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Studies on solar flat plate collector evaporation systems for tannery effluent (soak liquor)

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Abstract: Heat and mass transfer analysis of an incompressible, laminar boundary layer over solar flat plate collector evaporation systems for tannery effluent (soak liquor) is investigated. The governing equations are solved for various liquid to air velocity ratios. Profiles of velocity, temperature and concentration as well as their gradients are presented. The heat transfer and mass transfer coefficients thus obtained are used to evaluate mass of water evaporated for an inclined fibre-reinforced plastic (FRP) solar flat plate collector (FPC) with and without cover. Comparison of these results with the experimental performance shows encouraging trend of good agreement between them.

Key words: Boundary layer, Solar flat plate collector, Fibre-reinforced plastic flat plate collector, Open flat plate collector, Tannery effluent treatment, Pollution
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INTRODUCTION

The tannery effluent (soak liquor) spewed out by tanneries to the surroundings has been polluting the land and water bodies in and around the tanneries and is evaporated over a period of time. The rate of evaporation over this period is small in the natural evaporative ponds and so large area is required. But land in urban and semi-urban sectors is scarce and very costly. Hence, it is required to augment the evaporation rate by adopting some suitable techniques.

The rate of evaporation from shallow ponds depends strongly on the temperature of the effluent and the state of the surrounding air. One of the methods by which the evaporation rate can be increased is by increasing the contact area between the effluent and air and thus to increase its temperature. This can be achieved by allowing the effluent from the shallow basin to flow over an inclined solar flat collector. While the liquid flows over the collector, it is heated by solar energy that will help to increase the evaporation rate. Subsequently, the water falling a few metres as a thin sheet of liquid further augments the evaporation rate. Evaporating the water in the tannery effluent and recovering the salt, is one of the methods to use the abundantly available solar energy (Mani and Srinivasa Murthy, 1993; 1994; Srithar and Mani, 2003; 2004).

In this paper, the governing equations are solved by numerical technique. The profiles of velocity, temperature and concentration and their gradients are used to obtain the heat and mass transfer coefficients used for evaluating the evaporation rate of water in soak liquor.

COLLECTOR ANALYSIS

Conventional flat plate collector

Assuming steady state condition, energy balance equations for the plate and the glass (Mani *et al*., 1991; Gandhidasan, 1978; 1995; Kakabaev and Golaev, 1971; Srithar and Mani, 2004) are obtained as shown in Eqs.(1) and (2), respectively.

$$I_\beta[\tau\alpha]A\mathrm{d}t=E_\mathrm{r}+E_\mathrm{c}+E_\mathrm{k}+E_\mathrm{d}+E_\mathrm{s}, \qquad (1)$$

$$\alpha_\mathrm{g}I_\beta+\sigma(1/\varepsilon_\mathrm{s}+1/\varepsilon_\mathrm{g}-1)^{-1}(T_\mathrm{s}^4-T_\mathrm{g}^4)+h_\mathrm{s-g}(T_\mathrm{s}-T_\mathrm{g}) =\sigma\varepsilon_\mathrm{g}(T_\mathrm{g}^4-T_\mathrm{e}^4)+h_\mathrm{w}(T_\mathrm{g}-T_\mathrm{a}), \qquad (2)$$

where, I_β=the intensity of total radiation on an inclined surface, W/m^2; A=area of the collector, m^2; $[\tau\alpha]$=absorptance–transmittance product; α=thermal diffusivity, m^2/s; dt=time interval, s; E_c=heat transfer from solution by convection, J; E_d=heat transfer due to evaporation, J; E_k=heat conducted through the base, J; E_r=heat transfer by radiation, J; E_s=heat transfer to solution, J; α_g=absorptivity of the glass; σ=Stefan-Boltzmann constant, W/(m^2·K^4); ε_g=emissivity of the glass; ε_s=emissivity of the solution; T_g=glass temperature, K; T_s=solution temperature, K; T_a=ambient temperature, K; T_e=sky temperature, K; $h_\mathrm{s\text{-}g}$=convective heat transfer coefficient between the solution and glass cover, W/(m^2·K); h_w=heat transfer coefficient from glass cover to the ambient, W/(m^2·K).

