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Performance Evaluation of Alternative Evaporative Cooling Media

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Abstract : In this paper different cooling pads have been studied. Three types of cooling pad made of a cellulose, aspen fiber, and coconut coir were comparatively studied. This study is performed in summer and based on weather conditions of Bhopal, India; maximum dry bulb temperature of air 41.2 ˚C and 26.1 ˚C wet bulb temperature. The relative humidity of 31.1 % is carried out from online psychrometric calculator. The primary air velocity considered varies between 0.5 m/s to 3.0 m/s and the performance of the cooling pads are analyzed based on the saturation efficiency, leaving air temperature, specific humidity, relative humidity, cooling capacity and water consumption. Graphs are plotted for variation in Saturation efficiency and cooling capacity for different materials of pad with air mass flow rate. Saturation efficiency of the cooling pads made of cellulose was in the ranges of 64.55 to 55.29 %, for aspen it was 80.99 to 68.86%, and for coconut coir 68.15 % to 50.79 % was observed. It is seen that the saturation efficiency decreases with increase in velocity of air and the cooling capacity increases with air velocity. It is also observed that the Aspen fiber has higher efficiency while coconut coir has lower and the water consumption rate increases with air mass flow rate.

Keywords : Evaporative cooling, Saturation efficiency, Cooling capacity, Cooling pad, Cellulose, Aspen, Coconut coir.

1.0 INTRODUCTION

Evaporative cooling is a thermodynamic process. When water evaporates from the surface, it provides cooling effect. In adiabatic evaporation process, both heat and mass transfer takes place. The cooling media provides a large water surface in which the air gains moisture and the media is wetted by spraying water. When hot and dry air passes over a wet surface of the pad, the water evaporates and loses its sensible heat and gains equal amount of latent heat of water vapor, thereby reducing its temperature. [1]. When hot and dry air passes over a wet surface of the pad; it decreases process air temperature. The air flow may be counter flow or cross flow. The constant supply of air flow is caused by mechanically driven fan. The evaporative cooling performance depends on characteristics of pad, mass flow rate of air. When air passes through porous wet media, some amount of water evaporates and reduces the air temperature. The temperature of saturated moist air approaches nearly the WBT. The efficiency of evaporative cooling system is directly affected by factors such as type of pad material, thickness of pad and surface area of pads, mass flow rates of air, pad efficiency, dryness of the air and % RH of air passing through the pad and volume of water used. Hence selection of pad requires careful attention. To allow the evaporation process; the evaporative pad material should have good heat transfer characteristics and water absorbing capability.

Nomenclature

Afi	Face area of the pad at inlet (m²)
Afo	Face area of the pad at outlet (m²)
Cpa	Specific heat of air (J/kgK)
Vs	Specific volume of air (m³/kgK)
t1	Dry bulb temperature of ambient air (˚C)
t2	Dry bulb temperature of outlet air (˚C)
tw	Wet bulb temperature of ambient air (˚C)
H	Height of the pad (m)
k	Thermal conductivity of air (W/mK)
l	Thickness of the pad (m)
Qc	Cooling capacity (kJ/h)
Qw	Water consumption rate (Kg/hr)
RH	Relative humidity of air (%)
ρ	Density of air (kg/m³)
η sat	Saturation efficiency (%)

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Va	Average velocity of air through the pad (m/s)
Vf	Volume flow rate of air (m^3/s)
Vi	Velocity of air at the inlet of pad (m/s)
Vo	Velocity of air at the outlet of pad (m/s)
Vp	Volume of the pad (m^3)
W	Width of the pad (m)
ωi	Specific humidity of inlet air (kg/kg of dry air)
ωo	Specific humidity of outlet air (kg/kg of dry air)
ν	Kinematic viscosity of air (m^2/s)

2.0 LITERATURE REVIEW

Many researchers examined the performance of cooling pads in respect of mass flow rate, air velocity, thickness of pad and types of pad material.

