ME 311 Fluid Mechanics and Heat Transfer

Solar Paper Pulp Tile Dryer

Prof. Atul Bhargav

Radhika Patil, 12110069

Shrey Shah, 12110093

M Surya, 12110104

Introduction

Drying paper pulp is one of the most energy consuming processes in the paper manufacture industry. Almost half to equal amount of water as that of other materials needs to be evaporated for drying. A dryer is used in the last stage of pulp and paper manufacturing after pressing and other processes which also aid removal of water.

Generally, steam drying systems are used for drying paper on a large scale.

The aim of this project is to design a dryer system for drying paper pulp tiles using solar air heater.

Weather Data File:

Location: Ahmedabad, Gujarat, India.

Latitude: 23.03^{o} N

Longitude: 72.58^{o} E

Year of Data: 2011

Source: http://rredc.nrel.gov/solar/new_data/India/nearestcell.cgi

Data used –

Direct Normal Irradiation (DNI)

Diffuse Horizontal Irradiation (DHI)

Global Horizontal Irradiation (GHI)

Ambient Temperature (T_{surr})

Pressure (P)

Assumptions in the analysis:

Tile – Length (L) = Breadth (B)=1m

Area (A) =1m^2

Mass = 1kg

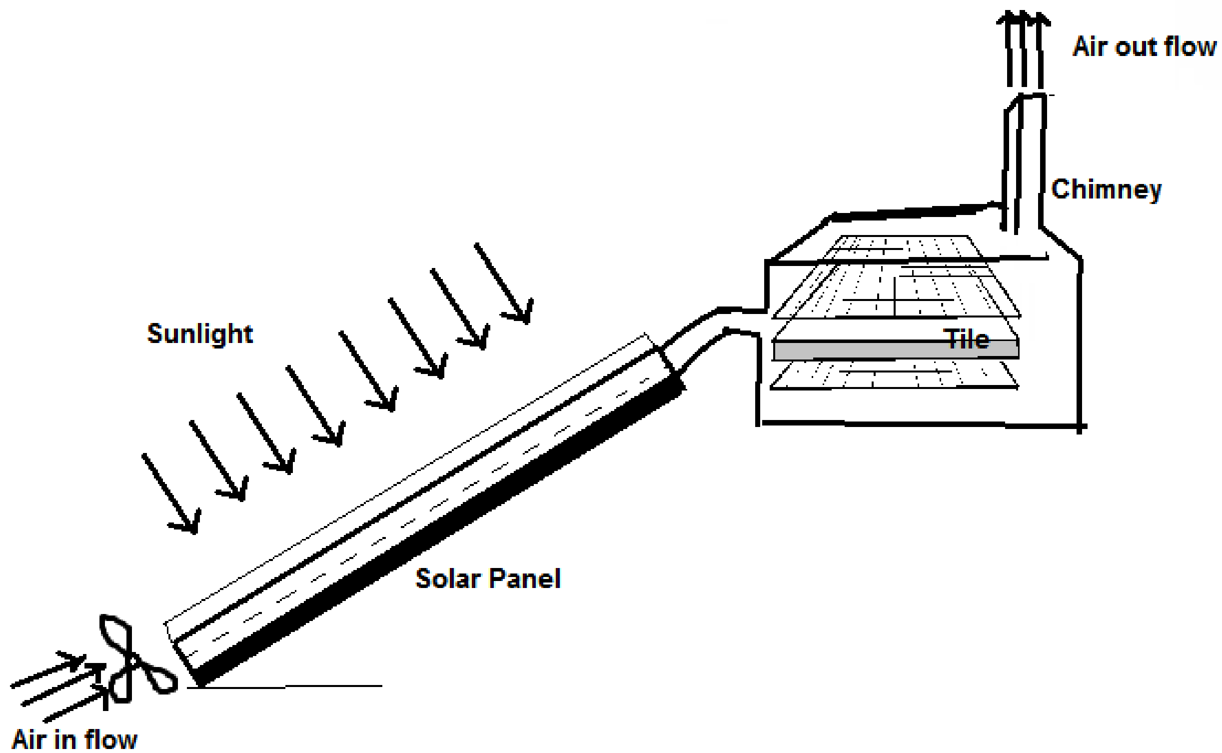
Mass of water in the tile = 100 g

Thickness is assumed to satisfy the density of the mixture to fit the dimensions.