Energy absorbed by the plate equals energy lost by conduction, convection and radiation, energy utilized for evaporation and energy gained by solution.

I_β is obtained by neglecting ground reflectance term (Mani *et al*., 1991) using:

$$I_\beta=(I-I_\mathrm{d})(\cos\theta_\mathrm{i}/\cos\theta_\mathrm{h})+I_\mathrm{d}(1+\cos\beta)/2, \qquad (3)$$

where I=global radiation intensity on a horizontal plane, W/m^2; I_d=diffuse radiation intensity on a horizontal plane, W/m^2; β=collector surface inclination, degrees; θ_i, θ_h are the solar incidence angle on an inclined and horizontal surfaces respectively and are given by (Gandhidasan, 1978):

$$\theta_\mathrm{i}=\arccos[\cos(l-\beta)\cos\delta\cos h+\sin(l-\beta)\sin\delta], \qquad (4a)$$

$$\theta_\mathrm{h}=\arccos[\cos l\cos\delta\cos h+\sin l\sin\delta], \qquad (4b)$$

where l=latitude, degrees; h=hour angle, degrees; δ=declination, degrees.

The absorptivity of the collector α_a is taken as 0.9 (Gandhidasan, 1978; 1995; Mani and Srinivasa Murthy, 1994; Collier, 1979; Kakabaev and Golaev, 1971; Srithar and Mani, 2003; 2004).

The energy lost by radiation is computed (Gandhidasan, 1995; Kakabaev and Golaev, 1971; Srithar and Mani, 2003; 2004) as:

$$E_\mathrm{r}=\sigma(1/\varepsilon_\mathrm{s}+1/\varepsilon_\mathrm{g}-1)^{-1}A(T_\mathrm{s}^4-T_\mathrm{g}^4)\mathrm{d}t. \qquad (5)$$

The heat conducted through the base is calculated (Gandhidasan, 1978; 1995; Kakabaev and Golaev, 1971; Srithar and Mani, 2003; 2004) from

$$E_\mathrm{k}=f^*kA(T_\mathrm{s}-T_\mathrm{a})\mathrm{d}t/\Delta x, \qquad (6)$$

where f^* is the factor, which includes the effect of side losses, taken as 110 percent of the bottom loss (Gandhidasan, 1978; 1995; Kakabaev and Golaev, 1971; Srithar and Mani, 2003; 2004); k=thermal conductivity of air, W/(m·K); Δx=thickness of the plate, m.

The energy taken away by the effluent is calculated from

$$E_\mathrm{s}=G_\mathrm{o}C_\mathrm{ps}\Delta T_\mathrm{s}, \qquad (7)$$

where, G_o=mass flow rate, kg/s; ΔT_s=temperature rise of the solution; C_ps=the specific heat of the effluent, J/(kg·K), is determined (Mani and Srinivasa Murthy, 1993; 1994; Gandhidasan, 1995; Kakabaev and Golaev, 1971; Srithar and Mani, 2003; 2004) by

$$C_\mathrm{ps}=a_1+a_2T_\mathrm{s}+a_3T_\mathrm{s}^2+a_4T_\mathrm{s}^3, \qquad (8)$$

where a_1, a_2, a_3 and a_4 are constants and are given by

$$a_1=4206.8-6.6197c+1.2288\times10^{-2}c^2, \qquad (9a)$$

$$a_2=-1.1262+5.4178\times10^{-2}c-2.2719\times10^{-4}c^2, \qquad (9b)$$

$$a_3=1.2026\times10^{-2}-5.5366\times10^{4}c+1.8906\times10^{-6}c^2, \qquad (9c)$$

$$a_4=6.8774\times10^{-7}+1.517\times10^{-6}c-4.4268\times10^{-9}c^2, \qquad (9d)$$

where c is salinity (g/kg or %) and h_w is calculated from

$$h_\mathrm{w}=4.8+3.33W, \qquad (10a)$$

and T_e is given by

$$T_\mathrm{e}=T_\mathrm{a}-6, \qquad (10b)$$

where W=wind speed, m/s.