Abdollah et al. [2] has found maximum efficiency at velocity 1.8 m/s for thickness 150 mm in pad 5090, on other hand the maximum pressure drop occur at thickness 75 mm for pad 7090 and velocity 1.8 m/s. Furthermore the minimum evaporated water is about 0.06 lit/min for thickness 75 mm at 1.8 m/s air speed in pad 7090. They concluded that when the air speed decreases and pad thickness increases, the optimum point may occur. R. K. Kulkarni and S.P.S. Rajput [1] observed that the saturation efficiency decreases with increase in mass flow rate of air. They have also seen that material with higher wetted surface area gives higher saturation efficiency and they obtain result, the Aspen material gives highest efficiency of 87.5 % while cellulose material gives lowest efficiency of 77.5 %. J.K. Jain, D.A. Hindoliya [3] concluded that performance of palash fibers to be better than that of other materials. They found effectiveness of palash fiber was 13.2% and 26.31% more than that of aspen and khus fibers respectively. The effectiveness of pad with coconut fibers was found to be 8.15% more than that of khus and comparatively with that of aspen pad. Palash fiber is well known material and has good water retain capability; it may be a better alternative to aspen fibers. Coconut fibers are also easily available and found to be better than aspen fibers. And they also observed that the Palash fiber offers about half the pressure drop compared to that of aspen. Therefore, these fibers may also be used as wetted media in evaporative cooling devices for higher effectiveness. Faleh Al-Sulaiman [4] has designed special setup to evaluate the performance of natural fibers. He found the results that the average cooling efficiency is highest for jute at 62.1%, compared to 55.1% for luffa fibers, 49.9% for the reference commercial pad and 38.9% for date palm fiber. And summarized the material degradation, the Jute has the least salt deposition with 4.8% (g of salt/g of dry fiber). Palm fiber and luffa have 27.3% and 37.2% respectively and commercial fiber has the highest amount of salt deposition (82%). And also found the mold formation highest for the jute fibers. Almost all the surface was affected (96.6%).Luffa has the lowest mold formation (8.6%). Palm and commercial fibers have 52.6% and 76%, respectively. Lateef L. Akintunji et .al. [5] has analyzed the performance of coconut coir pad as a media in direct evaporative coolers. The primary air mass flow rate considered varies between 0.16 kg/s to 0.54 kg/s and the performance analysis of the coconut coir pad is based on the saturation efficiency, leaving air temperature, relative humidity, cooling capacity and water consumption. They found the results of the analysis of the coconut coir based on the air flow rates considered reveal that the saturation efficiency decreases from 64.7% to 55.9%, the leaving air temperature increases from 25.20C to 27.10C, relative humidity decreases from 46.4% to 38.2%, the cooling capacity increases from 8230kJ/h to 24055.kJ/h and the water consumption increases from 3.57kg/h to 9.72kg/h. And from the results they concluded that the coconut coir pad performed better at lower air mass flow rates where lower leaving air temperature and relatively higher relative humidity are obtained. Banyat Niyomvas and Bunjerd Potakarat [6] have studied the efficiency of two different type of cooling pads made of a curtain fabric and a raw cotton fabric. They analyzed the effect at different speed of blower at 725, 1015, 1450 rpm and investigated the water flow rate 26 lit/min. And also found the saturation efficiency range between 46.3 to 61.3 % for curtain fabric and 29.7 to 39.2 % for raw cotton fabric. An average inlet and outlet temperature difference were 2.9 and 1.7 for a curtain fabric and a raw fabric, respectively.

3.0 METHODOLOGY

To compute the cooling performance of the pads, a special cooling chamber is designed and fabricated. The chamber is hollow square duct, size (0.6 x 0.6) and length 0.75 m, made of GI (galvanized iron) sheets. A suction fan is fitted at one

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end and the cooling pad box is designed box type to slide in the other section of the chamber. An inlet water tray is fitted on the top of the cooling box section. Several small holes provided in the tray to insure uniform distribution of the water. A drainage hole is also provides in the bottom of the pad box.

Two digital thermometers are used on each side of the pad for measuring the inlet and outlet tempeture of air. Several other devices are used, such as an anemometer to measure the air velocities and electronic regulator to control the speed of the fan for fixing the air velocity. A precise testing procedure is implemented in this study. The experiments are performed for each type of pad. In this experiment, average readings are recoded. The relative humidity of ambient air is calculated online.

3.1 Ambient condition

The experiment was usually performed in the peak time of the summer month. The inlet and outlet tempeture are noted down from the thermometer reading, and wet bulb temperature (Twb1) is from the psychrometer reading. The experiment was carried out on the ambient temperature of 41.2 ˚C**,** wet bulb temperature (Twb1) of 26.1 ˚C and relative humidity (RH) of 31.1 %.

