A Comparative Analysis of Experimental & Computational Data of Evaporation Cooler by Varying Cooling Pad Material.

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Abstract: Human comfort which lies at the soul of any psychometric changes is one of the need which has given rise to evaporative cooling system. The evaporative cooling device is one of the cheapest way of providing cool air and being widely used which lends its self for enhancement of efficiency. The computational fluid dynamics is a powerful computational tool which is most widely used for the simulations of all levels of complexity. Parameterization of a system enables the enhancement of system by defining and controlling the parameters of system under study. Various techniques of parameterization whether empirical or approximate study analysis are used to study the parametric data of system. A computational analysis can be carried out with help of commercial CFD software, ANSYS CFX to study the flow pattern of the fluid in the evaporative pads which provides the evaporative cooling system a parametric dimension which can be used to optimize the best material for pad material employed in evaporative cooling.

Keywords: **CFD, ANSYS, Evaporative Cooler.**

I. INTRODUCTION

An evaporative cooling system is a device that cools air through the evaporation of water which reduces the temperature of the air. The air which is cooled by the evaporation of water consumes less energy than the refrigeration. The conventional evaporative cooler uses wood wool as the pad material and the psychometric process followed can be shown in figure1. In dry weather conditions, evaporative cooling of air has added advantage over air-conditioner, as it increases the humidity which increases the comfort of building occupants. The cooling effect of evaporative cooling system dependent on the difference between the wet-bulb and dry-bulb temperatures. Computers are most widely used in computational and simulation work as it can perform the millions of calculations required to simulate the fluid flow problems related to Mechanical engineering. The computational fluid dynamics (CFD) is a computer based tool that uses numerical methods and algorithms to solve and analyze problems that involve fluid flows, heat transfer and other similar physical problems. The commercially available CFD packages uses sophisticated user interfaces to input problem parameters and to examine results.

II. CONVENTIONAL EVAPORATIVE COOLER.

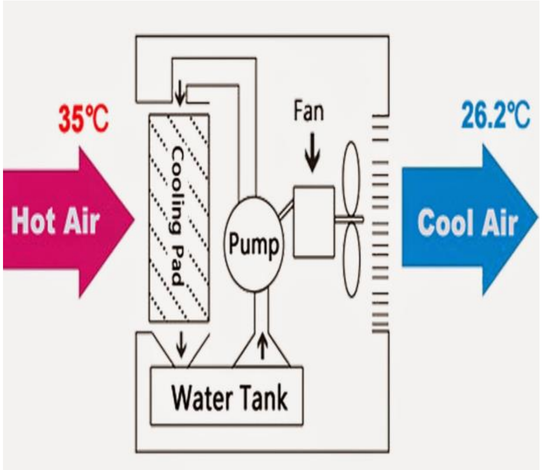

Fig.no.1. Conventional Evaporative Cooler Setup

An Evaporative cooling is a phenomenon in which evaporation of a liquid is entertained into surrounding air. This evaporation of liquid is taken place by absorbing latent heat from air. To find the measurement of water evaporated into air, the Dry Bulb and Wet Bulb temperature are needed to measure for determining the extent for evaporative cooling. The effect of evaporative cooling is considered as more when the differences between the two temperatures are more. When both temperatures remain same, then net evaporation of water in air doesn't occur. Air is passed over a large sheath surface of water where the same water is again and again recirculated by using spray nozzle. The air will take the water vapour and thus humidified. The latent heat of vaporization essential for the change of phase of water into vapour is provided by the air itself and hence the temperature of moist air decreases. The process is known as adiabatic since there is no external heat interaction between whole system and surrounding.

III. RESEARCH METHODOLOGY

The following methodolgy is used for optimizing the best evaporative pad material for evaporative cooler.

- The material for evaporative cooler with higher porosity is selected other than conventional material which is wood wool.

- The porosity of selected material is used to calculate the effective area of evaporation for each material. Then the evaporative cooling Pad geometry is subjected to boundary conditions and the reduction in temperature due to evaporation is calculated.

- The evaporative cooling pad of different material having different porosity will be subjected to CFD analysis using Fluent package of ANSYS using the boundary conditions of evaporation

- The experimental setup is to be fabricated to calculate the evaporative cooling effect for three different pad materials.

IV. Evaporation and Porosity of Cooling Pad

The pad used for evaporative cooling is subjected to continous flow of water from upper side of pad while the fluid which is air is flowing against the cross sectional area of the pad. Thus the water retained by the pad during its downward flow affects the evaporation of water and certainly the cooling effect of the evaporative pad.