For flow over an inclined closed flat plate collector, heat transfer by convection from solution to glass, is considered as free convection. For steady, laminar, incompressible and 2D flow, the governing continuity, momentum, energy and mass balance equations are obtained (Schilichting, 1979; Kays and Crawford, 1983) as shown in Eqs.(11)~(14), respectively:

$$\partial u/\partial x+\partial v/\partial y=0, \tag{11}$$

$$u\partial u/\partial x+v\partial u/\partial y=\gamma\partial^2u/\partial y^2+g\beta_c(T-T_a), \tag{12}$$

$$u\partial T/\partial x+v\partial T/\partial y=\alpha\partial^2T/\partial y^2, \tag{13}$$

$$u\partial C/\partial x+v\partial C/\partial y=D\partial^2C/\partial y^2, \tag{14}$$

where u=component of velocity in x direction, m/s; v=component of velocity in y direction, m/s; x=flow length, m; y=length perpendicular to flow, m; γ=kinematics viscosity, $\mathrm{m^2/s}$; g=acceleration due to gravity, $\mathrm{m/s^2}$; β_c=expansion coefficient=$1/T_a$; C=mass concentration, $\mathrm{kg/m^3}$; D=Diffusion coefficient, $\mathrm{m^2/s}$.

The boundary conditions are:

$$\text{At } y=0,\ u=u_s,\ T=T_s,\ C=C_s;$$
$$\text{At } y=\infty,\ u=u_a,\ T=T_a,\ C=C_a,$$

where u_a=ambient velocity, m/s; u_s=solution velocity, m/s; C_s=mass concentration of the water vapor in the solution, $\mathrm{kg/m^3}$; C_a=mass concentration of the water vapor in the ambient, $\mathrm{kg/m^3}$.

A stream function is introduced by putting $u=\partial\psi/\partial y$ and $v=-\partial\psi/\partial x$, then the resulting partial differential equation for stream function ψ can be reduced to non-dimensional ordinary differential equation by the similarity transformation, $\eta=yH(x)$, $\psi(x,\ \eta)=\gamma f(\eta)G(x)$, where $f(\eta)$ denotes the dimensionless stream function and η and H are dimensionless variables. Where,

$$G(x)=4(Gr_x/4)^{1/4} \text{ and } H(x)=(1/x)\cdot(Gr_x/4)^{1/4}, \tag{15}$$

where Gr_x=local Grashof number for inclined surface.

The respective momentum, energy and diffusion equations are then reduced to the dimensionless forms shown in Eqs.(16), (17) and (18), respectively:

$$f'''+3ff''-2f'^2+m_T=0, \tag{16}$$

$$m_T''+3fm_T'Pr=0, \tag{17}$$

$$m_C''+3fm_C'Sc=0, \tag{18}$$

where f' and f'' are the first and second derivatives of f with respect to η; m_C is dimensionless concentration; m_T is dimensionless temperature; Pr is Prandtl number; Sc is Schmidt number. The boundary conditions are:

$$\text{At } \eta=0, f=f'=0,\ m_T=1,\ m_C=1, f'=0,$$
$$\text{At } \eta=\infty, f'=0,\ m_T=0,\ m_C=0,$$

where

$$m_T=(T-T_a)/(T_s-T_a), \tag{19a}$$

$$m_C=(C-C_a)/(C_s-C_a). \tag{19b}$$

From Eq.(19b), the concentration is represented as:

$$C=m_C(C_s-C_a)+C_a.$$

For no slip condition, the concentration gradient can be as shown in Eq.(20):

$$(\partial C/\partial y)_{y=0}=(C_s-C_a)(\partial m_C/\partial y)_{y=0}. \tag{20}$$

