Solar and Wind Aided Cross Flow Natural Evaporator for RO Reject Management

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BACKGROUND

- Severe environmental problems are being faced by the Tiruppur, Erode and Karur districts of Tamil Nadu due to pollution caused mainly by effluents from the textile and dye industries.
- In order to control this pollution, (TNPCB) has mandated that the effluents from these industrial units should be completely treated and there should be zero discharge of waste from any unit.
- Many CETPs are set-up based on physico-chemical and biological processes, followed by tertiary treatments and finally Reverse Osmosis (RO) process

Background (Contd..)

- The reject from RO plant cannot be simply let out because it has a high concentration of Total Dissolved Solids (TDS)
- Usually, the reject from the RO plant is sent through evaporators to increase the concentration levels of dissolved salts to such an extent that they can be recovered through chilling process
- Solar evaporators are found to give inadequate performance due to various seasons, it has been recommended / directed by the TNPCB that the CETPs should use “mechanical evaporators” for the purpose of evaporating water from the RO plant reject

Background (Contd..)

- The general experience of CETPs with the use of mechanical evaporators has so far been not very positive.
- CETPs have been complaining that it is very costly to run the mechanical evaporators (10 lakh tons of wood is utilized every year to evaporate RO rejects from textile industry to recover salt in mechanical evaporators)
- The cost of operation is approximately Rs. 1.0 to 3.0 per one litre of water evaporated.
- As a result, industries are facing difficulty in operating the mechanical evaporators effectively, which is leading to frequent closure of the industrial units due to non-compliance with discharge standards.

Background (Contd…)

- Dr. Kumaravelu, then full time member of the State Planning Commission, Government of Tamil Nadu, had two meetings with the faculty members of IIT Madras to explore the possibilities of using "natural evaporators" in place of mechanical evaporators for salt recovery.
- He has also informed them about the attempts made by Mr. Kalidas, an enterprising entrepreneur, to demonstrate the effectiveness of natural evaporators for evaporating water from the RO reject in Tiruppur industrial area.
- It was mentioned that a natural evaporator with a surface area of 200 m^2 was able to evaporate 20,000 litres of water per day. Also, the cost of evaporation is almost one tenth of that achieved by a mechanical evaporator.

Graduation Tower

- Gradierwerk (Graduation Tower) is a type of outdoor inhalatorium found in certain spas.
- It consists of a wooden structure with thick layers of brushwood.
- The local mineral water, rich in sodium chloride, is pumped to the top of the wooden structure from where it gradually drips through the brushwood.
- Natural wind blows across this structure, resulting in evaporation of water dripping through the porous medium.
- The graduation towers are traditionally used in Poland for salt production (*wordsdomination.com/gradierwerk.html*).

Graduation Tower (Contd..)

- It may be noted that the water reaching the bottom of graduation tower will have a higher salt concentration than the inflow water at the top.
- Thus this type of a structure can be used for increasing the salt concentration in the RO reject by repeatedly cycling the water through the tower several times.

Present Effluent Treatment Methodology

- Decolouration
- Maintain BOD and COD
- Reverse Osmosis
- Mechanical Evaporation
- Crystallization of salt.

" The system works perfect till RO Stage – where 85-92 % water is recovered – the problem is in the last stage of treatment of the RO Reject"

