. The overall system performance is discussed and presented in this paper.

Keywords: evaporative cooling, porous ceramics, thermoelectric, humidity, temperature.

NOMENCLATURE

Symbol	Description [Units]	COP	Coefficient of performance
A	Area [m ²]		
C _p	Specific heat capacity [W/m ² K]		
P	Ambient atmospheric pressure [N/m ²]	Subscripts	
R	Universal gas constant [m ² /s ² K]	C	cold side
T	Temperature [K]	H	hot side
v	Air velocity [m/s]	ce	ceramic surface
ρ	Density [kg/m ³]	duct	duct cross-section
Z	Figure of merit for the thermoelectric material [2.8 to 3.0x10 ⁻³ /K]	in	inlet
		out	outlet
		s	saturated

1. INTRODUCTION

Space cooling for human comfort can be achieved with the application of different evaporative cooling methods, which are more environmentally friendly and less energy intensive as compared to the conventional air conditioning units.

Evaporative cooling can be used either through direct or indirect methods to lower the temperature in a building space. Direct evaporation cools fresh out door air by adiabatic saturation and then transfers the cooling air to the space. This type of cooling is suitable in hot and dry climates. Indirect evaporative cooling system employs heat exchangers to transfer cooling achieved by direct evaporation. This system is suitable for use in buildings that have low cooling loads and little requirement for humidity. The use of local fibres [1], honeycomb paper [2], and other porous materials in the application of evaporative cooling were reported. However, it was found to yield encouraging results and continues to be investigated for further improvements. The performance of porous ceramic evaporators for cooling applications including the effects of the materials porosity was reported [3]. Indirect evaporative cooling methods using porous ceramics evaporators can be integrated with some heat exchanging devices. An indirect system using porous ceramics and heat pipes as heat exchanger was investigated. These lead to the development of heat and mass transfer mathematical model, which can be used to predict the performance of the system [4].

The porous ceramics evaporative cooling set up can be integrated with thermo electrics to make the application of the system more flexible for either cooling with humidification or cooling with out humidification. Since thermoelectric devices can be operated on direct current (D.C.) power supply, *solar photovoltaic* can be exploited to power the evaporative cooling system integrated with thermo electrics. In these studies, evaporative cooling was experimentally used as a heat sink to the hot side of thermoelectric unit. Increased value of the coefficient of performance, (COP) was observed. Material failure resulting from higher temperature generated, at the hot side when a thermoelectric unit is in operation could be prevented. It is also a measure of reducing high humidity associated with direct evaporative cooling technology.

2. EVAPORATIVE COOLING USING POROUS CERAMIC EVAPORATORS

Evaporative cooling is the exchange of sensible heat in air for the latent heat of water droplets on wetted surfaces. It can be used to cool building air directly by evaporation or indirectly by contact with a surface previously cooled by evaporation. Ideally evaporative cooling is adiabatic or constant enthalpy process meaning that sensible heat is extracted from the air (dry-bulb temperature is reduced) while an equal amount of latent heat (in the form of water vapour) is added. The enthalpy or total heat remains the same [1]. To evaporate water the required heat is absorbed from whatever surface the water comes in contact

with. Therefore through evaporative cooling tremendous amount of heat can be removed from the space being cooled. Different materials can be used to create a suitable wet surface that can be exposed to air for evaporative cooling to take effect. Among the materials investigated and found to have significant potential for cooling of buildings were the porous ceramic evaporators [3].

The cooling performance of an evaporative cooling system using porous ceramic evaporators can be obtained using the following relationship [3].

$$\text{Cooling (Wm}^{-2}\text{)} = \frac{\rho A_{duct} v C_p [T_m - T_{out}]}{A_{ce}} \quad (1)$$

Where:

$$\rho = \frac{P}{RT}$$

3. THERMOELECTRIC SYSTEM

Thermoelectric device works on the basis of Peltier effects to achieve cooling or heating. This means that when a DC source passes through a cell made of n- and p-type semi conductor materials, one of the junctions will be cooled while the other becomes heated depending on the direction of the current. Therefore the device requires a power source and heat sinks to dissipate the energy generated or absorbed at the two junctions [5]. The use of thermoelectric for air conditioning is becoming more popular because they are environmentally friendly. However there is still need for improving the efficiency of their performance. Two ways of improving their efficiency are improving the thermoelectric material and provision of better or very effective hot-side heat sinks [6]. While the former has to be at the design and manufacturing stages the latter can be applied to the existing commercial systems.

