Development and Performance Evaluation of a Semi Indirect Evaporative Cooler

Maneesh Dubey
MANIT

SPS Rajpat
MANIT

DEVELOPMENT AND PERFORMANCE EVALUATION OF A SEMI INDIRECT EVAPORATIVE COOLER

Maneesh Dubey[1]*, Dr SPS Rajput[2]

[1]Department of Mechanical Engineering, MANIT,
Bhopal-462051, India.
e-mail: d.maneesh@gmail.com, Cell: +919425096093

[2]Department of Mechanical Engineering, MANIT,
Bhopal-462051, India.
e-mail: spsrajput@gmail.com, Cell: +919826195978

ABSTRACT

Direct evaporation systems lead to increased humidity causing ailments like Legionnaire's disease whereas indirect systems suffer from loss in efficiency. This paper describes the development of a test setup and performance evaluation of a Semi-Indirect Evaporative Cooler (SIEC) using specially made clay pipes. The SIEC may also be used as a sensible or enthalpic exchanger depending upon the characteristics of prevailing air. Water in the upper tank is made to drip at a controlled rate into the porous clay pipes which allow capillary action. A thin layer of water formed on the surface of clay pipes is used to exchange sensible and latent heat with the current of outdoor air. The water circulating pump which is a primary component of any evaporating cooling system is absolutely not required in the SIEC. The energy efficient SIEC can result in the direct saving of 30-40% of high grade electrical energy. This system yields cooled air and is especially suited for arid and semi-arid climates. This work consists of

- Fabrication of sheet metal structure for the cooler
- Manufacture of clay pipes with customized dimensions
- Fixing of clay pipes in the cooler at specific locations
- Testing and evaluation of the system in summer conditions

Key words: Evaporative system, Semi-indirect evaporative cooling, direct and indirect evaporative cooling, clay pipes, DBT and WBT, humidity.

1. INTRODUCTION

Cost of energy, impact on the environment due to the release of ozone depleting substances and green house effect due to the emission of CO_2 and the other economic factors have encouraged researchers to develop alternative cooling technologies. In the northern latitudes of the India, summers are very hot combined with low humidity leading to heat strokes and other inconveniences. Direct evaporative coolers are extensively used for human comfort in homes, offices and plants. They also find wide applications in animal shelters, poultry farms, green houses, textile mills and for product cooling. These coolers are manufactured by small and medium enterprises. The popularity of evaporative coolers may be attributed to high cost of air conditioners, increased electricity consumption and lack of adequate service infrastructure. It is estimated that there are over 30 million evaporative coolers used mainly during the summer months and nearly 5 million air conditioners in use in India. Together, they represent a total load of 39 million kW. Hence an improvement of 10% in the performance of these coolers is estimated to save about 2.4 million kW of electrical energy. In a direct evaporative cooler, the air is cooled by exposing it directly to liquid water. Hot dry air is converted to cool moist air by loosing its sensible heat to the latent heat of vaporization of water. There is heat and mass transfer in the process. Although, there is some sensible heat gain from the fan, their performance is close to the constant wet bulb temperature of the intake air i.e. isenthalpic or adiabatic cooling. Direct evaporative cooling does not perform true air conditioning but is able to provide human comfort by filtering and circulating cooled air. The major advantages of evaporative cooling are:

1. Higher thermal power per square metre of area.
2. Lesser electrical consumption.

3. Reduction in green house gases, identified as zero ODP and zero GWP systems.
4. Works better on hotter days and hence reduces demand charges.
5. Higher energy efficiency ratio of up to 36% as compared to 12% for compression refrigeration system.

Some of the major drawbacks with the direct evaporative cooling are:

1. Cooling achievable by adiabatic process is limited. The quantity of sensible heat removed can not exceed the latent heat required to saturate air with water vapour. The closer the process approaches being adiabatic, the greater will be its ability to cool the air. The greater the range through which water is cooled the less closely will the resulting equilibrium temperature approach the wet bulb temperature (WBT), which is the utmost limit.
2. The cooling process adds moisture to the air which increases the humidity in the cooling space too. This is contrary to the requirement as the relative humidity (RH) may rise to unacceptable levels.
3. The lowest possible dry bulb temperature (DBT) of air leaving the cooler is at 100% RH which is equal to WBT of ambient air. Evaporative cooling is therefore satisfactory only in areas where DBT exceeds 32℃and WBT is below 21℃.