Evaporation can be defined as the process where liquid water is transformed into a gaseous state. Evaporation can occur only when water is available. It also requires that the humidity of the atmosphere is less than the evaporating surface (at 100 % relative humidity there is no more evaporation). The evaporation process requires large amounts of energy. For example, the evaporation of one gram of water requires 600 calories of heat energy. Evaporation is often characterised as the removal of moisture from the porous media. The evaporation phenomenon occurs at the surface of the porous medium where the water gets vaporised into water vapour and the pores within the pad get replaced with ambient air. Evaporation is caused by factors such as convection of air, relative humidity, air temperature and infrared radiation. After the water from the surface turns into vapour it gets either replaced with ambient air that fills the pad pores or the pad draws the water from layers above the surface. This phenomenon is caused by the capillary flow inside the porous media where the water flows through hydraulic paths.The purpose of this proposed work is to optimize the best pad material for evaporative cooler which would have higher rate of evaporation than conventional material that is wood wool.

The volume of water retained by the evaporative pads per surface unit has been shown to be directly related to the water flow applied to the pads' upper part. Increasing the flow of water applied to the pads, which is directly related to the water retained in them, did not modify their saturation efficiency or the amount of evaporated water, but it did increase their resistance to the air flow. The porosity of the pads can also be determined as the ratio between the volume of air (Va) and the total volume (VT); or more easily if we know the solid volume of the cellulose sheets that make up the pad (Vs) and the volume of water retained by it (Vl), previously determined for a known volume of sample (VT).

The water vapour concentration is expressed in the Mollier diagram as kg/kg of dry air. The concentration limit in these units is not fixed: it depends on the air pressure. The process of water vaporisation is, however, quite independent of air pressure. The ambient air which is used for evaporating the water from the porous pad material is characterized by the amount of humidity which can be given by using the temperature of air and consequent application of moillers chart for calculation of specific humidity. The ambient temperature of 40 degrees Celsius is used for analysis.

For practical purpose we need to scale down the area of the pad and if we consider the pad material as of area 0.25 m^2 the effective area for evaporation in wood wool would be

Effective area of evaporation = 0.25 x 0.50 = 0.125 m^2

The dimensions of pad for evaporation are found to be 1.64 ft x 1.64 ft.

The thickness of wood wool pad is taken as 30 mm.

Now the heat carried away by evaporation of water from the pad material results in reduction of temperature. The amount of heat carried by evaporation can be calculated as follows.

Heat $q = h_{we} \times g_s$ ....(1)

Where h_{we}= enthalpy of water = 2454 KJ/ Kg

And g_s = amount of water evaporated from the surface of pad which is given by,

$g_s = \Theta \times A\, (x_s - x) / 3600$ Kg/ sec …….(2)

where Θ = 25 + 19 v which is evaporative coefficient in kg/m^2 h

and v = velocity of air above water surface = 0.5 m/sec

A = effective area of water on pad dependent on porosity of pad = 0.125

X_s = maximum humidity of saturated air at 40 degrees = 0.014659 kg/ kg

X = humidity of air = 0.0098 kg / kg

Substituting the above values in equation no. 2 we get value of g_s = 0.01645

Again substituting the value of g_s in equation no. 1

Heat carried by evaporation = 2454 x 0.01645 = 40.39 J

Thus the temperature difference in the air can be calculated as follows

$$Q = m \times C_p \times dt$$

Thus $$dt = Q / mC_p$$

$$dt = 40.39 / 4.2 = 9.6\,^{\circ}C \text{ as } C_p \text{ for water} = 4.2 \text{ KJ/ Kg K}$$

Efficiency of cooling of wood wool pad

For direct evaporative cooling, the direct efficiency measures in what extent the temperature of the air leaving the direct evaporative cooler is close to the wet-bulb temperature of the entering air. The direct efficiency can be determined as follows

$$\eta = (Tea - Tla)/(Tea - Twb)$$

Where:

η = direct evaporative cooling efficiency (%)

T_{ea} = entering air dry-bulb temperature (°C)

T_{la}= leaving air dry-bulb temperature (°C)