Performance equations were given for the evaluation of the cooling energy and the coefficient of performance (COP) of a typical thermoelectric cell system [5].

$$COP = \frac{Q_{cooling}}{Q_{input}} \quad (2)$$

Where:

$Q_{cooling}$ — is the cooling energy produced by the System

Q_{input} — is the electrical energy input to the thermoelectric cell.

Also the COP of a simplified model can be expressed as a function of cold side, hot side temperatures and

the figure of merit of the thermoelectric material, that is T_c , T_h , and Z , respectively [6], [7].

$$COP = \frac{T_c}{T_h - T_c} \frac{(1 + zT_M)^{\frac{1}{2}} - \frac{T_h}{T_c}}{(1 + zT_M)^{\frac{1}{2}} + 1} \quad (3)$$

Where, $T_M = (T_h + T_c)/2$

4. EXPERIMENTAL SET-UPS

The integrated system referred to as Evapo-Thermoelectric (TE)-Integrated system is schematically shown in figure 1a. The system consists of a chamber containing porous ceramic evaporators and an overhead water supply tank. This chamber is made up of a rectangular wooden box of 70cm x 50cm cross-section and a vertical height of 165cm, mounted on wheels for easy movement if required. It is thermally insulated outside with a 25mm-thick polyethylene insulation sheet to make the system function under adiabatic condition. The Water from the tank fills the evaporators to provide wet surfaces required for evaporation. At the bottom of the box is a condensate tank, which collects the condensate falling from the surface of the evaporators. The evaporative chamber can accommodate up to 25 ceramic evaporators arranged in five rows of five each. Each of the porous ceramic evaporators has the dimension of 43.5cm x 22cm x 2.2cm.

The thermoelectric unit is a commercial Valor model-802 type. A wooden casing was made to accommodate it and then insulated at the outside after it has been attached to the evaporative cooling chamber. It was installed such that the hot fins projects in to the outlet channel of the evaporative cooling chamber.

The experiment was carried in an environmental control chamber, which allowed for temperature and relative humidity values to be varied and controlled during testing. Different values of input temperatures and relative humidity were set in the environmental control chamber. Air under these set conditions was admitted in to the evaporation chamber where it exchanges heat with the wet surfaces of the porous ceramic evaporators. Instead of sending cold and humidified air to the room space it is channelled to the exhaust after passing over the hot fins of thermoelectric unit as illustrated in the figure 1. Cool air from the thermo electric unit is directly supplied to the building space with little increase in the humidity. The environmental chamber is partitioned so as to separate the set ambient temperature and relative humidity values from the building space required to be cooled. Insulation was also provided to minimise the infiltrations of these separated temperature and relative humidity set values.

The warm humid air from the thermoelectric hot side was channelled out. Each dry test was carried

out for not more than an hour to prevent overheating of the thermoelectric element, while the wet tests were conducted for several hours and no sign of overheating was noticed.

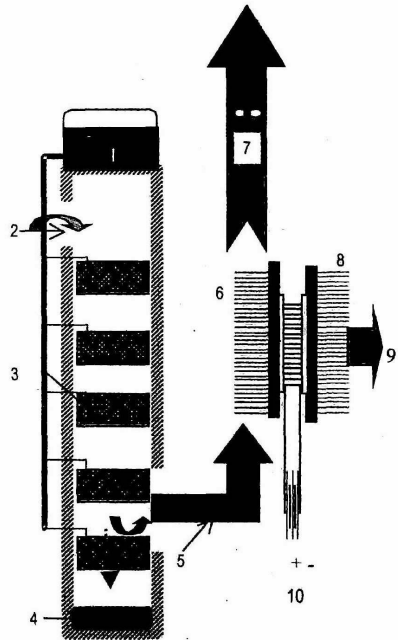


Figure 1: Ceramic evaporators and thermoelectric integrated cooling system

- 1—Water supply tank
- 2—Ambient air in
- 3—Porous ceramic evaporators
- 4—Condensate tank
- 5—Heat sinks to thermoelectric hot fins
- 6—Thermoelectric hot fins
- 7—Warm-humid air exhaust
- 8—Thermoelectric cold fins
- 9—Cool supply air to building space
- 10—Power supply to thermoelectric unit

5. RESULTS AND DISCUSSIONS

First experimental tests were conducted on the thermoelectric unit when the evaporative chamber containing porous ceramics was dry. Cold-side and hot-side temperatures of the system were recorded and plotted as shown in figure 2a. The system stabilises at a maximum hot side temperature of over 52°C and cold side temperature of 18°C that is having a temperature difference of 33°C, which results in low coefficient of performance. This also shows a need for better heat sink to prevent material failure due to over-heating when long-term system operation is required.