In the proposed Semi Indirect Evaporative Cooler, water filled in porous clay containers goes through the porous wall and wets the surface. This water evaporates as a result of air sweeping across the container surface. The surface and air thus get cooled. The noticeable fact is that the cooled air does not carry water droplets with it. A limited amount of water just sufficient to lower its temperature by few degrees is added to the air. The temperature of the air is further reduced sensibly due to its contact with the cooled pipe surface. [1-8].

2. EVAPORATIVE COOLING SYSTEMS

2.1. Direct evaporative systems

In a direct evaporative cooler, the air is cooled by exposing it directly to liquid water. Hot dry air is converted to cool moist air by loosing its sensible heat to the latent heat of vaporization of water. There is heat and mass transfer in the process. Although, there is some sensible heat gain from the fan, their performance is close to the constant wet bulb temperature of the intake air i.e. isenthalpic cooling. Its main drawback is the possible dispersion of Legionella, associated with the carrying of droplets in the supply air flow. [8].

2.2. Indirect evaporative systems

It is based on the cooling effect of water evaporation but not directly in the air flow, but separated by means of a nonporous wall. There is only heat transfer in the process between the air and the water cooled in a cooling tower. This system eliminates the problem of Legionella in the supply air flow, but it is not as efficient as the direct system.[8].

2.3. Evaporative cooling in porous media

There is mass (water) transfer through a porous media. Some of its applications are listed below:

(a) One application of evaporative cooling through porous media is a traditional system of cooling water for drinking. The water inside a ceramic porous container is cooled in the following way: the water inside the container goes through the porous wall and evaporates in its surface, taking the necessary energy from the water.

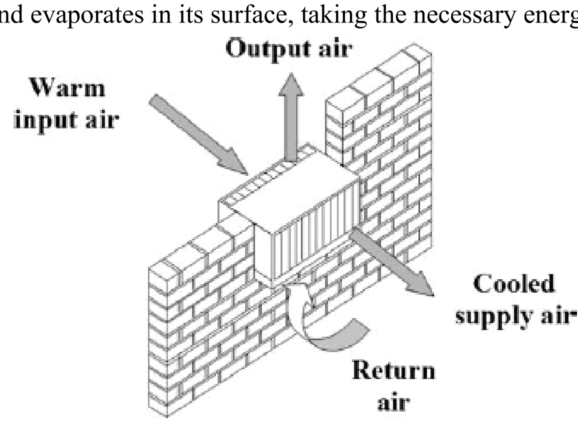


Fig 1. Air window system

(b) Porous ceramic evaporators have been analyzed [9-10] by using different rectangular prototypes with three different porosities, using the device as a direct evaporative cooler, having in one side of the ceramic outdoor air and in the other side pressured water.
(c) Finally, an air conditioning system has been developed which its designers have called ‘air window’, based on air cooling using intensive evaporation. This system is shown in the Fig. 1. The designers have managed to concentrate the ventilation, cooling and heating systems in a single block, thus creating a compact domestic system with an energy consumption 3–4 times lower than traditional vapour compression air conditioning systems. This equipment is made of polymeric porous material, and needs water and a fan. [11-15].

3. DESIGN OF THE PROPOSED SEMI INDIRECT EVAPORATIVE COOLER (SIEC)

The proposed SIEC consists of number of porous tubes attached to the bottom of a water tank through holes made specifically for this purpose. The vertical tubes are fixed with adhesive material to prevent leakage. (Fig 2). All these tubes and tank are filled with water. As water evaporates from the surface of these tubes, water level in the upper tank goes down. Hence this arrangement does not require any water circulating pump.

