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Regenerative Air Cooler - A Technique to Overcome Thermodynamic Limitation

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ABSTRACT

This paper presents an idea of overcoming thermodynamic limitation of an air cooler. With natural evaporation of water, any substance can be cooled up to Wet Bulb Temperature (WBT) of air, below which there is a need to go for refrigeration. A conventional direct evaporative cooler has been modified by adding regenerative heat exchanger in the path of incoming air stream. Experiments have been conducted to study the performance of the regenerative evaporative cooler. Regenerative air cooler is having higher cooling capacity and is an attractive low energy consuming device alternative for conventional methods of cooling leading to energy conservation in residential and commercial buildings. The cooler uses a part of the cooled air to perform sensible cooling which is not possible with the help of regular evaporative air cooler. It has been found that regenerative cooler is having higher cooling effectiveness with increased COP and it can perform efficiently even in humid climatic conditions.

Keywords: *—COP, Effectiveness, Regenerative, Wet bulb efficiency*

I. INTRODUCTION

Evaporative air coolers (EC) produce more humid and warmer air in comparison with conventional air conditioners. Also for the same cooling capacity more air has to be circulated and working fluid cannot be reused. Evaporation effectiveness is the important key factor in determining the performance of EC's. The efficiency of evaporative air cooling systems is strongly dependent on the state of the atmospheric air. The most suitable conditions for these systems are areas with hot and dry climate. With the evaporation of water any substance can be cooled up to wet bulb temperature of the air. Though evaporative coolers have better cooling capacity, the us age is restricted up to Wet Bulb

Temperature (WBT), and at operating conditions it is more than WBT. However, air cannot reach desired low temperatures with evaporation of water. The air supplied by the evaporative cooler is typically 80–90% relative humidity. Air is close to saturation state reduces the evaporation rate of moisture from the skin, nose, lungs, and eyes. High humidity in air accelerates corrosion, mostly in the presence of dust. This can noticeably reduce the life of electronic and other equipment. An EC can only produce cooling by humidification. It is not possible to perform sensible cooling. Hence the enthalpy always remains the same or sometimes goes up due to EC. For all their benefits and cost savings, air coolers still only work in the right climate. Therefore, new technologies and methods are needed for improved cooling capacity.

II. Literature Review

One of the most energy-intensive process in the ventilation and air-conditioning is the process of cooling. Traditional systems based on the compressor cycle consume lot of energy [1]. Refrigerants based on CFC/ HCFC/HFC are omnipresent in compressor circuits are very harmful to the environment [2]. In conventional systems energy has to be supplied to the compressor, condenser fan and blower. However, in evaporative cooling energy consuming components are blower and pump. Due to lower specific volumes of the water energy required for the pump is almost neglected. These factors led to the active development of evaporative coolers which consume far less energy and are ecological and environment friendly as the working fluids are water and air [3], [4].

Air cooler can perform well in hot and dry climatic conditions. More the degree of un-saturation, lower will be the WBT which can produce lower temperatures from the cooler. The Environmental Protection Agency(EPA) recommends between 30 and 60 percent humidity for human comfort zone. In order to use air cooler in humid climatic conditions and to overcome the thermodynamic limitation of an air cooler, a regenerative heat exchanger is added. To overcome the above limitation, sub WBT evaporative cooling is the solution because it facilitates cooling below the WBT of the ambient air. There are number of studies on achieving sub WBT's by evaporative cooling [5-7]. The soviet scientist Valery Maisotsenko improved evaporative cooling technology and given a modified cooling cycle as Maisotsenko-cycle (M-cycle) [8] which led to the development of regenerative air cooler. The M-cycle relies on the same principles as indirect evaporative coolers but its geometry and air flows are different. The M-cycle uses a unique plate-wetting and channel system that captures the energy available from evaporation to produce low temperatures.