Temperature of the tile = ambient surrounding temperature

Air – Ambient air is assumed to be dry, i.e. humidity =0%

Design of the system:



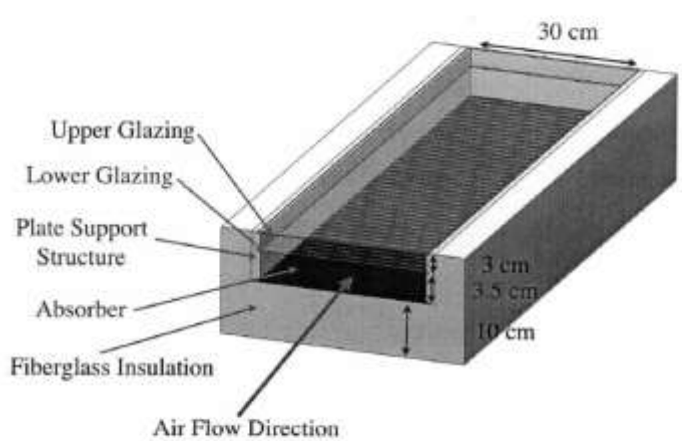
The system consists of one solar panel for drying one tile. Multiple panels may be used to dry multiple tiles.

Solar Panel: The Solar Panel is as per the design proposed in the following paper-

High Efficiency Solar Air Heaters with Novel Built-in Storage for use in a Humidification-Dehumidification Desalination Cycle, Edward K. Summers, Mechanical Engineering, June 2010, Massachusetts Institute of Technology.

The design is as follows-

The panel consists of aluminum absorber base coated with carbon black paint (α=0.96, ε=0.88), and double glazing of low iron glass glazing panels.



The outside is insulated with fiberglass insulation. It is without storage. The frame and other parts were made by wood to provide insulation.

The panel angle from the ground is kept as 45^{o}.

The efficiency of this panel is theoretically, η=58% as per the paper.

Air is blown in the solar panel using a fan from the bottom such that velocity of the air in the panel as well as in the dryer is v=0.1m/s.

The mass flow rate is adjusted as $m^{'}$= 0.03 kg/s

From the panel area exposed to sunlight,

$$P_{in} = I_g \times \ (Area\ of\ panel)$$

I_g = Total irradiation of sun on the panel.

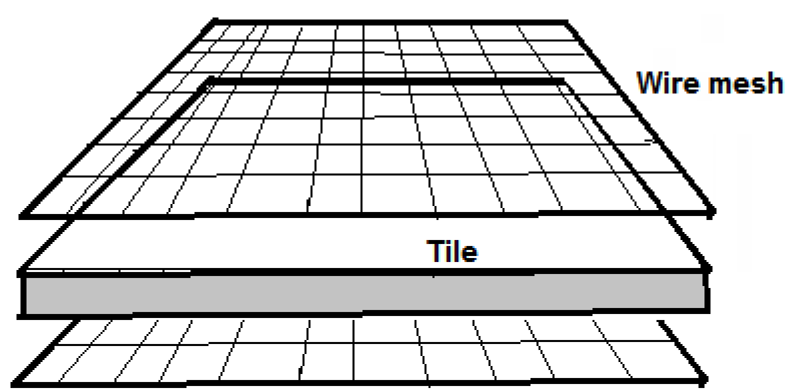
The value of I_g is calculated by the Solar Irradiation data provided.

Therefore, the rate of energy supplied to the air P_a= ηP_{in}

and the temperature rise of the air = $P_a/m^{'}c_p$

Dryer:

The tile is placed in between two wire meshes to support it and let air flow on both sides. The wire mesh also helps to induce turbulence in the air flow. Air leaves the dryer by a chimney, so that by natural convection, it will flow up and not re-circulate as it contains moisture.

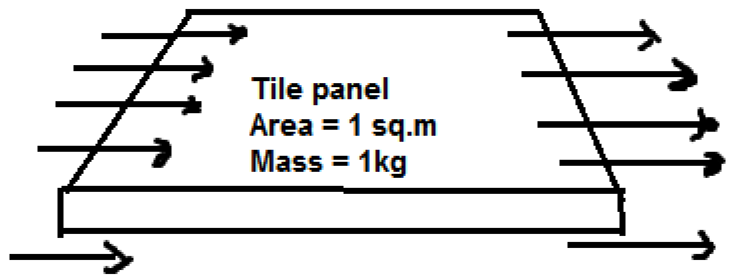


Energy required for Drying:

Assuming that Air at temperature T_o flows on both sides of the tile which is at T_{surr} temperature,

$$Net\ mass\ flow = mass\ flow\ by\ convection + mass\ flow\ by\ evaporation$$

Therefore for one side of tile,



$$\frac{dm}{dt} = \frac{h\,(\Delta T)}{h_{fg}} + h_m \rho_s$$

$$h = \overline{Nu}\, k/L$$

$$\frac{h_m}{h} = \left(\frac{Sc^{1/3}}{Pr^{1/3}}\right) \frac{D_{H2O,air}}{k}$$

Considering turbulent flow over flat plate,

$$\overline{Nu} = 0.68 Re^{1/2} Pr^{1/3}$$

$$Re = \frac{vL}{\upsilon}$$

v= velocity of air flowing over the tile = 0.1m/s

υ= 1.5 x 10^{-5} m^2/s

k = 0.03 W/mK

Pr = 0.7

$D_{H2O,air}$ = 24×10^{-6}

Sc=0.66

$\rho_s = P_s\, M/RT_s$

$h_{fg} = 2260 \times 10^3$ J/kg

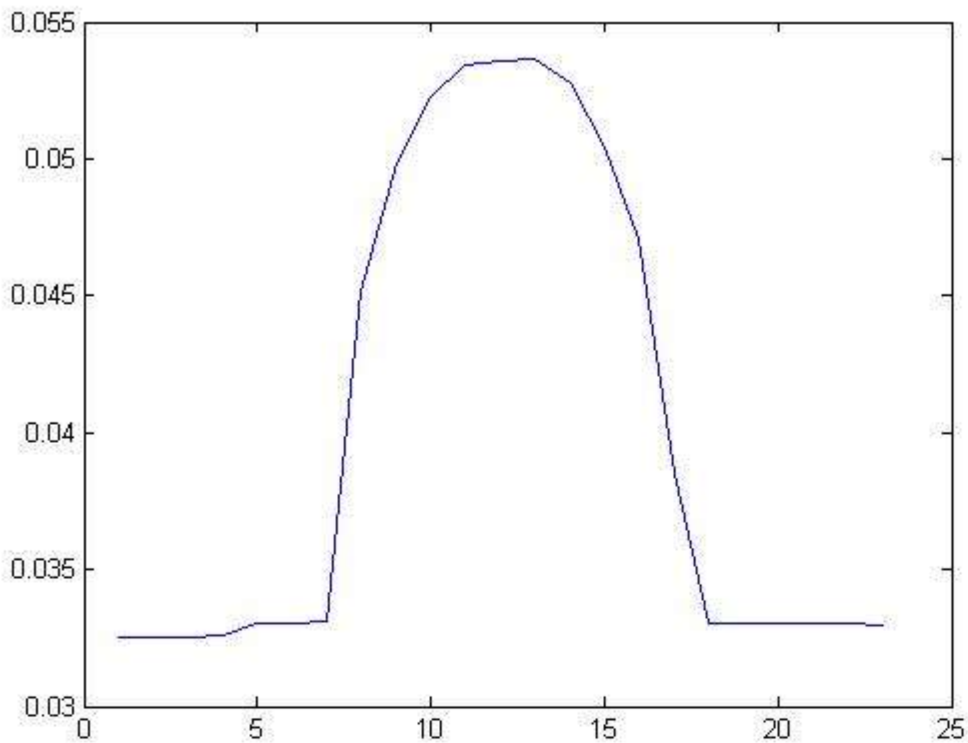
Therefore, mass removed per hour from both sides = 2 x $3600\left(\frac{h\,(\Delta T)}{h_{fg}} + h_m \rho_s\right)$

The overall efficiency of the dryer system can be calculated as

$$\eta_{dryer} = \frac{\text{Amount of water evaporated (kg) x Enthalpy of vaporization of water (kJ/kg)}}{\text{Number of electric units consumed for fan (kWh)x } 3600\left(\frac{\text{seconds}}{\text{hour}}\right) + \text{Incident solar energy(J)}}$$