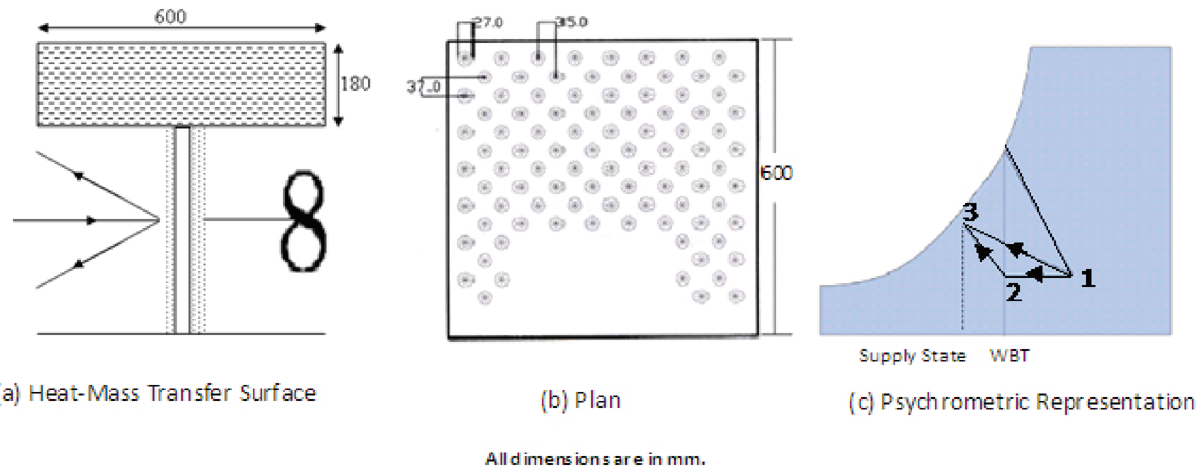


Fig 2. Design of the proposed SIEC

The outside air to be cooled is drawn in by the exhaust fan and comes in the contact with the wetted surface of these tubes. When an air stream contacts with the wetted surface, it is divided into two parts, one of which will circulate through the fan and another will flow out from the opening of the cooler to some other directions after making contact with the tube surface. The temperature of water at the surface of the tubes gets reduced as a result of adiabatic saturation. After few numbers of cycles the temperature of water at the tube surface will attain wet bulb temperature of outside air. Now the other part of air stream which is to be circulated to the conditioned space through fan will first cool sensibly at the wetted surface and further adiabatic saturation of this air results in a low supply temperature of air. The partial pressure of water vapour in the outdoor air is the controlling factor in this mass transport process. When the relative humidity of the outdoor air is low, magnitude of evaporation will be higher.
The design of this porous clay pipe cooler for evaporative recovery has been carried out taking economic and technical factors into account, thus making it feasible, efficient and economical. By feasible we mean a design that can be installed, and by efficient, one which consumes lesser amount of high grade energy. The water circulating pump which is a primary component of any evaporating cooling system is absolutely not required in the proposed system and results in energy efficient and low capital cost system. In the proposed system the supply air temperature is partially reduced by sensible cooling and partially by adiabatic saturation, hence in this respect it has been called semi-indirect.

4. EXPERIMENTAL SETUP

A proto type of Semi Indirect Evaporative Cooler has been developed in following stages:

4.1 Material Selection

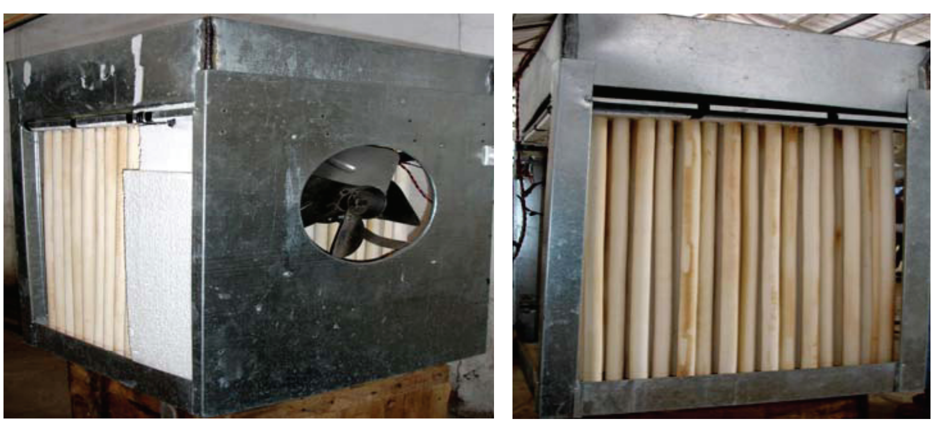
Aluminum Foam developed at Regional Research Laboratory Bhopal has interconnected pores and good strength. Pore size larger than requirement and cost make it unsuitable for commercial use. Properties and cost favoured the selection of earthen pots. Manufacturing of pipes from earthen clay was not possible because of the unsatisfactory binding strength. Methods to increase the binding strength of clay adversely affect its porosity. Intensive study of various aspects of different materials concluded that clay used in water filter candles is a viable option. Clay pipes of 14 mm inner diameter, 27 mm outer diameter and 27 inch length according to customized requirements were manufactured in ***Kalpana Refactory Works, Than, Gujarat, India.*** The composition of these pipes is

- Clay
- Saw dust
- Binding material

% Composition and the binding material used were not disclosed by the manufacturer. Table 1 summarizes the various possible material and their drawbacks in manufacturing of the pipes.