Specific volume (*Vs*) = 0.9113 (calculated by online psychrometric calculator) [6].

$$\rho = \frac{1}{Vs} \text{ kg/m}^3 \qquad \text{.....(1)}$$

Where *Vs* is 0.9113 m^3 /kg

C_{pa} = 1007 J/kgK , and ωi is 0.01615 kg/kg of dry air

3.2 Air mass flow rate

The inlet and outlet velocities of air through the pad are measured and Volume flow rates are calculated by considering the density at selected ambient condition. The velocities of air through the cooling pad are taken 0.5, 1.0, 1.5, 2.0, 2.5, and 3.0 in m/s. The mass flow rate of air is calculated by the formula on the basis of the frontal area of the pad, velocity of air and density.

$$Ma = \rho \times Vf \qquad \text{.....(2)}$$

3.3 Geometrical parameters

Three different types of pads are considered in this study. The position of pad is in such a way that air passes across the pad horizontally. In this position of pad only one dimensional cross flow of air takes place.

(1) Cellulose Pad (2) Aspen Pad (3) Coconut Pad

Fig: 1 Different type of cooling media

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The thickness of the pads are considered 0.1 m. Face area is taken as the area of the pad through which air enters the pad and is calculated by using equation

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$Afi = W \times H$ …..(3)

Volume of the pad is given by

$Vp = W \times H \times l$ …..(4)

Volume flow rate of air

$Vf = Vi \times Afi$ …..(5)

In this study inlet and outlet velocities are same, so volume flow rate at inlet and outlet of the pad will be same.

Table 1. Geometrical parameters of the cellulose cooling media

l	0.1
Vp	00275
Afi	0.275
Afo	0.275

4.0 COOLING PAD PERFORMANCE PARAMETERS

The inlet temperature of air t_1 is 41.2 ℃, wet bulb temperature of air t_w is 26.1 ℃, and relative humidity *RH* is 31.1%.

The saturation efficiency of cooling pad is calculated based on the following relation [3]

$$\eta\ sat = \frac{[t1 - t2]}{[t1 - tw]} \times 100 \qquad \text{…..(6)}$$

η sat = Saturation efficiency, t_1 = Ambient temperature, t_2 = outlet temperature from pad, tw = bet bulb temperature of outside air.

As the evaporative cooling proceeds along constant wet bulb line, it means that the wet bulb temperature of the inlet and outlet air is the same i.e. 26.1 ˚C. Relative and specific humidity of the leaving air is determined by the online psychrometric calculator [6]

Cooling capacity of evaporative cooling pad is expressed as equation [5]

$$Qc = Ma \times Cpa \times [t1 - t2] \times 3.6 \qquad \text{…..(7)}$$

The water consumption rate which is a function of the specific humidity and the mass flow rate of air are calculated from equation

$$Q\omega = Ma\,[\omega o - \omega i] \times 3600 \qquad \text{…..(8)}$$

The above parameters are calculated for different media and mass flow rates of air and shown in table 3 for cellulose material pad and in tables 4, 5 shows for aspen and coconut fiber pad respectively.

5.0 RESULTS AND DISCUSSIONS

Table 2, 3, and 4 shows the performance parameters for evaporative cooling pad of cellulose, aspen, and coconut coir respectively.

Table 2. Performance parameters of the cellulose cooling media

Vi	0.5	1.0	1.5	2.0	2.5	3.0
Vo	0.5	1.0	1.5	2.0	2.5	3.0
Vf	0.138	0.275	0.413	0.55	0.688	0.825
t_2 ℃	30.63	31.41	31.88	32.2	32.44	32.64
Ma	0.151	0.302	0.453	0.603	0.754	0.905
η sat %	69.58	64.55	61.4	59.34	57.73	56.4
ωo	1.94×10^{-2}	1.91×10^{-2}	1.89×10^{-2}	1.88×10^{-2}	1.87×10^{-2}	1.86×10^{-2}
RH	69.73	65.59	63.22	61.66	60.51	59.56
*Qc*KJ/hr	5786	10718	15305	19674	23945	28084
$Q\omega$ Kg/hr	2.18	4.03	5.72	7.4	8.98	10.46