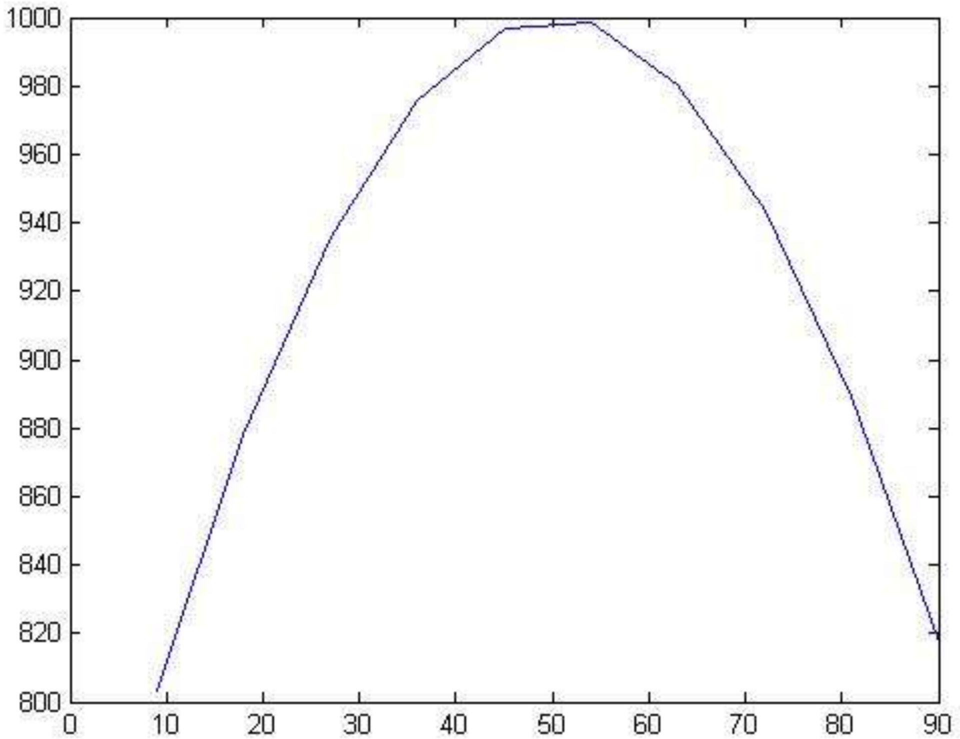
Results and Plots

The plot of mass of water evaporated (in kg) on y axis vs. time of day (24 hours) (on Jan 1)

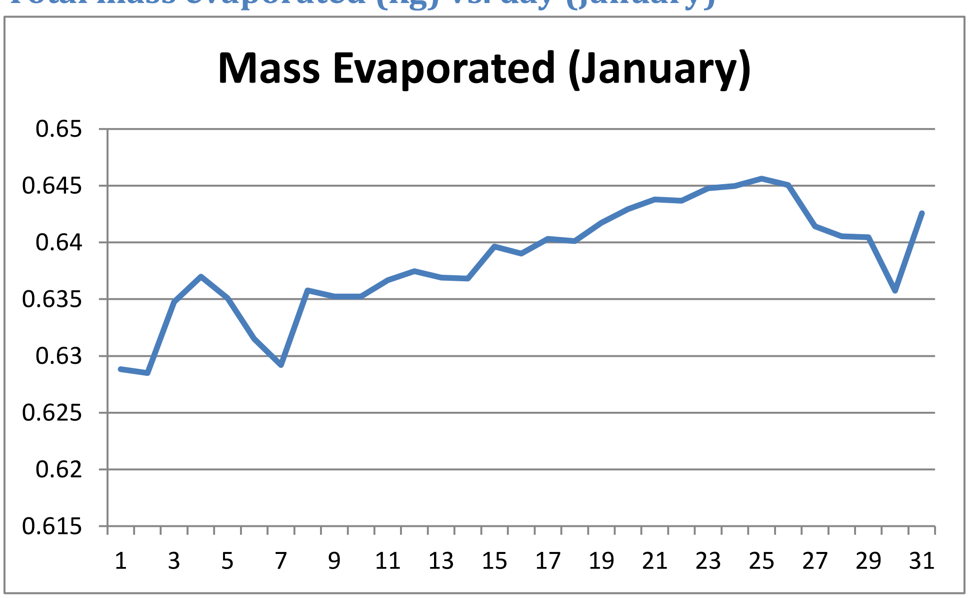


We observe that solar energy is available only from 0600 hrs. to 2000 hrs. at the maximum. Therefore, further simulations have been carried out only for these 14 hours for each day.

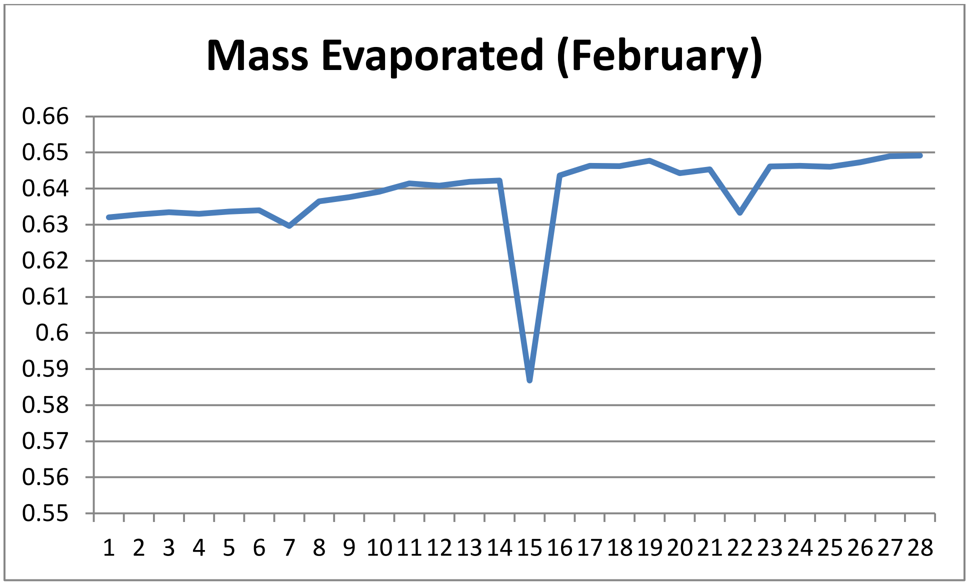
Plot of Solar Irradiation vs. angle of tilt of panel (12 pm, January 1)