Sherwood number Sh is defined as (Kays and Crawford, 1983; Gandhidasan, 1978),

$$Sh=[x/(C_s-C_a)](\partial C/\partial y)_{y=0}=h_{Dx}x/D. \tag{21}$$

or

$$-[x/(C_s-C_\infty)](C_s-C_a)(\partial m_C/\partial y)_{y=0}=h_{Dx}x/D.$$

by chain rule differentiation:

$$\partial m_C/\partial y=(\partial m_C/\partial\eta)(\partial\eta/\partial y)=(m_C')_{y=0}\cdot H(x).$$

$$\therefore h_{Dx}=-D(Gr_x/4)^{1/4}\cdot(m_C')_{y=0}, \tag{22}$$

where h_{Dx} is local mass transfer coefficient, m/s.

Average mass transfer coefficient,

$$h_D=(1/x)\int h_{Dx}\mathrm{d}x. \tag{23}$$

The computation is repeated for different velocity profiles ranging from 0 to 0.9 and average mass transfer coefficient h_{DA} of all velocity profiles, is obtained. Then, β_m, the mass transport coefficient (s/m), is given (Collier, 1979) by:

$$\beta_m=h_{DA}/RT_f, \tag{24}$$

where T_f=mean temperature of solution and ambient, K; R=gas constant for water vapor, J/(kg·K).

The energy utilized for the evaporation of water from the effluent is estimated (Gandhidasan, 1978;

1995; Kakabaev and Golaev, 1971; Srithar and Mani, 2003; 2004) as:

$$E_d=\beta_m A(p_{s,ave}-p_A)h_{fg}dt, \qquad (25)$$

where p_A=partial pressure of water vapour in the ambient air, N/m^2; h_{fg}=latent heat of vaporization from the solution, J/(kg·K); $p_{s,ave}$=the average vapour pressure of seawater, N/m^2, in bar, and is given (Mani and Srinivasa Murthy, 1993; 1994; Gandhidasan, 1995; Kakabaev and Golaev, 1971; Srithar and Mani, 2003; 2004) by

$$p_{s,ave}=p_w(1-0.000537c), \qquad (26)$$

where p_w is saturation pressure of water in the effluent at T_s, N/m^2.

Then, the mass of water evaporated during this time interval is evaluated (Gandhidasan, 1978; 1995; Kakabaev and Golaev, 1971; Srithar and Mani, 2003; 2004; Churchill, 1977; Burmeister, 1993) as:

$$dm=\beta_m A(p_{s,ave}-p_A)dt, \qquad (27)$$

where dm=mass of water evaporated from the solution, kg/s.

β_m obtained from Eq.(24) is used in Eqs.(25) and (27), to determine the energy utilized for evaporation of water and mass of water evaporated respectively. Prandtl and Schmidt numbers for air is taken as 0.7 and 0.6 respectively.

The local Nusselt number Nu_x is defined by (Schilichting, 1979; Kays and Crawford, 1983)

$$Nu_x=xh_{cx}/k=-(m'_T)_{y=0}\,Gr^{1/4}2^{-1/2}, \qquad (28)$$

where h_{cx}=local heat transfer coefficient, W/(m^2·K).

The average Nusselt number (Nu) for any velocity profile is obtained by,

$$Nu=(1/x)\int Nu_x dx. \qquad (29)$$

Averaging the Nusselt numbers for all velocity profile range yields the resultant Nusselt number from which, the heat transfer coefficient from solution to glass, $h_{s\text{-}g}$ is obtained. This heat transfer coefficient is used in Eq.(30), to calculate the energy lost by convection from solution to cover.

The energy lost by convection from solution to cover is evaluated (Gandhidasan, 1978; 1995; Kakabaev and Golaev, 1971; Srithar and Mani, 2004) from

$$E_c=h_{s\text{-}g}A(T_s-T_g)dt. \qquad (30)$$

For the next time step, the parameters are redefined as follows:

$$T_s=T_s+\Delta T_s. \qquad (31)$$

The computational procedure is carried out by treating the meteorological variables as input data and by assigning an initial value to solution temperature equal to ambient temperature and the time interval, dt, is assumed as 5 s. For this condition, the glass cover temperature and the increase in solution temperature during this time interval is computed by solving Eqs.(2) and (1), respectively. For evaluating ΔT_s in the simulation, the experimentally measured values of solar insolation, ambient temperature, wind speed and relative humidity of the corresponding day and hour are used. Then, the mass of water evaporated during this time interval is evaluated from Eq.(27). For the next time step, the parameters are redefined by using Eq.(31). This procedure is repeated till the typical closure time of the experimentation.