Table 3. Performance parameters of the aspen cooling media

Vi	0.5	1.0	1.5	2.0	2.5	3.0
Vo	0.5	1.0	1.5	2.0	2.5	3.0
Vf	0.138	0.275	0.413	0.55	0.688	0.825
t_2 ℃	28.91	29.62	30.04	30.38	30.60	30.79
Ma	0.151	0.302	0.453	0.603	0.754	0.905
η sat %	80.99	76.31	73.55	71.35	69.88	68.86
ωo	2.02×10^{-2}	1.99×10^{-2}	1.97×10^{-2}	1.95×10^{-2}	1.94×10^{-2}	1.94×10^{-2}
RH	79.79	75.47	73.03	71.11	69.89	68.86
Qc KJ/hr	6328	12678	18327	23652	28974	34153
$Q\omega$ Kg/hr	2.61	5.00	7.03	9.12	10.88	10.88

Table 4. Performance parameters of the coconut coir

Vi	0.5	1.0	1.5	2.0	2.5	3.0
Vo	0.5	1.0	1.5	2.0	2.5	3.0
Vf	0.138	0.275	0.413	0.55	0.688	0.825

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t_2 °C	30.86	32.23	32.76	33.06	32.72	33.5
Ma	0.151	0.302	0.453	0.603	0.754	0.905
η sat %	68.15	59.14	55.65	53.65	55.87	50.79
ωo	1.93×10^{-2}	1.88×10^{-2}	1.85×10^{-2}	1.84×10^{-2}	1.85×10^{-2}	1.82×10^{-2}
RH	68.48	61.51	59.01	57.63	59.19	55.68
Qc KJ/hr	5660	9820	13860	17794	23179	25262
$Q\omega$ Kg/hr	2.13	3.71	5.07	6.53	8.44	9.15

5.1 Cooling capacity

The cooling capacity with different velocity shows in fig. 2. If velocity of air increases, the mass flow rate of water is also increases; hence the cooling capacity of air is increased. The cooling capacity range 5786 to 28084 kJ/h for cellulose, 6328 to 34153 kJ/h for aspen, and coconut has lowest capacity range 5660 and 25262 kJ/h. The cooling capacity is increased with increase in velocity of air for all pad material.

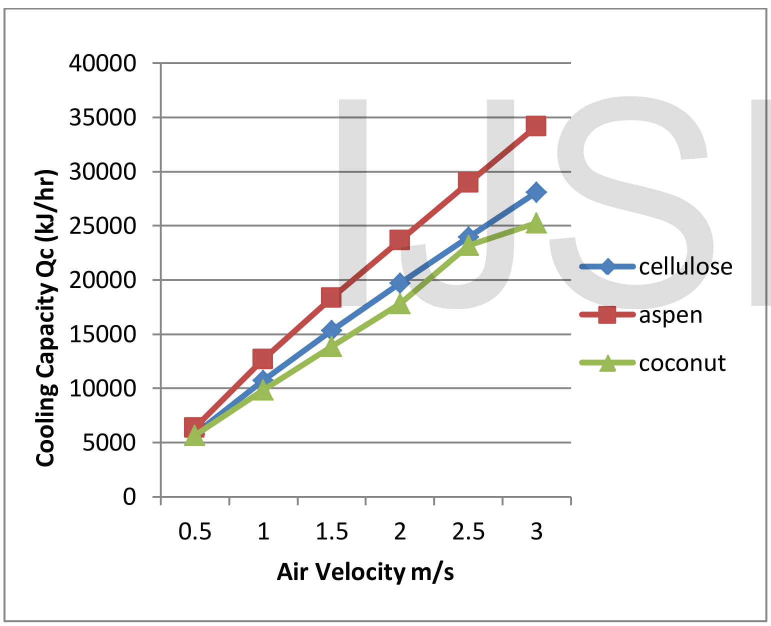

Fig : 2 Cooling capacity of different media

5.2 Saturation efficiency

The variation in saturation efficiencies with mass flow rate of air through the evaporative cooling media are shown in fig. 3. The saturation efficiency range between 69.58 % to 56.4 % for cellulose, 80.99 to 68.86 % for aspen and range between 68.15 to 50.79 % for coconut coir at different velocity range between 0.5 to 3 m/s of air. The saturation efficiency is a function of air velocity. Saturation efficiency decreases with increase in velocity of air, because air has lesser contact time to cause evaporation of water. It means that there is an inverse relation between mass flow rate and saturation efficiency. The efficiency of aspen material has higher than the cellulose and coconut coir.