After the dry test, the porous ceramics evaporators in the evaporative cooling chamber were then supplied with water to provide wet surfaces for the evaporative cooling. Variation of the temperatures and relative humidity values were recorded. These results are plotted in figures 3a and 3b. In this case the hot side and cold side temperatures stabilised at 13.2°C and 42°C, respectively as can be seen in figure 3a. Figure 3b shows the significant rise in relative humidity between the inlet or set ambient temperature (T_a) and relative humidity (RH_a). The 30% rise in relative humidity that would have been admitted to the building space was exhausted out (RH_{exhaust}) at a lower value of less than 20%. Also there was no significant rise in the space cooled by the thermoelectric cooler. The increase of about 15% in the relative humidity was as a result of decrease in the temperature on the existing conditions in the space. A bar chart representation of the comparative performance result is shown in figure 4. These values are lower than the above stated values for the dry –tests.

Ideal coefficient of performance (COP) value was evaluated using equation (3). For the wet tests, COP value of about 1.4 was and 0.89 for the dry test. Since the real COP value can be about 70% of the real value [7], the values obtained here are then 0.98 and 0.62 for the wet and dry tests respectively. Therefore by integrating the thermoelectric cooler with porous ceramic evaporative cooling, the COP of the system can be improved by over 30%.

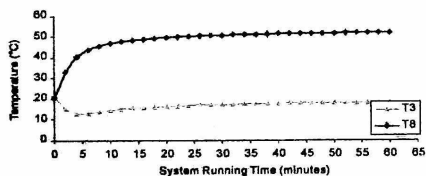


Figure2: Variation of the hot-side and cold-side temperature with time for a dry-test, when the porous ceramic evaporators were empty

T3- Thermoelectric unit cold side temperature
T8- Thermoelectric unit hot side temperature

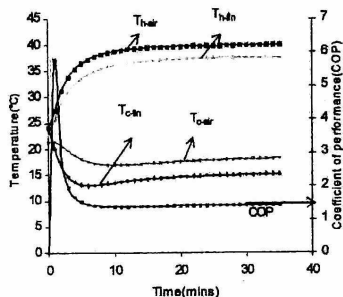


Figure3a: Timely variation of hot-side and cold-side temperature for the thermoelectric pellets and the corresponding surrounding air when running with evaporative cooling heat-sink

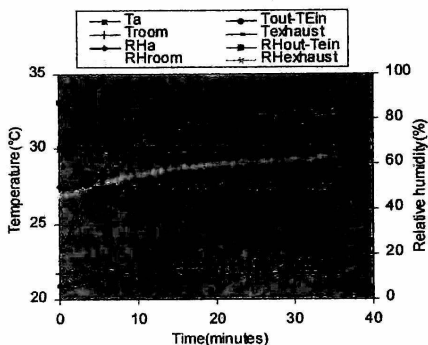


Figure3b: Variation of temperatures and relative humidities with time for a test with water-filled ceramics evaporators (wet-test)

6. CONCLUSIONS

Tests results and other reports have indicated the suitability of evaporative cooling in situation where increase in humidity can be acceptable.

Comparatively, running a thermoelectric under this integrated arrangement showed over 30% increase in COP and lower temperatures were obtained without much increase in relative humidity. This therefore provides the prospect for using an integrated system with thermoelectric unit. The evaporative cooling part provides the heat sink needed for improving the efficiency of the thermoelectric system. These tests have shown that evaporative cooling using porous ceramics has got potential application as a heat sink to thermal systems not only on thermoelectrics. The system has also got an advantage of not continuously using energy to circulate the cooling water. It therefore saves extra energy required for running a pump.

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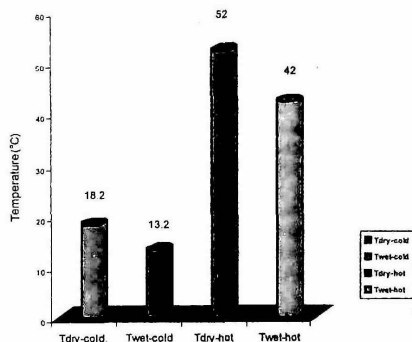


Figure 4: Comparative Temperature Profiles for TE test with dry and wet Evaporative Cooling Chamber

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