Generally evaporative coolers are suitable for hot and dry conditions, whereas Indirect Evaporative Cooler (IEC) can be used even for humid conditions [9]. The advantage of the IEC compared with the EC is that no moisture is added into the air allowing better air comfort. This type of arrangement has gained growing attention and fast development over the past few decades [10], [11]. Research and development of the IEC were rapidly flourishing. The main focus in literature was found to be optimization of the geometrical and operational parameters related to the heat exchanger [12], analyses of the system performance in terms of cooling effectiveness, COP, moisture entrains dissipation and thermal resistance [13], [14]. Presently a new type of IEC systems i.e., dew point cooling was developed allowing the air to be cooled below the WBT of the incoming air. Research work on IEC system has been reported abundantly in literature [15], [16]. The IEC is completely environmental friendly where the only limitation is the requirement of water.

Majority of researchers have presented their analysis based on two or three stage evaporative coolers. From the open literature few data is available on regenerative heat exchanger. In the present work a regenerative heat exchanger has been added to direct evaporative cooler which pre-cools the air before entering. This method allows for producing air at a temperature lower than that can be achieved with the conventional evaporative cooler by modifying an evaporative air cooler with the addition of regenerative heat exchanger. This method extends the application of evaporative coolers for commercial and other industrial applications.

2.1. Regenerative Air Cooler (RAC)

This type of cooler can be used for both dry and humid climatic conditions. With reference to the psychrometric chart shown in Figure 1, the atmospheric air first cools in the regenerative air to air heat exchanger (process 1-X) sensibly without changing the moisture content present in the air by rejecting heat to the cold sink. The air is further cooled in the cooler (process X-Y). Part of the low temperature air which is coming from the cooler is taken out for the cold sink in the regenerative heat exchanger. This achieves lower temperatures than simple air coolers without further increase in the moisture content. If there is no regenerative heat exchanger the cooling process is represented as process 1-2. From the psychrometric chart it can be observed that lower temperatures can be achieved with the regenerative cooler as opposed to the simple air cooler without increase in humidity content. Since there is no additional work input either, the expected cooling efficiency of the RAC is better than that of simple cooler.

III. Experimental Set-Up

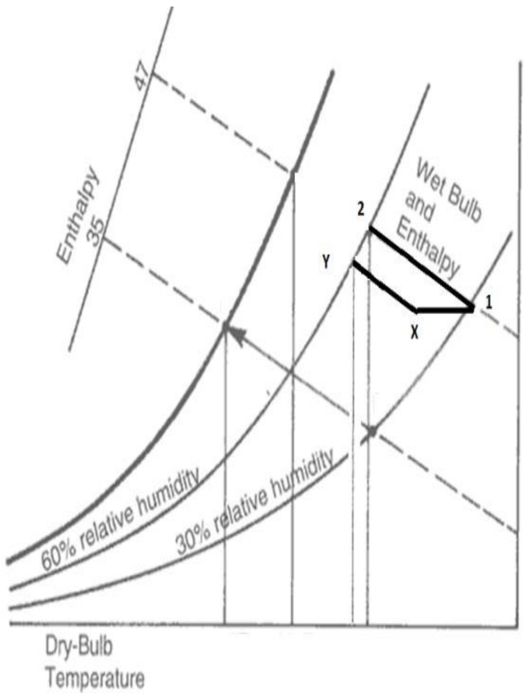

Figure 1: Psychrometric Chart

A RAC is fabricated and tested for the performance evaluation. Photographic view of the experimental setup is shown in figure 2. With help of sling psychrometer the values of DBT and WBT are measured with an accuracy of ±0.3° C. The properties of specific humidity (w), enthalpy and DPT are evaluated using psychrometric relations. Velocity of air is measured using anemometers with an accuracy ±2%. Cooler has been made of galvanized iron sheets of thickness 2 mm. The cooler has a variable speed controller and pump is used to spray water over the pads. Experiments are conducted at various climatic conditions on the simple evaporative cooler and the modified setup with regenerative air cooler. Performance of the regenerative evaporative cooler could be represented by wet bulb effectiveness, Wet bulb depression specific humidity and COP.