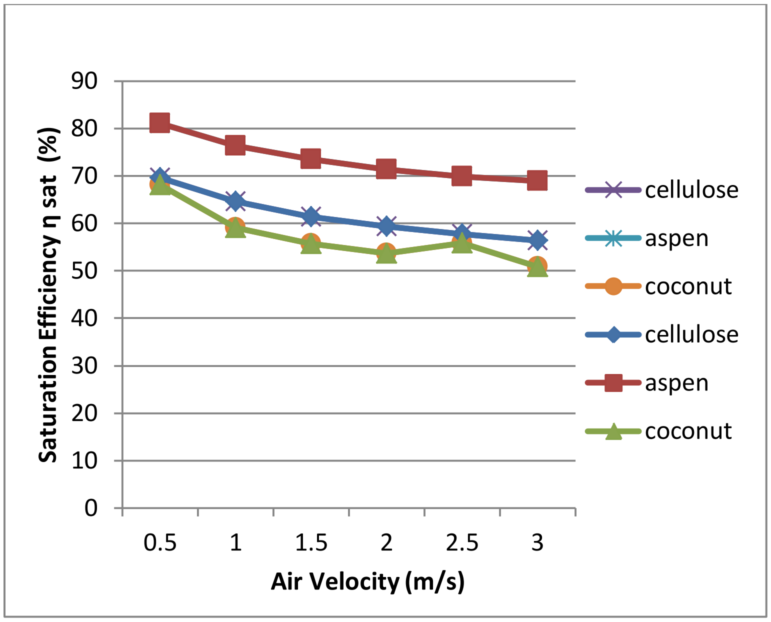

Fig: 3 Saturation efficiency of different media

5.3 Leaving air temperature

Fig. 4 shows the relation between air velocity and leaving temperature. The leaving air temperature range 30.63 to 32.64 ℃ for cellulose, range 28.91 to 30.79 ℃ for aspen and the coconut coir has higher temperature range 30.86 to 33.5 ℃. From the fig. 4 the leaving temperature of air increases with increase in air velocity. The efficiency and cooling capacity are depends on the difference of the ambient temperature and leaving air temperature. If the leaving air temperature is high the efficiency and cooling capacity of the pad are low.

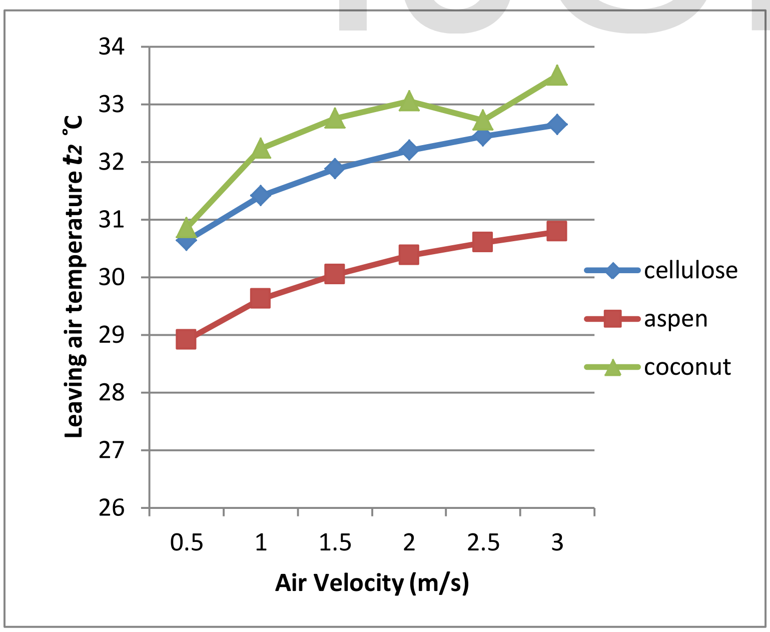

Fig: 4 Air leaving temperature for different media

5.4 Relative humidity

Fig. 5 shows the relation between relative humidity and air velocity. The relative humidity decreases with increase in velocity of air because mass flow rate of water is increased. The relative humidity of air increases if the contact time of air with wetted pad is increased. RH of the aspen pad is higher than with both evaporative pads.

