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Laboratory Performance Of Evaporative Cooler Using Jute Fiber Ropes As Cooling Media

R.K.Kulkarni*, S.P.S. Rajput**, S.A.Gutte***, D.M.Patil***
*(Department of Mechanical Engineering, TSSM's PVPIT, Bavdhan, Pune-411021, India)
** (Department of Mechanical Engineering, MANIT, Bhopal 462051 India)
*** (Department of Mechanical Engineering, SVPM COE, Malegaon Baramati, Pune-413115, India,)

ABSTRACT: Evaporative coolers use a variety of cooling media like wood wool, cellulose, aspen. This paper analyses the performance of jute fiber ropes as alternative cooling media. They are capable of retaining high moisture and have a large wetted surface area. Hot and dry air is allowed to flow over the wet jute rope bank tightly held between two plates which are integral part of two tanks. The inlet conditions of air varied from 30.5 ^{0}C dry bulb temperature and 52 % relative humidity to 34.5 ^{0}C dry bulb temperature and 32 % relative humidity. Outlet temperature of air is measured and saturation efficiency and cooling capacity are calculated. The outlet dry bulb temperature is obtained between 25.8 $^{\mathbf{0}}$C and 26.2 $^{\mathbf{0}}$C**.**The saturation efficiencies range from 69 % to 59 % and the cooling capacity is obtained between 6173 kJ/h and 11979 kJ/h. Thus jute fiber ropes prove to be a good alternative cooling media in evaporative cooler.
***Keywords* -** Evaporative cooler, Jute ropes, Saturation efficiency, Cooling capacity

I. INTRODUCTION

Evaporative cooling is a physical phenomenon in which evaporation of water into surrounding air cools an object or water in contact with it. The amount of heat needed for evaporation of water is drawn from the air. The wet-bulb depression of air, i.e. difference between dry and wet bulb temperature, is a measure of the potential for evaporative cooling. The greater the difference between the two temperatures, the greater is the evaporative cooling effect. When the temperatures are same, evaporation of water will not occur, and there is no cooling effect. It is one of the oldest methods for cooling, but it has been put on sound thermodynamic footing in recent years. It is a process of adiabatic saturation of air when a water spray is made to evaporate into it without transfer of heat from or to the surrounding. The cooler can be fabricated easily with low initial investment and the operation is simple.

Conventional air conditioning system requires high capital investment and operating costs due to high power consumption. Furthermore, the restrictions imposed by protocols limit the type of refrigerants that can be used in these systems. In contrast, evaporative cooling systems have low power consumption and offer large energy savings. This system uses water, which causes no harm to environment. Therefore; this method can be used for comfort cooling, livestock housing and storage of fruits, vegetables and horticultural produce.

Although the evaporative cooling does not perform all the functions of true air conditioning but it provides comfort by filtering and circulating the cooled air. Evaporative cooling is more effective when dry bulb temperature of inlet air is high and relative humidity is low.

Thus it is more suitable for summer when it is most needed. Many regions in India like part of part of Rajasthan, Bihar, M.P., Vidarbha and north Maharashtra and some hot regions in north have such weather where evaporative cooling works very effectively.

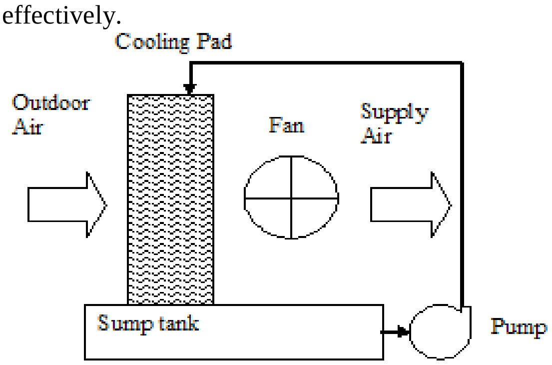

Fig. 1. Direct evaporative cooler

1.1 Direct evaporative cooling system:

Schematic of direct evaporative cooling system is shown in Fig. 1. It uses a fan to pull outside air through media (pads) that are kept wet by spray of water. If the outside air is sufficiently dry and hot, the water evaporates on the surface of pads. The heat required for evaporation is taken from air and air is cooled. The dust particles are trapped on the surface of the pad and washed down along with the water. Thus air is filtered and cooled. The water is delivered via tube from a sump tank with the help of a pump. The tank is supplied with tap water whose level may be controlled by a float valve. The resulting fresh, cool, humidified air is blown into room.