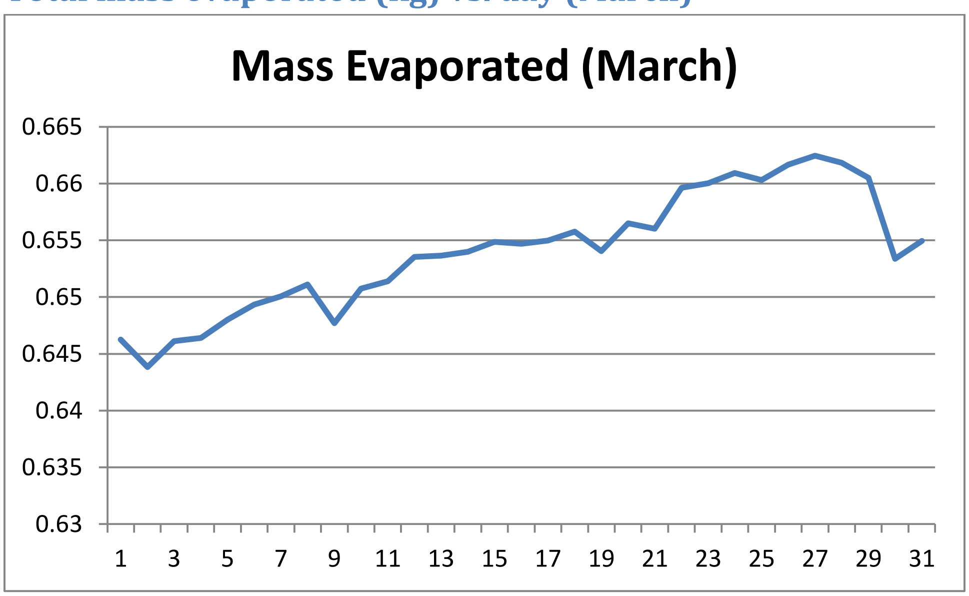
Total mass evaporated (kg) vs. day (January)



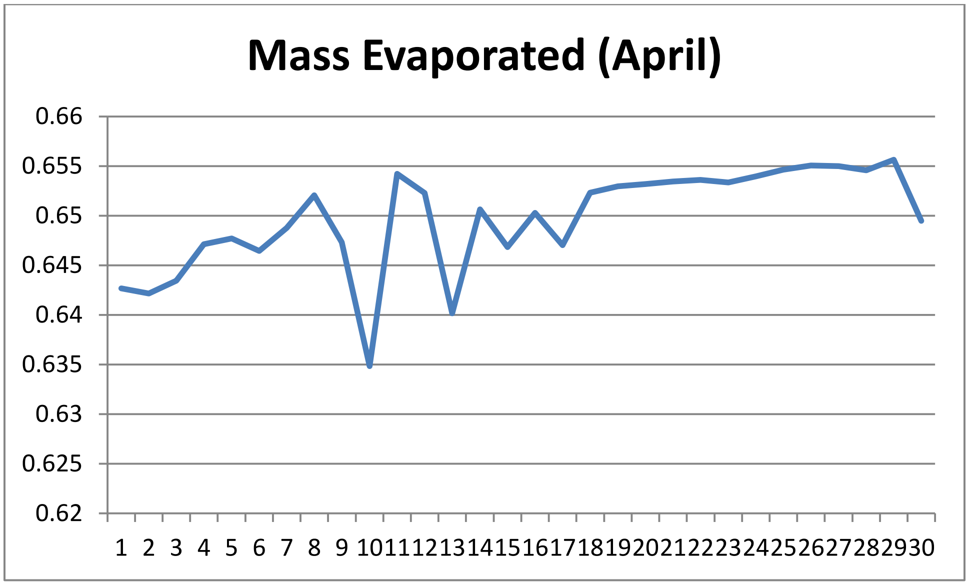
Total mass evaporated (kg) vs. day (February)