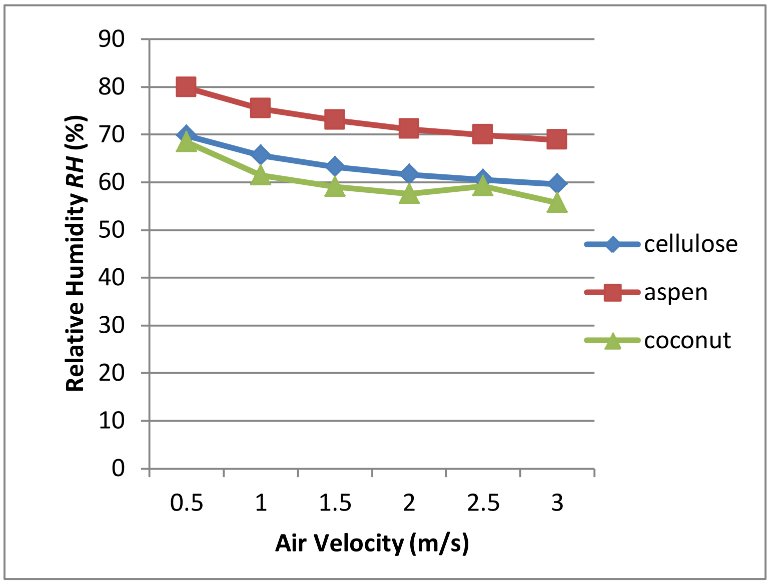

Fig: 5 Humidity variations for different media

5.5 Water consumption rate

Fig. 6 shows the water consumption rate varies with air mass flow rate; therefore it increases with air velocity. In result found that aspen has high cooling capacity range 6328 to 34153 kJ/h, cellulose has range 5786 to 28084 kJ/h, and coconut has lowest capacity range 5660 and 25262 kJ/h.

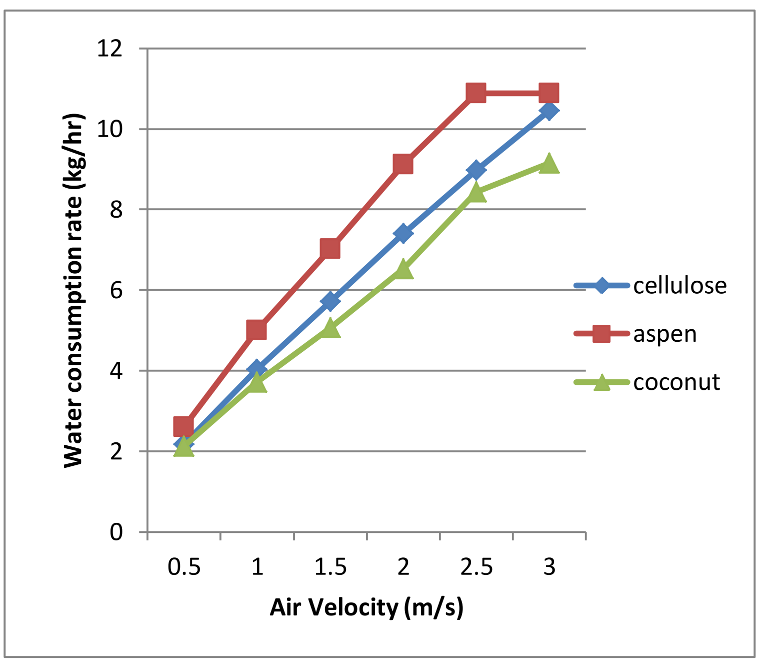

Fig: 6 Water consumption rate for different media

6.0 CONCLUSION

The results show that the saturated efficiency at air velocity 0.5 m/s is highest for aspen material at 80.99% compared to 69.58% for cellulose pad, 68.15% for coconut coir. From these results, it can be concluded that efficiency depends upon thickness of the pad because higher thickness of pad increases the contact surface area. And saturation efficiency also depends on the velocity of air passing through the pad. Higher velocity causes less contact time for evaporation of water. The saturation efficiency of pad depends upon the wetted surface area of the pad because higher wetted surface area causes grater evaporation of water into air, thereby decreasing the temperature of air. The leaving temperature of air increases with increase in the air mass flow rate while the relative humidity decreases with increase in the mass flow rate of air. The performance of coconut coir is also well, it has good water soaking ability, and its performance graph is almost near the cellulose pad; so it may become another alternative option of cooling pad.

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