Table 1. Various possible pipe material & their limitations in SIEC

Floral Foam	Difficult procurement. Easy deformation, High Porosity.
Normal Foam	Low rigidity, Difficult to achieve some desirable shapes.
Porous Metals	Very few numbers, Expensive, Difficult Processing and Procurement, Bulky.
Ceramics	Insufficient porosity, Expensive, Heavy.
Earthen Clay	Difficult to shape in pipes, Low strength, Excessive weight.
Chalk	Less porosity, Low strength.
Brick Clay	Difficult to shape in pipes, Smaller pipe length, Heavy.
Clay of Filter Candles	High brittleness, Heavy.



(a) (b)

Fig.-4. Experimental Set-up

4.2 Fabrication

The cooler body was fabricated using sheet metal of 18 gauge thickness. Proper arrangement of pipes in suitable array includes:

a. Designing of Array

Relative position of pipes had decided as it has a direct relationship with the effectiveness of the cooler. Parameters affecting the array design are

i. Proper contact of air with the pipe surface: Optimum contact of air with water surface should be made available to allow sufficient for air to get cooled.

ii. Time/Number of Contacts: Increasing the time/number of contacts, the air starts taking extra moisture with it and on decreasing the same effective cooling is not achieved. Thus, an optimum number of pipes were decided.

b. Fixing of Pipes

Various options available were metal, plywood, thermocole and polymer sheet etc. Metal sheet and plywood were ruled out due to difficulty in fabrication and likely breakage of brittle pipes during transportation. Polymer sheet is easily available with the required hole diameter. Thermocole sheet is easily workable with help of tool shown in Fig 4. The tool head which is of the diameter of required hole is heated in a candle flame and holes are punched. Pipes are fixed in these holes.

4.3 Arrangement for Water

Water tank is fitted at the top of pipe array in SIEC whereas it is located at the bottom in traditional evaporative coolers. Holes of approximately 2 mm diameter are punched in the tank. The array of holes matches the pipe array to ensure that the water dripping from the tank holes fall directly into clay pipes without dripping. The water once filled in the tank fills the pipe cavity. The water in the pipes come out from the pores and forms a very thin layer on the outer surface which evaporates as it gets in contact with the hot and dry ambient air. In this manner the water is supplied in a regulated manner. There has to be water tight seal between the tank bottom and the top cross section of the pipes.

4.4 Sealing of the pipes

Air tight caps having diameter equal to the inner diameter of the pipes were tightly fitted in the pipe cavity to avoid dripping of water from the bottom.

4.5 Cooling Fan

Cooling fan used in the SIEC was a local exhaust fan operating on AC with 220 Volts and 50 Hz frequency having 1440 rpm as the maximum speed. Four speed electronic regulator was used as the testing had to be done at varying fan speeds.

5. TESTING METHODOLOGY

Cooler is kept in a room of 2.5 m x 2.5 m and test is carried out at different times in a day for getting the average values of parameters for evaluating the cooler performance. Cooler fan switched on after measuring the DBT, WBT of outdoor air with the help of sling psychrometer. After the steady state condition is reached, DBT and WBT of the indoor air were measured. The air flow rate, water flow rate, water temperature and pipe temperature were also recorded. The test was repeated by varying outdoor air conditions and fan speed. Relative humidity was calculated using the values of DBT and WBT or directly with the help of psychrometric chart. The effectiveness of evaporative cooler is a crucial parameter to compare the performance of two coolers or that of a single cooler at different conditions. The effectiveness was calculated by the following relation:

6. RESULTS AND DISCUSSION

The tests on the SIEC were carried out on different days to consider the day to day variations in the climatic conditions. Each set of readings corresponds to approximately one hour of testing at four different fan speeds. The outdoor air conditions were assumed to be constant for the testing period though a slight variation was observed.