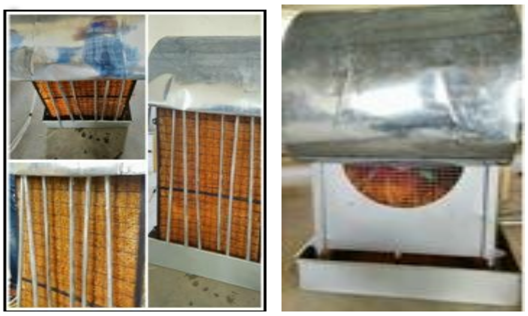

Figure 2 Regenerative Air Cooler

Table 1. Cooler Specifications

Dimensions: l×b×h (mm)	458×585×915
Outlet dimensions(mm)	405
Airflow m^3 /h	0 - 15000
Air pressure(kPa)	115
V/Hz	240/50
Motor	3PH
Fan speed(rpm)	0 - 1400
Blade diameter(mm)	385
Net weight (kg)	56
Water capacity(lts)	12
Override protection	y es
Pump protection	y es

3.1. Wet Bulb Effectiveness

It is the ratio between actual temperature drop across the heat exchanger to that of maximum temperature drop with respect to WBT. It represents the ability of the air cooler to have lo w temperature.

$$\epsilon_{WB} = \frac{DBT_{in} - DBT_{out}}{DBT_{in} - WBT_{in}} \quad (1)$$

3.2. Wet Bulb Depression (WBD)

WBD represents the degree of saturation of the incoming air. When the incoming air is most unsaturated this value is more. So that more temperature drop of air can be expected.

$$WBD = DBT - WBT \quad (2)$$

3.3. Specific Humidity(W)

It is the amount of water vapour that is present in kg of dry air. It represents number of water particles present in the air. Even the value of w is very small but as light change in its value drastically influences the human comfort.

3.4. Coefficient of Performance (COP)

It is defined as the ratio of the cooling capacity of REC to the power supplied. This could be expressed in the following equation

$$COP = \frac{\rho V C_p}{W_{in}} (DBT_i - DBT_o) \quad (3)$$

IV. Results and Discussion

The performance of regenerative air cooler is studied under dry and normal climates. DBT is varied fro m 33°C to 42°C in step of 3°C, while the relative humidity (RH) is varied from 30 to 50% in steps of 10%. Tests are carried out to observe influence of humid it y on the performance of an air cooler with and without regenerative heat exchanger. During the tests RH at the exit to the air cooler is restricted to 70%, beyond which comfort levels decrease.