Open flat plate collector

For an open flat plate collector, theoretical computation is carried out by using Eq.(1) by replacing the product [$\tau\alpha$], by absorptivity of the plate.

The energy lost by radiation is computed (Gandhidasan, 1978; 1983; Mani and Srinivasa Murthy, 1994; Collier, 1979; Srithar and Mani, 2003) as

$$E_r=\sigma\varepsilon_s A(T_s^4-T_e^4)dt. \qquad (32)$$

The energy lost by convection from solution to ambient air is evaluated (Gandhidasan, 1978; 1983; Mani and Srinivasa Murthy, 1994; Collier, 1979; Srithar and Mani, 2003) from

$$E_c=h_{s\text{-}a}A(T_s-T_a)dt, \qquad (33)$$

where $h_{s\text{-}a}$ is convective heat transfer coefficient between the solution and ambient air, W/(m^2·K).

Eqs.(1), (3) and (4), Eqs.(6)~(9) and Eqs.(24)~(27) are used in open flat plate collector for evaluating the respective performance explained as in the previous section. Under this condition, the increase in solution temperature during this time interval is computed by solving Eq.(1). To evaluate ΔT_s in the simulation, the experimentally measured values of solar insolation, ambient temperature, wind speed and relative humidity of the corresponding day and hour are used. Then, the mass of water evaporated during this time interval is evaluated from Eq.(27). For the next time step, the parameters are redefined as by using Eqs.(31a) and (31b). This procedure is repeated till the typical closure time of the experimentation.

The values of the product Gr/Re^2 of the experimental result falls in the range of combined convection region, where Re is Reynolds number. Hence, combined free and forced convection is considered in the analysis of open flat plate collector.

The correlation for combined convection is (Churchill, 1977; Burmeister, 1993)

$$Nu^3 = Nu_N^3 + Nu_F^3, \tag{34}$$

$$Sh^3 = Sh_N^3 + Sh_F^3, \tag{35}$$

where subscripts 'N' and 'F' denote natural convection and forced convection, respectively.

The corresponding boundary layer equations for forced convection are solved by following the procedure given in (Gandhidasan, 1978), for evaluating the Nusselt and Sherwood numbers. The procedure described above is used for evaluating free convection Nusselt and Sherwood numbers. Then, the combined convection Nusselt and Sherwood numbers are evaluated using Eqs.(34) and (35), respectively. The heat transfer coefficient $h_{s\text{-}a}$, obtained from Eq.(34) is used in Eq.(33) to determine the energy lost by convection from solution to ambient air. The mass transport coefficient thus obtained from Eqs.(35) and (24), is used in Eqs.(25) and (27), to determine the energy utilized for evaporation of water and mass of water evaporated respectively.

EXPERIMENTATION

The schematic arrangement of the experimental systems for open and conventional flat plate collector are shown in Fig.1. A 4 m×1 m with 5 mm thick blackened fibre-reinforced plastic (FRP) sheet is used as an absorber surface. To avoid corrosion material used for pipes, tanks and valves are polyvinyl chloride (PVC). The bottom of the sheet is insulated with 75 mm thick glass wool. In the conventional flat plate collector, the spacing between the plate and the glass cover is chosen as 100 mm to prevent condensation of water at the bottom of the glass cover and the bottom and top sides of the collector walls are removed to permit the water vapour to escape upon vaporization. In the setup, tank A is a calibrated tank and tank B is a constant head tank. By the pump P, the effluent from tank A to tank B is transferred through pipeline L_1, and the excess liquor is allowed to return to tank A through pipeline L_2. Thus, constant head is maintained in the tank B. Now, thin film of effluent is allowed to flow over the collector by the distribution header D. The valve V controls the flow rate. The experimental studies were carried out at Madurai, India with the orientation of γ_s=0 and l=10 °N, where