Alternative – Natural Evaporator

Gradier werk in Germany

GREEN TEXTILE MOVEMENT

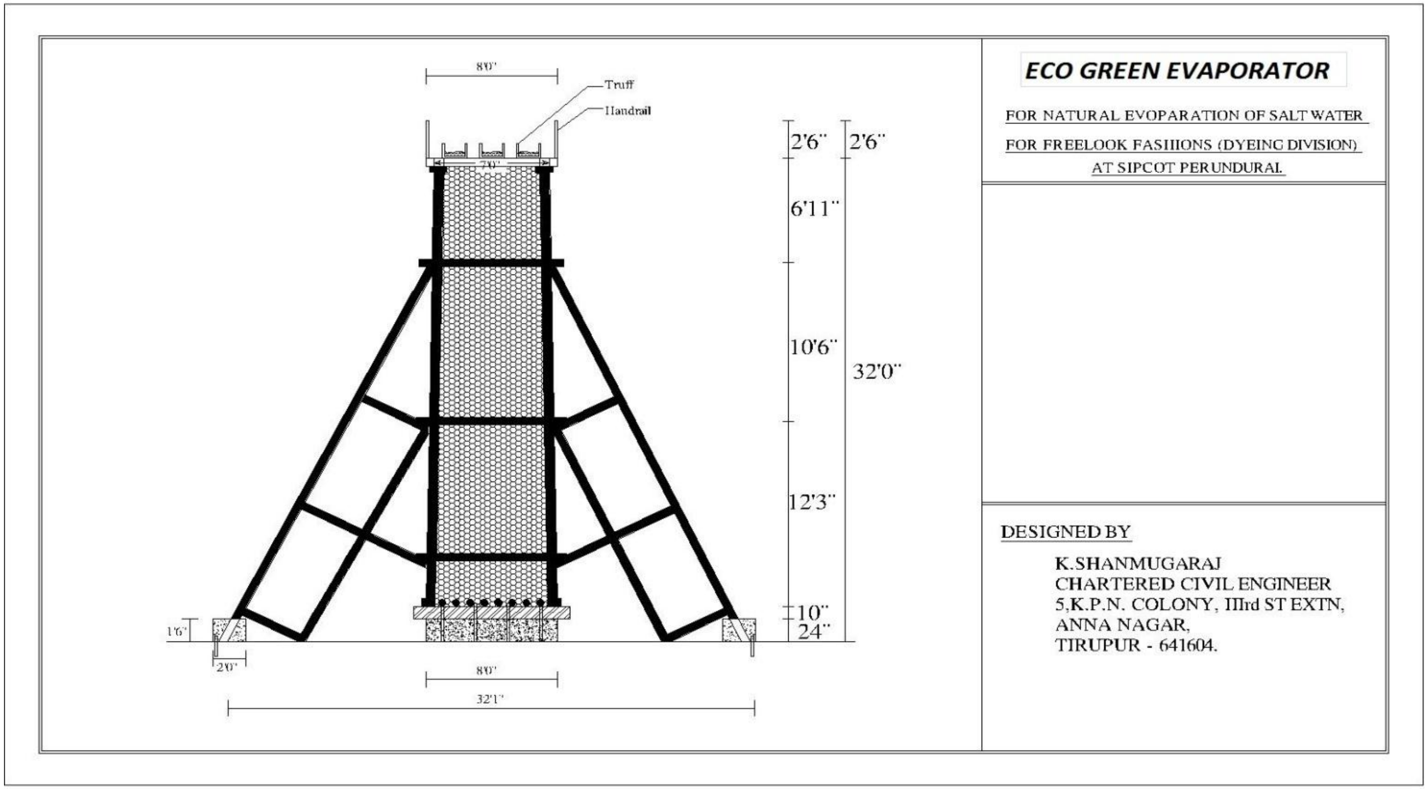
Advantages of Natural Evaporator

1. Enriches soil moisture – helps agriculture
2. Savings in Firewood and power – helps arrest deforestation
3. Carbon Emission Free - eligible for carbon credit
4. Environmental friendly
5. Operational Friendly
6. Affordable
7. Quick installation and commissioning

Pilot Plant

- Installed a pilot plant of Dimension 2.3m x 1m x 2 m Height
- Results were very encouraging

Design and Construction of the Eco Green Evaporator (EGIE) Tower



Construction of EGIE Tower

Construction of EGIE Tower

GREEN TEXTILE MOVEMENT

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Construction of EGIE Tower

Construction of EGIE Tower

Video Of EGIE

Installed at Freelook Fashions- Perundurai

Selection of Tower Packing material (FILL)

- **<u>Fill</u>:** The fill used in the EGIE tower is twigs of babul tree,
- ***Botanical name*** - Prosopis Juliflora

<u>It tolerates extremes of temperature and moisture</u>. It is suited for planting on marginal lands and can survive both drought and flooded conditions.