T_{wb} = entering air wet-bulb temperature (°C)

the value of temperature inlet air entering the pad media = 45°C

value of wet bulb temperature of inlet air entering the pad media = 30.5°C

value of temperature of outlet air exiting the pad media = 35.4°C

Thus the value of cooling efficiency after calculation is found to be

η = 66.2 %

The other evaporative pad materials with higher porosity selected are Khus and cellulose and the porosity of each are 0.55 and 0.91 respectively. Accordingly the values of porosity are used to calculate the amount of water evaporated from the surface of pad and the amount of heat carried by each pad material. Thus the results of various calculations on the three pad materials can be summarized as follows

Table.no.1. Results for reduction in temperatures

PAD MATERIAL	POROSITY IN %	INITIAL AIR TEMP .in K	FINAL AIR TEMP .in K	REDUCTI-ON IN AIR TEMP in K .	COOLING EFFICIENCY In %
WOOD WOOL	50	318	308.4	9.6 K	66.2
KHUS	55	318	307.5	10.5 K	72.41
CELLU-LOSE	95	318	300.7	12.7 K	87.5

V. ANALYSIS OF COOLING PAD

The evaporative pad material is subjected to the flow of air which while passing the pad material losses its heat due to contact of water retained by the pad material. Thus the interaction of flow of air takes place with water droplets of different sizes which can be analysed using computational fluid dynamics study of the system under the consideration.

ANSYS WORKBENCH is used to analyses the cooling effect of various pad material of evaporative cooler with respect to their porosity. The workbench provides with different forms of analysis such as static , thermal and fluid but the relevant in this system is fluid analysis of the system which would render the effect of porosity or the amount of water retained by the pad material in context of the reduction in temperature of air passing through it. The porosity of conventionally used pad is defined first and then pad with higher porosity are subjected to the analysis of the system.

The Fluent flow analysis module of ANSYS Workbench is being employed for the analysis of three cooling pad material . The boundary conditions of porosity vary for each pad material and the effect is incurred in the for evaporation from the surface of pad. The various boundary conditions and results of fluent flow analysis can be seen below.

The meshing of pad forms the initial step of analysis and is done by using fine mesh option to discretize the assembly into smaller 3 D element as shown in figure below

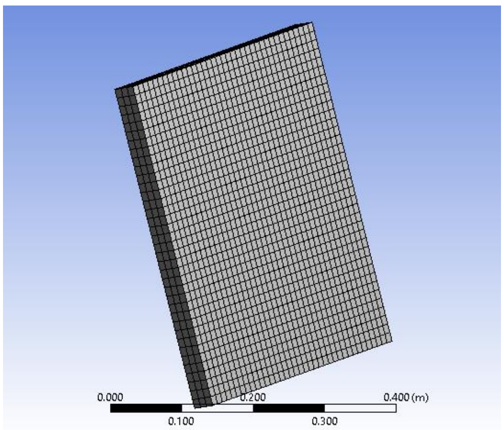

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Fig.no.2. Meshed view of Cooling pad

The application of boundary condition to the meshed component is initiated by providing the discrete phase model to the system which is followed by defining the injection of water droplets as shown in the above figure. The rosin rammler distribution for the pad material is defined in the following way as shown below

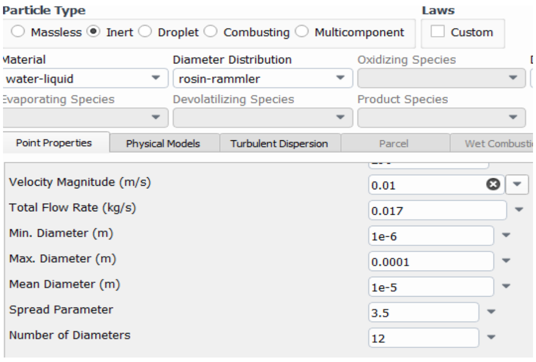

Fig.no. 3 Rosin Rammler distribution of water droplets

The water retained by different pad materials on the account of their porosity can be viewed in the form of rosin rammler droplets as seen on the pad geometry below.

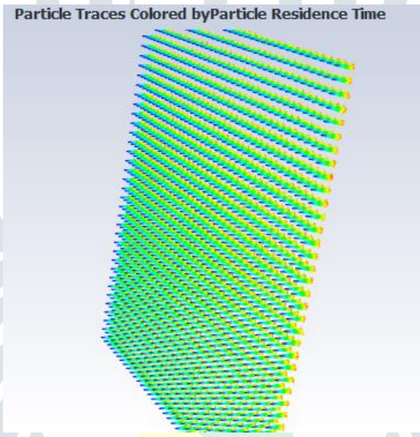

Fig.no.4 Water droplets on the pad material

The results of reduction in temperature for three different pad materials can be seen below.