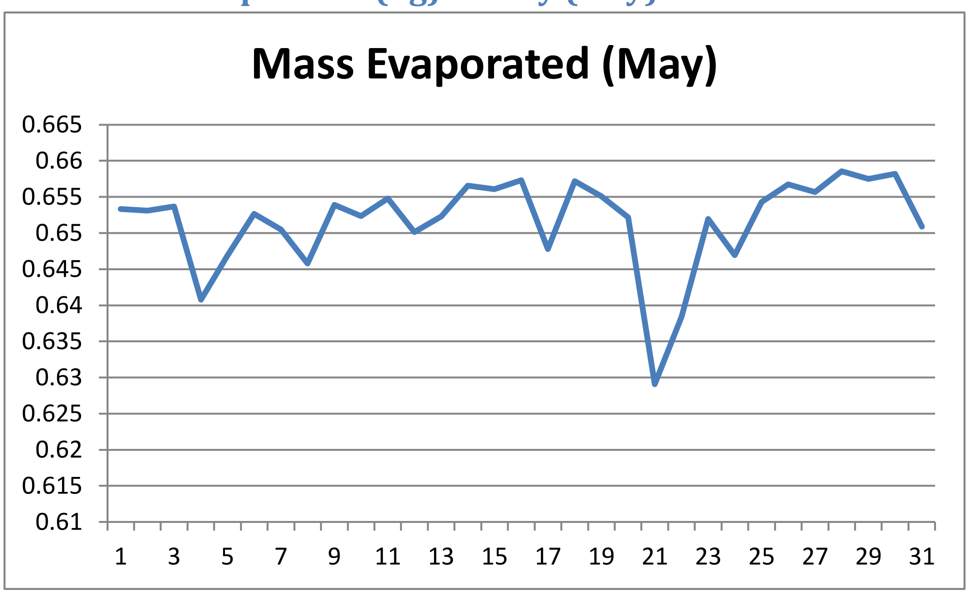
Total mass evaporated (kg) vs. day (March)



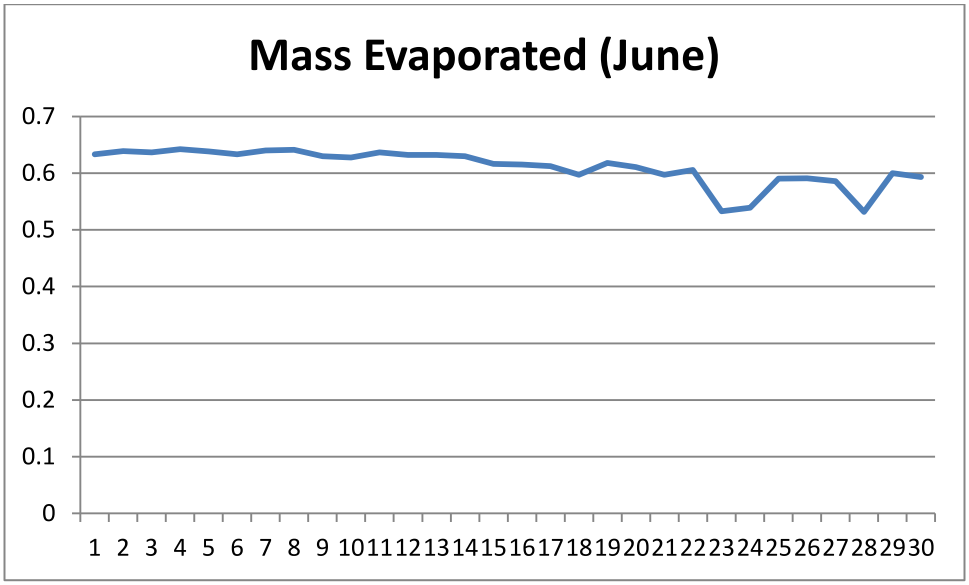
Total mass evaporated (kg) vs. day (April)



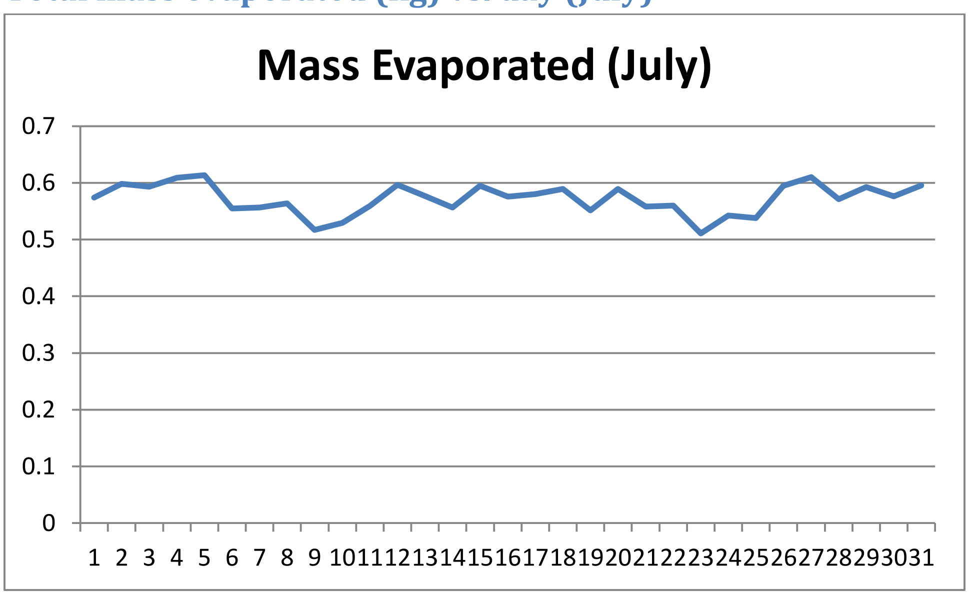
Total mass evaporated (kg) vs. day (May)