- ***Availability in Tamil Nadu****, the species grows widely in the districts of Salem, Erode, Dharmapuri and Coimbatore. plantations under social forestry programmes, (. (source : Internet)*

Field Visit

Field visit to Confident Process, Tiruppur on October 6, 2010 by IITM faculty (From left: Dr. A. Kannan , Dr. K. Srinivasa Reddy, Mr. A. C. Kalidas, Dr. Ligy Philip, Dr. B. S. Murty, Mr. K. Sudhakaran)

Pictures

Picture of a Gradierwerk (http://commons.wikimedia.org/wiki/File:Gradierwerk_Bad_Salzuflen.jpg)

Evaluation of the system on request of TNPCB

Observations and Suggestions:

- Our studies on the performance of the natural evaporator system installed in the premises of "Free Look Fashions", Plot No. R7, SIPCOT, Perundurai, Erode (Dist), Tamil Nadu" suggests that the natural evaporator system can be a viable alternative to the mechanical evaporators for treating the RO reject from the textile industry.
- The cost of recovering the salt from the R.O rejects is much less in Natural Evaporators compared to the presently used Mechanical Evaporators. Hence, the acceptance, adoption and chances of properly operating a natural evaporator is much higher than that of a mechanical evaporator.
- The huge quantities of fuel, especially used at present in the form of wood fuel in the Mechanical Evaporator can be totally eliminated through the use of Natural Evaporators, thus not only contributing to economy, but also to the Environment by contributing to the mitigation of carbon emission and thereby to the "Global Warming"
- Drift control measures taken by the industry is working satisfactorily.

Observations and Suggestions (Contd..)