1.2 Indirect evaporative cooling system.

Schematic of indirect evaporative cooling system is shown in Fig. 2. It involves two airstreams: one primary or product airstream and the other secondary or working airstream. Two air streams travel through alternate passages in plate type heat exchanger. The water is sprayed in secondary air channels and this air gets cooled. The absolute humidity of this air increases during evaporation. Primary air travels through alternate channels and gets cooled due to cooling effect created by secondary air. As the primary air stream does not make direct contact with water, moisture is not added and its absolute humidity will not increase. Many researchers have endeavored to improve the performance of evaporative cooling systems by implementing appropriate changes in design, process and materials. Common materials used for cooling media are cellulose,

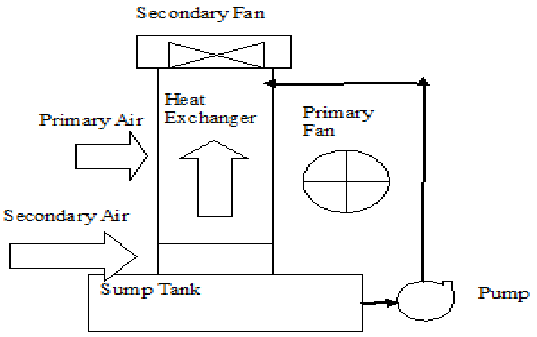

Fig. 2. Indirect evaporative cooler

aspen and woodwool. The alternative materials tried out by researchers are corrugated paper, high density polythene, PVC sponge mesh, jute, date palm and luffa fibers etc.Kulkarni and Rajput (2010) theoretically analysed the performance of jute fiber ropes in the form of rope bank as wetted media in evaporative coolers. They obtained the saturation efficiency values between 57 % and 87 % for different arrangements of rope bank and air mass flow rate between 0.9 kg/s and 0.3 kg/s. Gunhan et al. (2007) made the study to evaluate the performance of pumice stones, volcanic tuff and greenhouse shading net as alternative to commercial CELdek pads. They conducted the tests at different air velocities, water flow rates, and pad thickness. The temperature and humidity during the test was maintained at 30 ^{0}C and 40 %. Their results showed good performance of volcanic tuff material at 0.6 m/s air velocity. Beshkani and Houseini (2005) conducted the work on durable corrugated paper as wet media with wetted surface area of 400 m^2/m^3 and modelled them. Important parameters affecting the efficiency were studied. Anyanwu (2004) designed and tested an evaporative cooler with clay cabinet reinforced with steel wires and coconut fibre as packing material which enhanced water retention capacity of walls. He concluded that performance of such cooler was significantly affected by seasonal weather and it is suitable for short term storage of fresh farm products. Camrago et al. (2004) developed a mathematical model of direct evaporative cooler and presented their experimental results with rigid cellulose media having area density of 370 m^2/m^3. The performance was measured by saturation effectiveness derived in terms of heat transfer coefficient, air mass flow rate; wetted surface area of cooling media and humid specific heat. Jhonson et al. (2003) described the use of hollow fiber membranes in evaporative cooling applications for space air-conditioning. They presented a series of experimental and analytical parametric studies to assess heat and mass transfer phenomena in evaporative cooling with hollow fiber membranes. Liao and Chiu (2002) developed a wind tunnel technique for measuring performance of the pad. They used coarse fabric and fine fabric PVC sponge mesh as wetted media. The fan pad system was simulated on the basis of measurements of air velocity, dry and wet bulb temperatures and pressure drop. The correlations for heat and mass transfer coefficients were formulated for two pad materials. Al-Sulaiman (2002) designed a test set-up to evaluate the performance of jute, date palm and luffa fibers as wetted media. His findings showed that jute has highest cooling efficiency followed by luffa and date palm. Salt deposition was the least for jute; however it had poor resistance to mold forming. There was difficulty in keeping the jute fibers uniformly distributed after wetting and therefore he recommended the treatment of jute fibers to get higher mold resistance. Dai and Sumathy (2002) tested a small household evaporative cooler using durable honeycomb paper as wetted media. Mathematical model was presented and experimentally validated to predict the performance. They predicted liquid gas interface temperature by such model and evaporative cooling process was quantitatively analysed. Taha et al. (1994) fabricated and tested a special type of evaporative cooler which used charcoal granules as an outer wetted layer. Their tests showed 10-13 ^{0}C reduction in ambient temperature. They claimed the use of cooler to maintain vegetables and food below the ambient temperature. Dowdy et al. (1986) tested aspen media experimentally to determine heat and mass transfer coefficients for evaporative cooling process. They presented a method of sizing an evaporative cooler with derived equations. Thus, it is seen that variety of materials that can be used as cooling media in direct evaporative cooler is very large. Hence there is need to analyze the performance of alternative materials in terms of saturation efficiency and cooling capacity. Further, the performance of a cooler using jute ropes as cooling media has not been analyzed. Hence the attempt is made to fabricate and analyze the performance of such cooler in the present work.