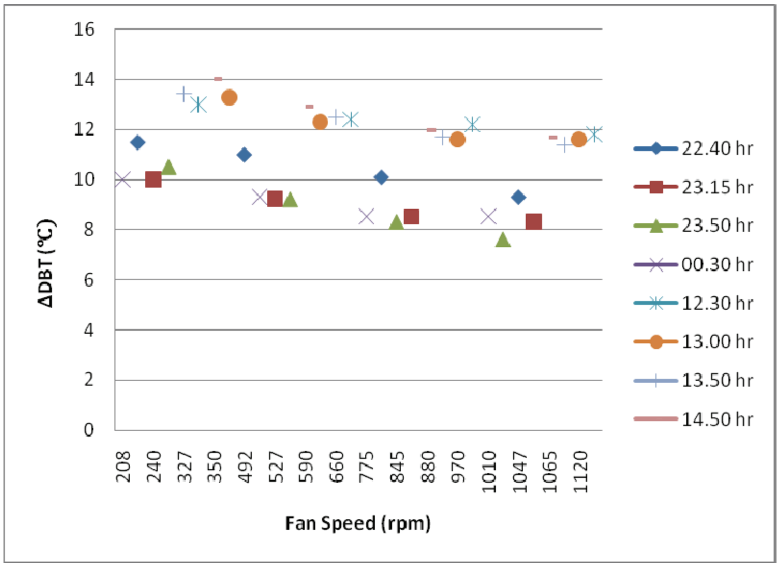


Fig 5. ΔDBT vs Fan Speed

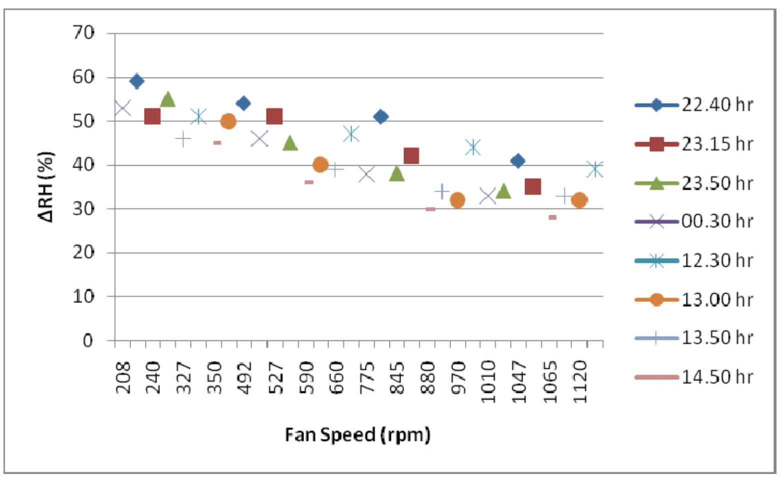


Fig 6. ΔRH vs Fan Speed

The steady state conditions were allowed to reach before recording the observations. The results are plotted in figure 6 and 7 to determine the performance of SIEC. It is evident from the performance graphs that the decrease in DBT reduces with increase in the fan speed i.e. the leaving air temperature increases with increase in the speed of the fan. The variation in the temperature of pipes was found random. In most of the cases the temperature of water reaches the adiabatic cooling value but in very few cases it was recorded below the WBT of the entering air. The effectiveness of SIEC is observed to decrease with increase in the fan speed. In essence, the SIEC can be recommended to achieve comfort during summer in regions like Northern India where the ambient air is hot and dry.

By making some modifications in the design it can act as water cooler as well as water purifier as the water gets cooled to a very low temperature.

7. CONCLUSIONS

After investigating the performance of SIEC, the following key conclusions have been derived:

1. The decrease in DBT reduces with increase in fan speed i.e. the leaving air temperature increases with increase fan speed. The decrease in conventional evaporative coolers is around 5-8°C whereas a temperature reduction of 14°C was achieved in SIEC.
2. The difference in RH of leaving air and entering air decreases with increase in fan speed, the variation being high at lower speed and vice versa. The rise in RH obtained is around 8-10 % whereas the SIEC increases the RH by 30-40 % approximately.
3. In any evaporative cooling system about 30-40% of electricity is consumed by the pump for circulating water at the heat and mass transfer area. The energy efficient SIEC does not use a water circulating pump and hence can result in the direct saving of 30-40% of high grade electrical energy.
4. Capital cost of proposed system is about 20% higher than conventional evaporative cooling system of the same size.
5. The effectiveness of the SIEC has been observed to increase with increase in dryness of outside air.

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