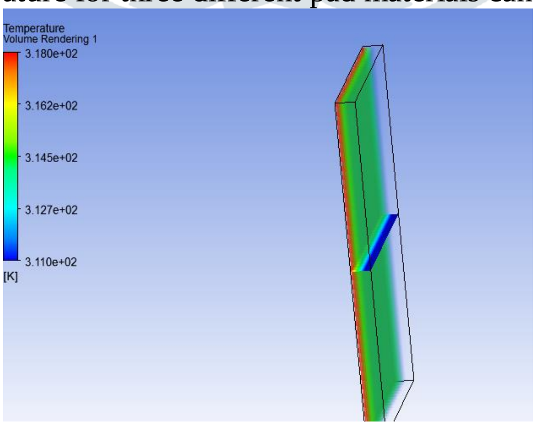

Fig.no5 Result for rduction in temperature for wood wool pad

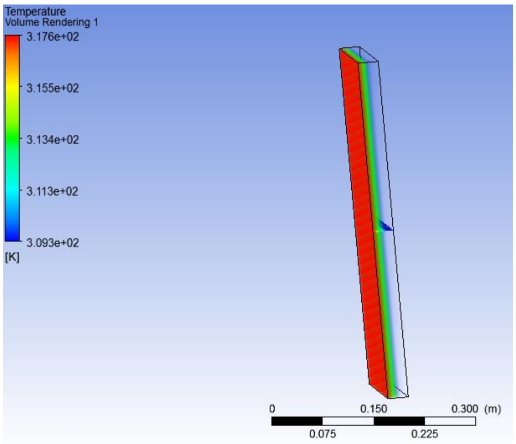

Fig.no6 Result for rduction in temperature for khus pad

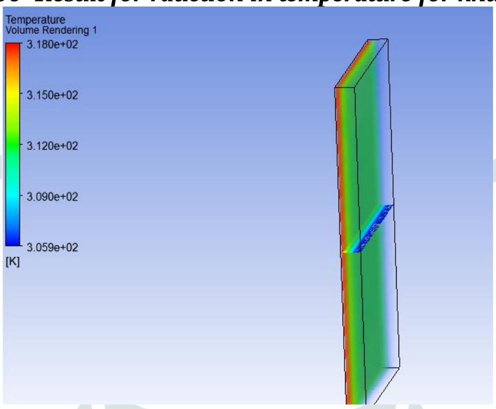

Fig.no7 Result for rduction in temperature for cellulose pad

VII. EXPERIMENTAL SETUP

The process of analysis of evaporative cooler using different pad materials is followed by the experimental analysis of evaporative cooler system. The experimental setup consists of an evaporative whose specification are selected such that a evaporative pad of dimension 1.5 ft x 1.5 ft is installed in the setup. The evaporative cooler is standard brought out which consists of evaporative cooling pad at the rear side of the setup. This process of selection of evaporative cooler is followed by manufacturing of khus and cellulose pad for further analysis. The khus pad is made by combining the khus material and confining to the size of wood wool pad by subsequent spreading and constraining of the khus material. The pad of required dimension is manufactured. The cellulose pad are available in market having different thickness of 2 inch , 4 inc and 8 inch . The cellulose pad of 2 inch thickness is elected and constrained to the dimension of the wood wool pad. The various materials can be seen in following figures.

Fig.no.8.Installation of wool pad

Fig.no.9. Installation of Khus pad

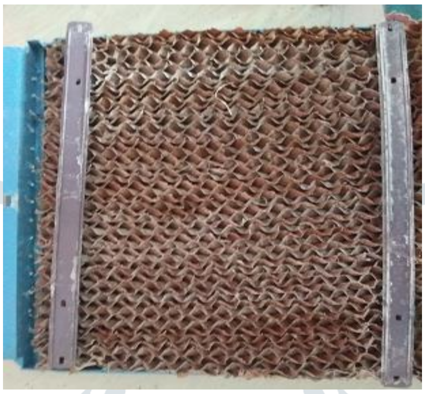

Fig.no.10. Installation of cellulose pad

The procedure of measurement is simple which involves the placing of sensor probe in the air cooled by the pad and projected on the sensor probe by the movement of fan. The wood wool pad is fixed first and the evaporative cooler set up is run for 10 minutes to calculate the stabilized result of the setup. The probe is placed in round dome shaped vessel which is fixed in front of setup so as to take the accurate readings which might have been inaccurate due to interference of the surrounding air.The next step is to take readings at three points along the length of flow of air as shown in figure below and taking this reading for period of 10 minutes each. This is followed by removing of wood wool pad and placing of khus pad to take the readings of khus pad which again is removed and replaced by cellulose pad to do the same.