II. MATERIALS AND METHODS

Jute is a long, soft, shiny vegetable fiber that can be spun into coarse, strong threads. Advantages of jute are high moisture retention capacity and ease of manufacture with no skin irritations. [14] Jute is biodegradable and does not harm the environment when it becomes a waste.

Hence jute fiber is chosen as media for evaporative cooler. Jute fibers cannot be used in their normal shape because it is difficult to retain the shape after wetting. Hence the jute fibers are used in the form of rope bank. According to theory of rope banks either compact or widely spaced bank can be used for the purpose. But due to fabrication limitations of the fixing plate for ropes, widely spaced bank is chosen for the experimental set up. Surface area of ropes forms the wetted surface for evaporation of water. Water pump used to circulate water over the rope bank. A fan draws hot and dry air over the ropes and water gets evaporated on the surface of ropes. Heat required for evaporation is taken from air as well as water. Hence air gets cooled and its moisture content gets increased. Make up water is added in the tank if required after running the unit for long time. The necessary instrumentation is done for measurement of different parameters.

III. EXPERIMENTAL SET UP

The experimental set up consists of major components such as jute rope bank, inlet/outlet duct, water tanks, fan with motor, pump and required instrumentation. The actual experimental set up is fabricated in local workshop having all manufacturing facilities. Figure 3 shows the schematic of the experimental set up while Fig. 4 shows the actual experimental set up.

3.1 Arrangement of Wetted Media.

Figure 3 shows the arrangement of the jute rope bank inside the frame. The front area of the frame is 0.4 m × 0.4 m and its depth is equal to 0.3 m. Ropes are tightened in upper and lower plates with the wires and held vertically straight. In general, staggered and compact banks achieve higher heat transfer rates when compared to in-line and widely spaced banks (Khan et al., 2006). Therefore staggered array is preferred for the testing. According to the size