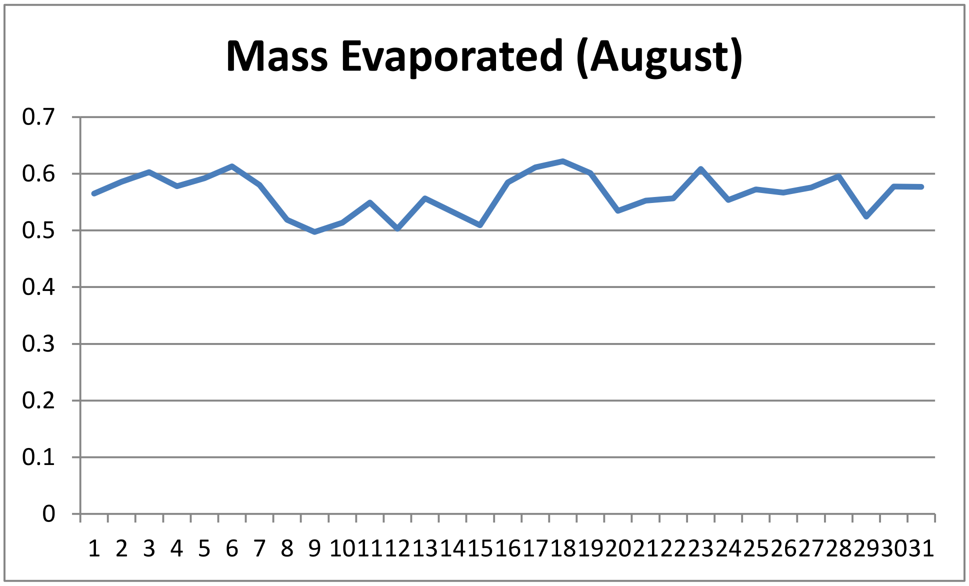
Total mass evaporated (kg) vs. day (June)



Total mass evaporated (kg) vs. day (July)



Total mass evaporated (kg) vs. day (August)



Conclusion

Solar air heaters have not been sufficiently explored in pulp and paper drying industry. Most of the applications until now are in agricultural sector. If properly designed, these may prove to be a viable alternative for saving electricity.

Matlab codes for the analysis

Code for Irradiation I_g:

```
function Igp =  irradiation(n,t_std)
%longitude and lattitude of the location
% longitude of standard time location
Long_loc = 72.58;
Lattitude=23.03;
Long_std = 82.5;
% theta_p and phi_p are zenith and azimuth angles for a plane we want to
% calculate
 theta_p=45;
 phi_p=25;
 % rho_g = reflectivity of ground - here concrete
 rho_g=0.4;

% calculations---

B= 360*(n-81)/364;
Et= 9.87*sind(2*B)-7.53*cosd(B)-1.5*sind(B);
min= ((Long_std-Long_loc)/15) + (Et/60) + ((t_std)-(floor(t_std)))*100/60;
t_sol_hr = (floor(t_std))+((t_std-floor(t_std))*100/60)+ ((Long_std-
Long_loc)/15) + (Et/60);
% ((t_sol_hr-floor(t_sol_hr))*60/100)
t_sol = floor(t_sol_hr)+((t_sol_hr-floor(t_sol_hr))*60/100);


% declination angle 'dec'
dec = asind(-sind(23.45)*cosd(360*(n+10)/365.25));

% zenith angle 'theta_s'
omega=(t_sol_hr-12)*360/24;
theta_s=acosd((cosd(Lattitude)*cosd(dec)*cosd(omega))+(sind(Lattitude)*sind(d
ec)));
if theta_s>90
    theta_ss=180-theta_s;
else
    theta_ss=theta_s;

end

% azimuth angle 'phi_s'-  angles west of south are positive
phi_s= asind(cosd(dec)*sind(omega)/sind(theta_ss));



 %theta_i = solar incidance anfle
 theta_i = acosd((sind(theta_ss)*sind(theta_p)*cosd(phi_s-
phi_p))+(cosd(theta_ss)*cosd(theta_p)));
```

```
 % Irradiance incident on a tilted surface is Igp
 % Idir = Direct Normal Irradiation DNI
 % Idif = Diffuse Horizontal Irradiation DHI
 % Igh = Global Horizontal Irradiation GHI

 Idir=DNI(n,floor(t_std));
 Idif=DHI(n,floor(t_std));
 Igh=GHI(n,floor(t_std));

 Igp=Idir*cosd(theta_i)+Idif*((1+cosd(theta_p))/2)+Igh*rho_g*((1-
cosd(theta_p))/2);
 Igp_dir=Idir*cosd(theta_i);
 Igp_dif=Idif*((1+cosd(theta_p))/2);
 Igp_gh= Igh*rho_g*((1-cosd(theta_p))/2);
end
```