Fig.no.11 Experimental setup for temperature measurement

VII. RESULTS AND ISCUSSION

The evaporative pad which forms an essential part of evaporative cooler is subjected to change in the material in context of selecting the material having higher porosity than the conventional wood wool material. The boundary conditions of experiment such as temperature of air and water are considered while anlaysing the system of evaporative cooler analytically and by using the computational fluid dynamics approach.

The computational fluid dynamics analysis is followed by the analytical analysis process and the ANSYS fluent software is used for the purpose of calculating the reduction in temperature. The analysis is set with defining the boundary conditions of temperature of air and water and defining the rosin rammler distribution for each mater according to its porosity.

The experimental analysis forms the last step of analysis of cooling pad in which each pad is installed in the position to perform the evaporative cooling operation. With boundary conditions of the pad being same the highest reduction practically was found for cellulose pad.

Table no. 2. CFD results for different pad materials

Property	**CFD Analysis of Cooling Pad**		
Material for Pad	Wood Wool	Khus	Cellulose
Porosity of Pad	0.50	0.55	0.91
Temperature of Water	300K	300 K	300 K
Initial Temperature of Air	318 K	318 K	318 K
Final Temperature of air	310 K	309.3 K	305.9 K
Temperature Reduction	8 K	8.7 K	12.1 K

Table.no.3 Experimental results for different pad materials

Property	**Experimental Analysis of Cooling Pad**		
Material for Pad	Wood wool	Khus	Cellulose
Initial Temperature of Air	318K	318K	318K
Initial Temperature of water	300 K	300K	300K
Final Temperature of Air	309.48K	308.75K	306.95K
Temperature reduction	8.52K	9.25K	11.05K
Initial Humidity	30 %	30%	30%
Final Humidity	62.55%	64.5%	73.23%

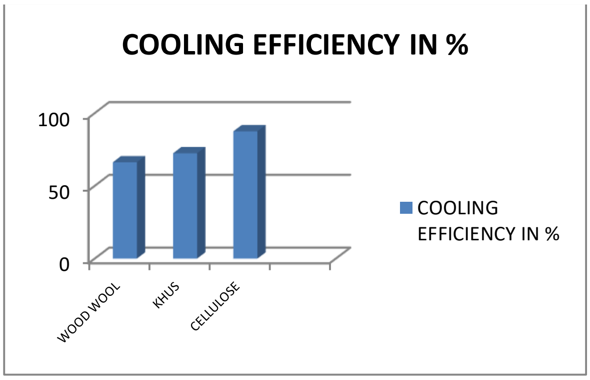

Fig.no.12 Comparison of cooling efficiency for different pad materials

IX. CONCLUSION

The presented work is initialized with selection of higher porosity material than conventional wood wool material. This is followed by calculating the evaporation rate for three different materials and subsequent reduction in temperature is measured analytically. In order to parameterize the system of analysis of evaporative cooler parametrization of the input features is done with aid of computer aided engineering software which is ANSYS fluent. The reduction in temperature is calculated using the software which could define the relation of porosity to the amount of evaporation and the temperature reduction. The process is validated by experiments involving installation and running of evaporative cooler setup.

- The Material conventionally used for evaporative cooler was wood wool which was to be replaced by higher porosity material which are found to be khus and cellulose. The porosity of cellulose is the highest among the three pad materials.
- The porosity of material defines its fluid retention capacity and the effective area available for same ambient air was calculated using analytical process for each material.
- The evaporation rate was calculated with subsequent reduction in temperature and cellulose showed highest reduction of 17.3 K due to higher porosity which leads to higher evaporation and evaporation leads to cooling.
- The analytical process is followed by CFD analysis in which ANSYS Fluent was employed to define the discrete phase in each pad material and the reduction of temperature was calculated .Higher reduction was found for cellulose material.
- The experimental analysis contained the fabrication of setup and corresponding measurement of the temperature which again showed higher reduction for cellulose pad material.

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