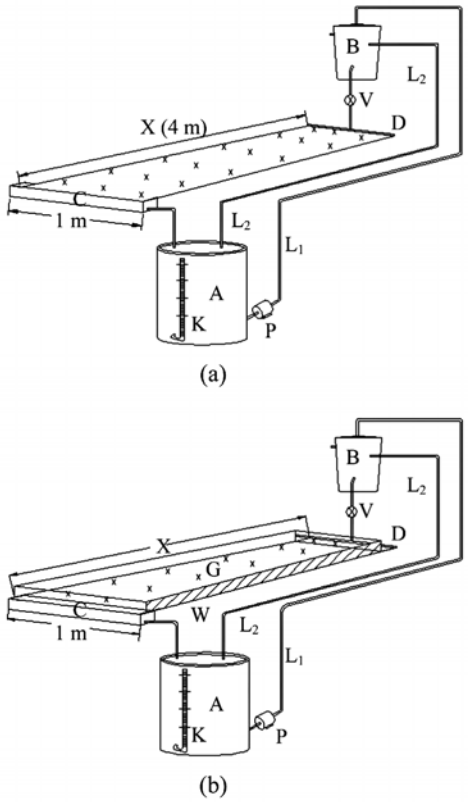


Fig.1 Open (a) and conventional (b) FRP plate collector effluent evaporation system

A: Calibrated collection tank; B: Constant head tank; C: Collecting tray; D: Distribution header; G: Glass; K: Piezometer; L_1: Pipeline to tank B; L_2: Return pipeline to tank A; P: Centrifugal pump; V: valve; W: Wooden frame; X: Flow length

γ_s is surface azimuth angle, degrees; l is latitude, degrees. The liquor is collected at the bottom end C of the absorber plate and then flows into tank A for recirculation. The soak liquor obtained from the tannery is clarified by adding 100×10^{-6} of Alum and 250×10^{-6} of Poly aluminum chloride and mixing thoroughly. Then this mixture is permitted to settle for 2 to 3 h. The clarified soak liquor (supernatant) is taken for the evaporation. This clarified fresh soak liquor is mostly colorless with the major constituent being Sodium Chloride.

During experimentation, by adding known quantity of freshwater to the tank A on hourly basis, the concentration of the effluent is maintained constant. This known quantity of water is equal to the amount of water evaporated during this one hour, which is measured by using calibrated piezometer. The solar radiation is measured by using calibrated Kipp-Zonon solarimeter with integrator. The solution temperature and plate temperature are measured by using calibrated copper-constantan thermocouples with millivolt meter. Relative humidity of the air is inferred from the measurement of dry bulb and wet bulb temperatures, using calibrated mercury-in-glass thermometers. Calibrated vane type anemometer is used for the measurement of wind speed. Concentration of the solution is estimated based on mass balance by mixing known quantity of sodium chloride salt with water initially. Subsequently, this is measured by using specific gravity meter. Table 1 gives the instrumentations accuracy and range of respective parameters measured during experimentation.

During experimentation days, the experiment was started at 9 h. Hourly measurements of parameters namely mass flow rate, effluent temperature, insolation, wet and dry bulb temperatures, wind speed and evaporation rate were carried out from 9 to 17 h daily. These experiments were carried out for a period of one year by varying the mass flow rate of the effluent flowing over FRP flat plate collector.

RESULTS AND DISCUSSION

Fig.2 shows the temperature and concentration distribution for the non-dimensional velocity profile of 0 and 0.9 respectively for the natural convection boundary layer. The temperature and concentration gradients decrease in the increasing direction of velocity profiles. This effect is shown in Fig.3. Table 2 gives the temperature and concentration gradients for the natural convection velocity profile.