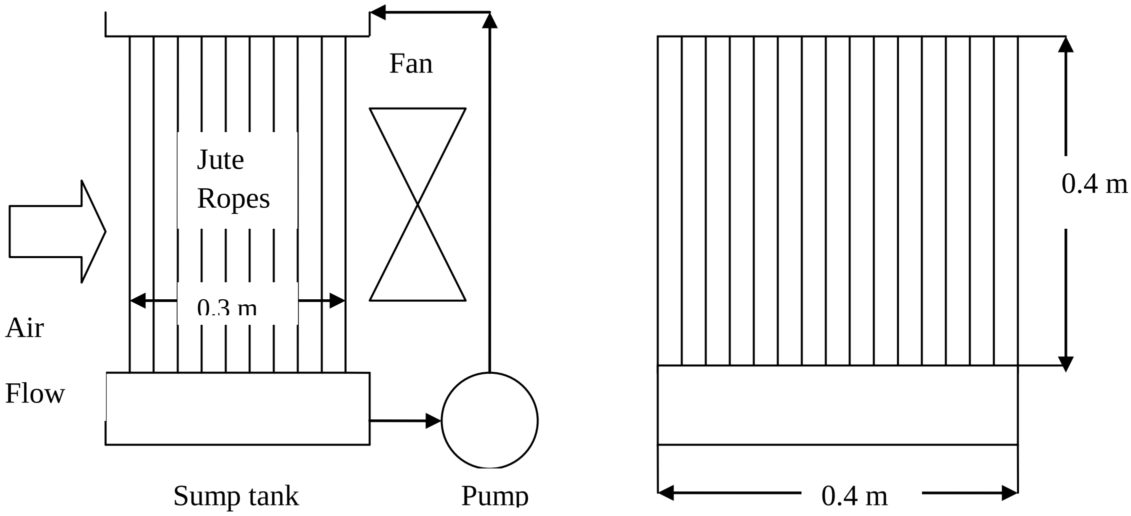

Fig.3 Schematic arrangement of jute rope evaporative cooler

Table 1. Geometrical parameters of rope bank

Parameter	Value
D	28mm
ST	38mm
SL	39mm
SD	39.68mm
N_L	7
No. of ropes in 1st, 3rd, 5th 7th rows	10
No. of ropes in 2nd, 4th, 6th rows	10
N	70
A_w	2.463 m^2

of the rope bank area, the longitudinal pitch is approximately 1.39 D and the transverse pitch is 1.36 D. The width of rope bank area is 400 mm and depth is 300 mm. By leaving a gap of 15 mm on both sides and 10 mm between two rows, 10 rows of the rope are fitted across the width. Similarly, by leaving a gap of 16 mm and 22 mm on sides and 11 mm between two rows, 7 rows of the ropes are fitted across the depth. Thus 70 ropes are arranged in the rope bank area. Total height of each rope is 400 mm and 50 mm margin is kept on upper and lower side. Hence each rope length is 500 mm and total requirement of ropes is 35 m. Table-1 shows the geometrical parameters of jute rope bank arrangement.

These ropes are fixed in upper and lower plates which form the part of upper and lower tank for water circulation. The depth of upper and lower tank is 150 mm. The flow of water is maintained from lower tank to upper tank with the help of a re-circulating pump. The pump capacity is 3800 LPH with head 2.8 m and rated power of 40 W. Thus water continuously drips

through the rope and keeps the ropes wet. The cylindrical surface of each rope acts as wetted surface and the total wetted surface area of the entire rope bank is given by Eq. (1)

$$A_w = N \Pi D H \quad m^2 \tag{1}$$

$$= 2.46 \text{ m}^2.$$

Inlet and outlet ducts for air are fabricated out of mild steel plates to suit the rope bank area. Their depth is 400 mm each. A fan of diameter 380 mm draws the hot air over the jute ropes from the inlet and delivers cool air to the room. Rated power of the fan is 160 W and free air delivery is 4000 m^3/hr.

3.2 Instrumentation

Instrumentation consists of arrangement to measure flow rate of air, power consumed and dry and wet bulb temperatures of inlet and outlet air.

3.2.1 Temperature

Dry and wet bulb temperatures of the air at inlet and outlet are measured by two thermocouples and a temperature indicator. Thermocouples are of J type with the range of -190 to 760 ^{0}C. Temperature indicator has least count of ±0.1 ^{0}C.

3.2.2 Velocity of air

having least count of ±0.1 m. The average

Fig.4. Actual experimental set up

Velocity of air at various points at the inlet and outlet ducts is measured by a vane anemometer velocity is used for the calculation of the flow rate of air.