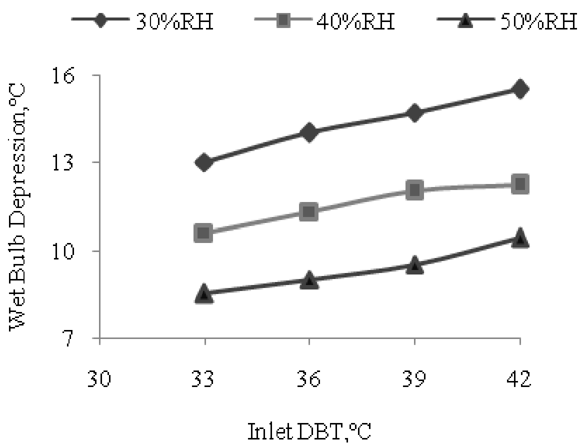

Figure 3 : Inlet DBT Vs Outlet DBT at Different RH

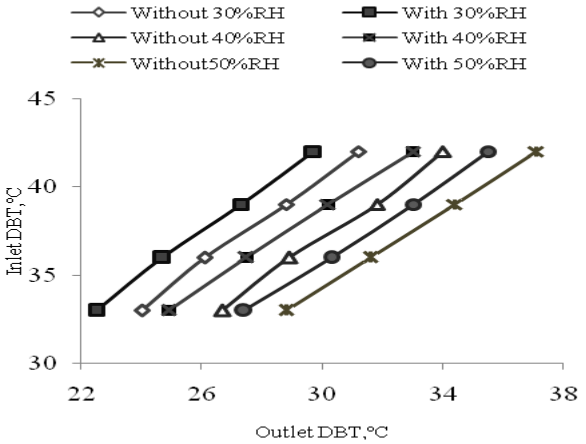

Figure 4 : Influence of WBD at Different RH and Inlet DBT

Influence of RH at different at mospheric temperatures is shown in the figure 3. It is found that with the decrease in the value of incoming air, RH results in higher temperature drop in both the air coolers configurations, with and without regenerative heat exchanger (RHE). At lower RH, air is more unsaturated and is capable of absorbing more moisture thereby taking more heat. With the addition of RHE lower temperatures are produced compared with a normal EC without further increase in the moisture content. This is due to removal of sensible heat from the incoming air in the RHE be fore entering into the wet pads than the EC.

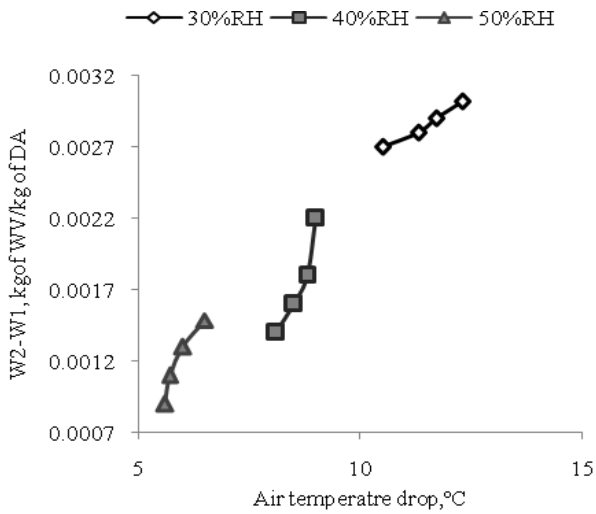

Figure 5: Influence Of WBD at Different RH and Outlet DBT

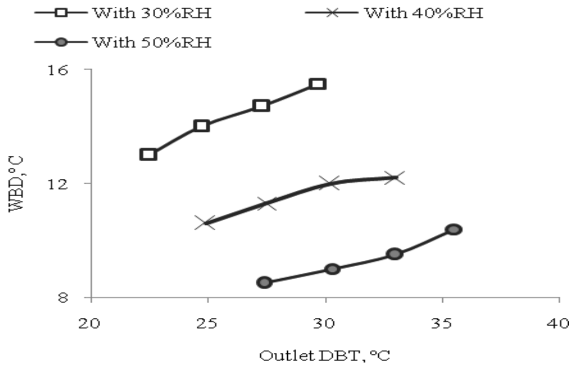

Figure 6: Influence on Air Temperature Drop with Moisture Added at Different RH

Similar results are shown in figure 4 displaying the WBD (WBD=DBT-WBT) at different RH and inlet DBT's. It is observed that WBD increases with decrease in RH and with increase of DBT. This can be attributed that at lower RH air has the capacity to take more heat, resulting in increased WBD. It is known that the water carrying capacity of air mainly depends on the temperature. With the increase in DBT, the capacity of air to absorb moisture increases which leads to increase in WBD. However, with the evaporation of water, any fluid can be cooled up to WBT of incoming air. Figure 5 provides the effect on WBD at different RH and outlet DBT. It is observed that at higher RH values air capacity to abs orb moisture decreases resulting in lower WBD. This increases the air outlet temperature. With decreasing RH, the exiting air DBT is very close to the WBT of incoming air.