Code for calculating energy and mass of water removed

```
function MR = energy(n,t_std)
% Area of the panel in sq.m
L=1;
w=0.3;
Area=L*w;
% properties of air density kg/m^3, cp_a J/kg-K
% rho_a = 1.15;
cp_a=1000;
%pipes flow- X sec area = da sq.m , velocity = v m/s
% T_surr=DRYBULBTEMP(n,t_std);
P_air=PRESSURE(n,t_std);
Ts=100+273;
v_in=0.1;
m_dot=0.03;

%incident irradiation = Igp
Igp=irradiation(n,t_std);
%Incident power on the panel = Pi
% Pa = absorbed energy
Pi= Igp*Area;
% Pa=absorptivity_plastic*Pi;


% Assuming all the energy is transfered to the air
% Pa = m_dot * cp * delta_T
% delta_T = Pa/(m_dot*cp_a)

%properties of external flow
nu=1.5e-5;
Re= v_in*L/nu;
Pr=0.7;
k=0.03;
```

```
Sc=0.66;
D_H2O_air=24e-6;

Nu_bar=0.68*(Re^0.5)*(Pr^(1/3));
h_bar=Nu_bar*k/L;

hm=((Sc/Pr)^(1/3))*(D_H2O_air/k);

m_conv=hm*((P_air*0.018)/(8.314*Ts));
dm1=3600*m_conv;
Q_net2=0.58*Pi;
% Q_in=h_in*Area*(Ts-T_surr);

dt=Q_net2/(m_dot*cp_a);
% T_in = T_surr+dt;

% M= 0.04;
% cp_w=4179;
hfg=2260e3;

dm2 = 3600*dt*h_bar/(hfg);
MR=2*(dm2+dm1);
end
```

Code for analyzing over a period of N days

```
function mass_result = analysis(start,N)
% N=2;
hours=14;

mass_result=zeros(N,hours+1);
time=zeros(1,hours);
for t=1:hours
    time(t)=t-1;

end

for n=1:N
totalmass=0;
for i = 1:hours
    mass_result(n,i)=energy(n+start,i+5);
    totalmass=totalmass+mass_result(n,i);
    [n+start,i+5]

end
mass_result(n,hours+1)=totalmass;

end

end
```

References

[1] *High Efficiency Solar Air Heaters with Novel Built-in Storage for use in a Humidification-Dehumidification Desalination Cycle*, Edward K. Summers, Mechanical Engineering, June 2010, Massachusetts Institute of Technology.

[2] Suman Saurav, M. M. Sahu*, Heat Transfer and Thermal Efficiency of solar air heater having artificial roughness: a review,* International Journal of Renewable and Sustainable Energy. Vol. 2, No. 3, 2013, pp. 99-109. doi: 10.11648/j.ijrse.20130203.14

[3] Air flow Formulas, National Energy Management Institute Committee, 2005

[4] Handy Manual, Paper and Pulp Industry, UNIDO and MITI Japan, 1993

[5] *Performance evaluation of an enhanced fruit solar dryer using concentrating panels,* James Stiling, Simon Li, Pieter Stroeve, Jim Thompson, Bertha Mjawa, Kurt Kornbluth, Diane M. Barrett, 2012

[6] *The effect of tilt angle on the performance of evacuated tube solar air collector: experimental analysis*, Vishal Dabra, Laxmikant Yadav, Avadhesh Yadav, International Journal of Engineering, Science and Technology, Vol. 5, No. 4, 2013, pp. 100-110

[7] *Solar thermal energy technologies for industrial applications - India's experience,* Shirish Garud, Fellow,TERI, May 2008

[8] *A SURVEY OF AIR-HEATER OPTIONS, DIY Solar Projects,* www.BuildItSolar.com

[9] *Solar Drying- A technology for sustainable agriculture and food production,* R. J Fuller, University of Melbourne, Australia