3.2.3 Power

The energy meter is used for measuring the power consumed by water pump and fan. AC-single phase energy meter with energy meter constant of 3200 pulses/kWh is used for measuring power consumption. Measurement of time for five pulses of energy meter is used for calculation of power.

VI. METHODOLOGY

4.1 Mass flow rate of air

Mass flow rate of air is varied by using fan speed. At every set of reading three flow rates are available corresponding to three fan speeds. It is calculated on the basis of inlet area of the frame for the ropes, density and velocity of air at the entry.

4.2 Ambient Conditions

Dry bulb temperature and wet bulb temperature of inlet air are slightly changed during a short time interval of three hours. Three different set of readings are recorded at 9.00 am, 12 noon and 3.00 pm. These readings are recorded in the month of February and hence much higher ambient temperatures are not prevailing.

4.3 Observations

Each set of reading comprises of velocity, dry bulb and wet bulb temperatures and energy meter reading. Fan speed is also recorded as a part of observations. These readings for a particular day are shown in table 2.

4.4 Performance parameters

Mass flow rate of air is calculated by using the Eq.(2)

$$Ma = \rho \times V_a \times H \times W \quad \text{(kg/sec)} \qquad (2)$$

Relative humidity of air at inlet and outlet is obtained from online psychometric calculator [15]. Saturation efficiency [Watt and Brown 1997] is obtained by using Eq. (3)

$$\eta = \frac{DBT_1 - DBT_2}{DBT_1 - WBT_1} \times 100 \qquad (3)$$

Cooling capacity of such a cooler is obtained by using Eq.(4)

$$Q = Ma \times Cp \times (DBT_1 - DBT_2) \times 3600 \text{ (kJ/h)} \qquad (4)$$

Energy consumed by the fan and pump is calculated from time required for five pulses of energy meter as given by Eqs.(5) and (6).

$$P = \frac{No.of\ pulses}{Energy\ meter\ constant\left(\frac{pulses}{kWh}\right) \times Time\ for\ 5\ pulses\ (hr)} \text{ kw} \qquad (5)$$

$$P = \frac{5 \times 3600}{3200 \times t} \text{ kW} \qquad (6)$$

The performance parameters calculated for various reading sets are shown in table 3. 5**.**

IV. RESULTS AND DISCUSSION

5.1 Fan speed and Mass flow rate of air

Fan speed is adjusted with regulator switch and it is obtained from 1000 to 1360 rpm. Corresponding mass flow rate of air is obtained from 0.3 kg/s to 0.4 kg/s. Approximately same mass flow is obtained for same fan speed at different sets of readings. Density of air average temperature is used for calculation of at mass flow rate in Eq. (1).

Table 3. Performance parameters for jute rope evaporative cooler

Time	Speed (RPM)	Ma (Kg/s)	RH Inle(%)	RH Outlet(%)	Sat. Eff.(%)	Cooling capacity(kJ/hr)	Energy (kW)
9.00 am	1000	0.3623	51	76	58.75	6173	0.1838
	1200	0.3834	52	75	56.96	6255	0.1992
	1360	0.4095	52	74	54.43	6383	0.2036
12.00 noon	1000	0.3028	41	72	61.90	7135	0.1818
	1200	0.3728	39	71	61.46	9055	0.1942
	1360	0.3956	39	71	60.55	9465	0.2016
3.00 pm	1000	0.3098	32	72	68.7	10108	0.1876
	1200	0.3466	32	71	67.94	11183	0.1915
	1360	0.3798	32	78	66.41	11979	0.2045

5.2 Saturation Efficiency

Saturation efficiency gives idea regarding the performance of the cooler with jute material. It ranges from 59 % to 69 % for inlet dry bulb temperature of 30.5 ^{0}C to 34.5 ^{0}C. As dry bulb temperature increases saturation efficiency shows an increasing trend. This is because hot air has low partial pressure of water vapour thereby causing more evaporation of water and air losing more heat to water. Loosely packed jute fibers gave average efficiency of 62.1 % at the air speed of 2.4 m/s in the experiments performed by Al-Sulaiman **(**2002). Thus the jute fibers in the form of ropes are performing better in terms of saturation efficiency. Kulkarni and Rajput (2010) theoretically obtained the saturation efficiency values between 57 % and 87 % for different arrangements of jute rope bank and air mass flow rate between 0.9 kg/s and 0.3 kg/s.