In the conventional system, the collector is covered with single transparent cover to reduce the top

Table 1 Accuracies, uncertainties and ranges of measuring instruments

Serial No.	Instrument	Accuracy	Range	Error (%)
1	Kipp-Zonon solarimeter	±0.05 W/m^2	0~5000 W/m^2	±2.5
2	Digital anemometer	±0.1 m/s	0~100 m/s	±5.0
3	Wet and dry bulb thermometer	±0.5 °C	−10 °C to 50 °C	±4.0
4	Mercury-in-glass thermometer	±0.5 °C	0 °C to 120 °C	±1.0

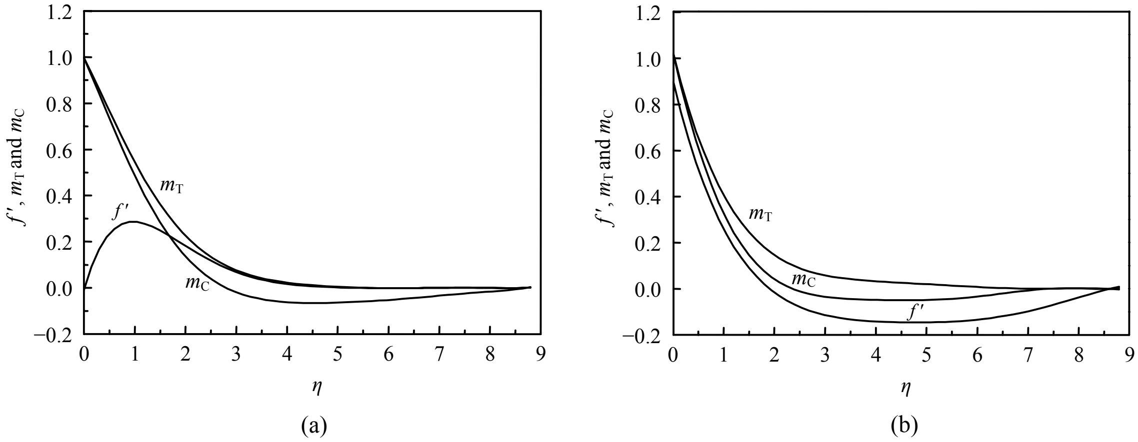


Fig.2 Temperature and concentration distribution at f'=0 (a) and f'=0.9 (b) for conventional collector

heat loss, thus the solution temperature increases, which in turn increases the heat transfer coefficient between the solution and glass, leading to increase in the partial pressure difference between the solution interface and the ambient air. This causes the conventional system to realize higher Reynolds and Sherwood numbers than the open flat plate collector for the same operational and meteorological conditions. These effects are shown in Fig.4.

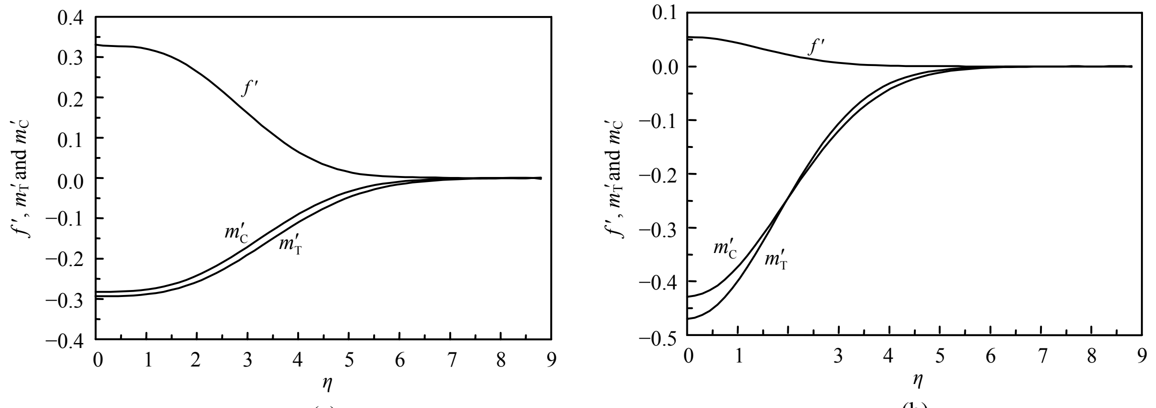
The experiments were carried out for four different concentrations ranges between 5% and 20% with increment of 5%. Mass flow rate is also varied between 200 and 500 L/h with increment of 100 L/h. Fig.5 compares the theoretical and experimental evaporation rate over the time of the given day and shows that the theoretical evaporation rate is 6% higher than that of the experimental value. Also, conventional FPC with glass gives 4% to 28% higher performance than the open FPC.