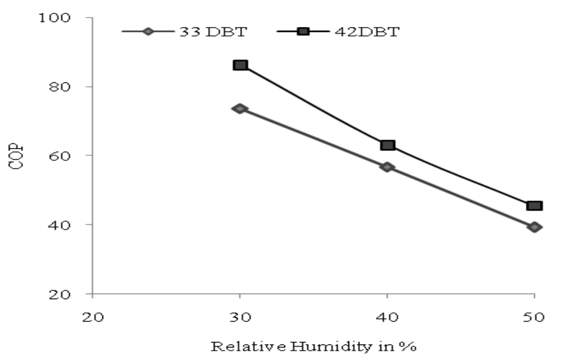

Figure 7: Influence of RH at Different Inlet DBT on the Effectiveness of Air Cooler With and Without Regenerative Air Cooler

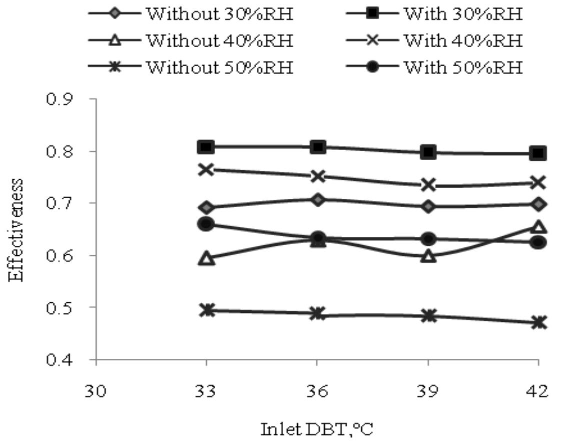

Figure 8: Variation of COP With RH at Different Inlet DBT's

Consumption of water decreases with an increase in RH as shown in the figure 6. More the quantity of evaporated water, lower is the air temperature at the exit to the cooler. Therefore maximum temperature drop (DBT inlet- DB Toutlet) is obtained for 30% RH. Effectiveness is the ability to reach lowest possible temperature with the evaporation of water. From figure 7 it is observed that effectiveness of the regenerative cooler is always better than that of the evaporative cooler for all the selected RH and DBT's. With the addition of RHE atmospheric air is first cooled sensibly without change in moisture content thereby condition of the air entering to the air cooler with decreased DBT and WBT resulting in low temperatures at the exit from RAC than that of the EC. COP (Coefficient of Performance) is measure of cooling capacity to the power consumption. Figure 8 shows the variation of COP at different ambient conditions. Cooling capacity increases with decrease in RH as well as increase in air DBT. The maximum COP is obtained for the hot and dry condition (30% RH and 42°C).

VI. Conclusions

In the present work, regenerative heat exchanger is added to the evaporative cooler and its cooling effectiveness has been studied experimentally at different operating conditions. Based on the experiments the following conclusions are drawn.

- Effectiveness of the evaporative cooler increased with the addition of regenerative air cooler.
- Relative humidity is the dominating factor which influences the cooling performance, with better performance found at around 30% RH value of inlet air
- Maximum COP is obtained for inlet air conditions at 42°C and 30% RH for the range of the parameters tested
- By further modifying the design of the heat exchanger, it is possible to attain temperatures lower than WBT of incoming air

Nomenclature

DBT Dry Bulb Temperature	*RHE Regenerative Heat Exchanger*
WBT Wet Bulb Temperature	*RH Relative humidity*
DPT Dew Point Temperature	*DA Dry air*
WBD Wet Bulb Depression	*wv Water vapour*
CFC Chlorofluorocarbon	*ε Effectiveness*
HCFC Hydro chlorofluorocarbons	*w Specific humidity*
HFC Hydro fluorocarbon	*ρ Density of air kg/m3*
EC Evaporative air cooler	*C_p Specific heat of air, J/kg/K*
IEC Indirect Evaporative Cooler	*W_{in} Energy input, watts*
RAC Regenerative Air Cooler	*V Volume of air, m3*

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