The variation of saturation efficiency with air mass flow rate is shown in Fig. 5. It shows that as the dry bulb temperature increases with time, efficiency increases. At the same time, as mass flow rate of air increases with fan speed, the efficiency shows decreasing trend. This is because air gets less time for contact with water on jute surface and amount of water evaporated decreases. This trend is repeated for three sets of readings at different times.

5.3 Cooling Capacity

Cooling capacity of the cooler based on the mass flow rate is obtained from 6173 to 11979 kJ/h for air mass flow rate values between 0.3 to 0.4 kg/s. The variation of cooling capacity with air mass flow rate is shown in Fig 6. At a particular set of reading, as air mass flow rate increases, cooling capacity increases as greater mass of air being cooled but with moderate saturation efficiency. As dry bulb temperature increases with time, cooling capacity also increases due to increase in saturation efficiency. This trend is repeated for three sets of readings at different times.

VI. CONCLUSION

Jute fibers can be used as an alternative cooling media for an evaporative cooler. These fibers can be used in the form of rope bank to keep them in vertically tight position. The cooler works in a simple manner just like other swamp coolers using conventional materials like woodwool or cellulose. The efficiency of such cooler ranged from 59 to 69 % for inlet dry bulb temperatures from 30.5 to 34.5 ^{0}C. The cooling capacity of the cooler is obtained between 6173
to 11979 kJ/h for air mass flow rates between 0.3 and 0.4 kg/s. Such cooler will be beneficial where conventional materials like cellulose or wood wool are either scarce or not readily available.

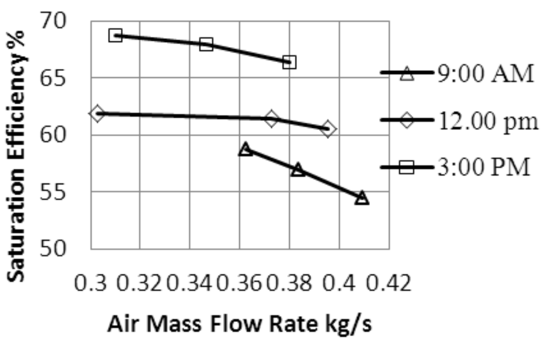

Fig.5 Variation of saturation efficiency

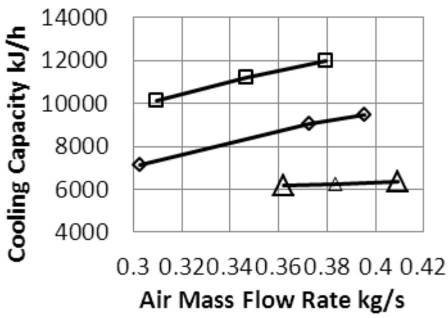

Fig. 6 Variation of cooling capacity

NOMENCLATURE

Aw	total wetted surface area (m^2)
Cp	specific heat of air (J/kg/K)
D	diameter of the ropes (m)
DBT1	inlet air dry bulb temperature (^{0}C)
DBT2	outlet air dry bulb temperature (^{0}C)
H	height of the frame (m)
Ma	mass flow rate of air (kg/s)
N	total number of ropes
N_L	number of rows depth
P	power consumed by fan and pump(kW)
Q	cooling capacity (kJ/h)
SD	diagonal pitch between ropes (mm)
SL	longitudinal pitch (mm)
ST	transverse pitch (mm)
t	time for 5 pulses of energy meter(s)
Va	average velocity of air at the entry to rope bank (m/s)
W	width of the frame (m)
Greek letters	
ρ	density of air (kg/m^3)
η	saturation efficiency of cooler
Acronyms	
DBT	dry bulb temperature
WBT	wet bulb temperature
RH	relative humidity

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