CONCLUSION

From the solution of the boundary layer equations the Nusselt and Sherwood numbers for both conventional and open flat plate collector systems are calculated. Using this, the mass of water evaporated in the effluent is determined. The theoretical results are compared with the experimental results. The maximum deviation of the experimental performance is 10% in comparison with that of the theoretical

Table 2 Values of $m'_T(0)$ and $m'_C(0)$ for natural convection boundary layer

u/u_∞	$m'_T(0)$	$m'_C(0)$
0	−0.47	−0.53
0.3	−0.58	−0.66
0.6	−0.64	−0.73
0.9	−0.73	−0.832



(a) (b)

Fig.3 Distribution of temperature and concentration gradients at f'=0 (a) and f'=0.9 (b) for conventional collector

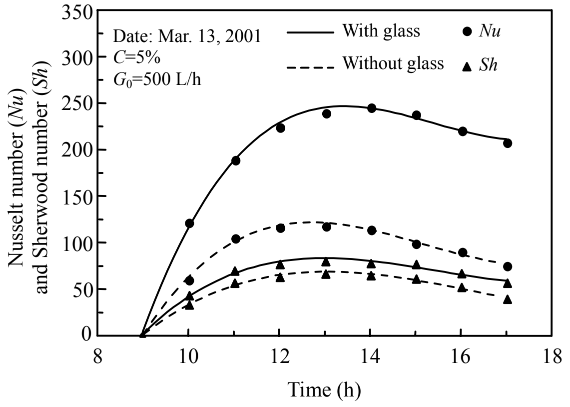


Fig.4 Comparison of Nusselt and Sherwood numbers for conventional and open flat plate collectors

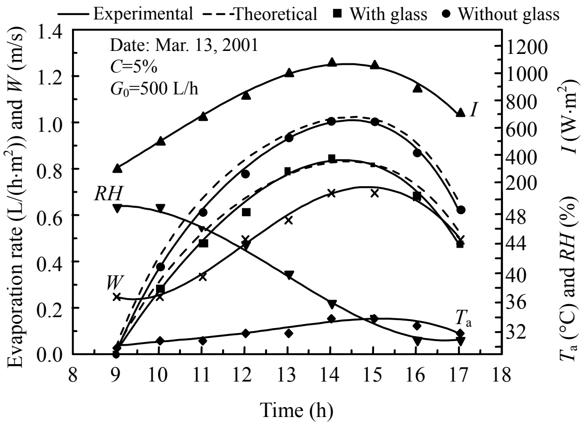


Fig.5 Comparison of theoretical and experimental performance. *RH* is relative humidity

analysis. The conventional FRP-FPC gives 4% to 28% higher performance than the open FRP-FPC.

Evaporation rate of water in the effluent increases due to increase in insolation, wind speed and decreases in relative humidity, mass flow rate and effluent concentration. The FRP-FPC can be successfully used for evaporating tannery effluent despite corrosion problem. Also the conventional FPC gives better performance compared to open FPC by reducing top heat loss.

According to the guidelines of Tamil Nadu Pollution Control Board (Mani and Srinivasa Murthy, 1993) in a pan area of 1 m^2 the average evaporation rate is 4.5 mm/d. It is inferred that the evaporation rate obtained in 1 m^2 area of conventional FRP-FPC is 7.5 mm day and for open FRP-FPC the corresponding evaporation rate is 6.3 mm/d. Thus an average area of 29% and 40% is saved by using open FRP-FPC and conventional FRP-FPC respectively.

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