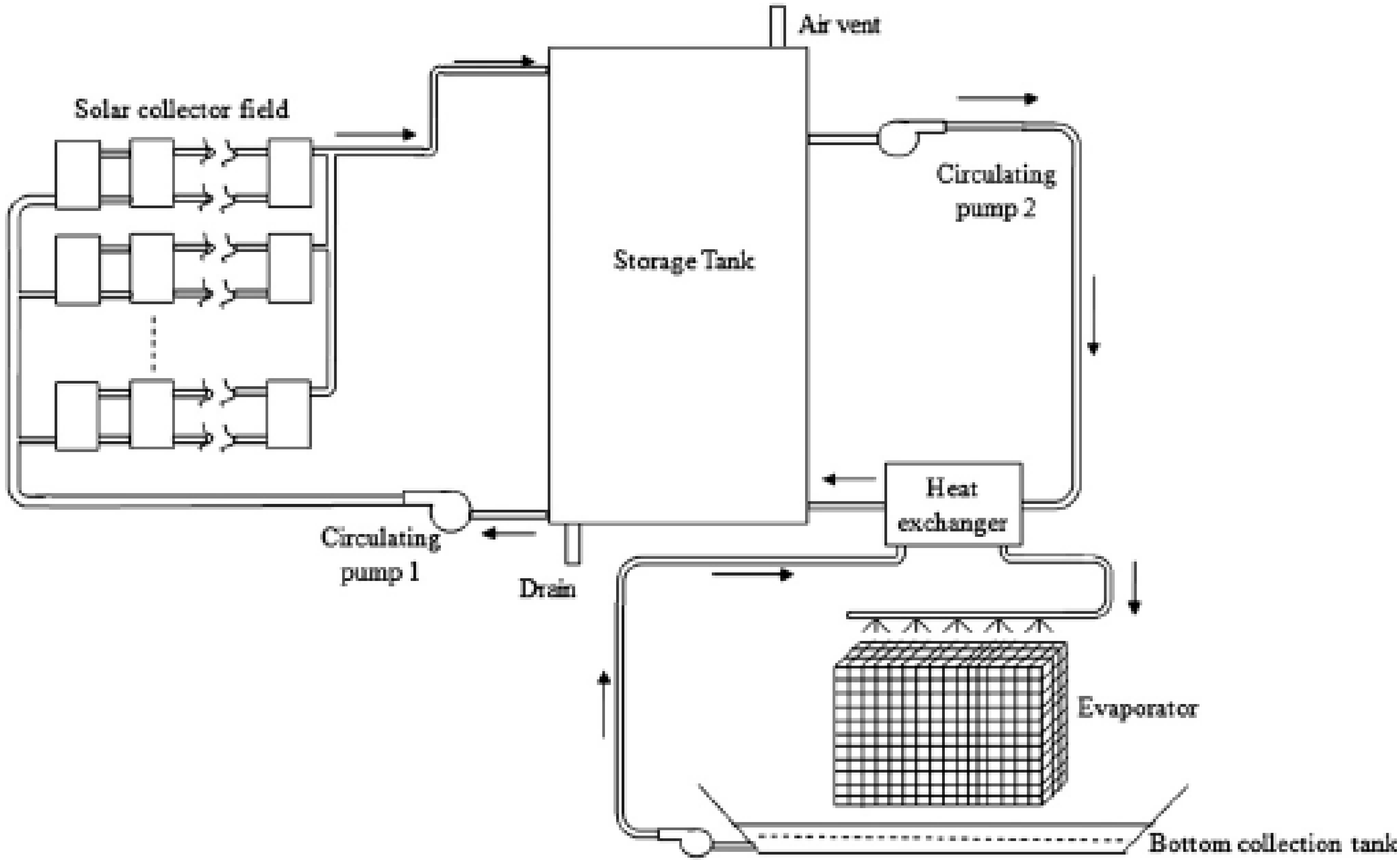
- There is a concern about the reject management during rainy / cloudy days using natural evaporator. The industry should provide details of alternative arrangements for the treatment of RO reject during the rainy days, and when the humidity is high. Enforcing agency should ensure that alternative arrangements are in place.
- Detailed monitoring of air quality around the natural evaporator was carried out by IIT Madras during 1st July 2011 to 3rd July 2011. PM_{10} , $PM_{2.5}$ and VOC concentrations around the natural evaporators were well within the ambient air quality norms.
- As and when the natural evaporators are allowed to be operated by the industry, enforcing agency (TNPCB) should closely monitor the working of natural evaporator, and make sure that there is a mass balance of salt in the system. Industry should maintain a proper log book, indicating the total salt used in the industry as raw material, and the salt recovered.
- The salt recovered should be either reused or stored properly.
- As and when the natural evaporators are adopted by the industry, random monitoring of air quality (PM_{10}, $PM_{2.5}$, VOC and cation and anion concentrations) should be carried out to ensure adherence to the stipulated standards.
- The stipulated **ZERO DISCHARGE** of effluents conditions can be effectively achieved by using **this type of NATURAL EVAPORATOR SYSTEM studied by us**

OBJECTIVE

Objective of this study is to optimize the design of a natural evaporator in order to make it a viable alternative to conventional evaporators for further concentrating RO rejects from the dyeing and textile industry.

Scope

- Experimental studies on model evaporators to optimize the design for the following;
  - Thickness (Depth) of the evaporators (in the wind direction);
  - Type of packing media (brushwood / synthetic material);
  - Packing density;
  - Flow rate of effluent ;
  - Distribution system at the top of the evaporator
- Modeling of evaporation process in a natural evaporator to help scaling of the results from model to field scale natural evaporators;
- Design a solar heat exchanger for preheating the RO reject to increase the effectiveness of natural evaporator

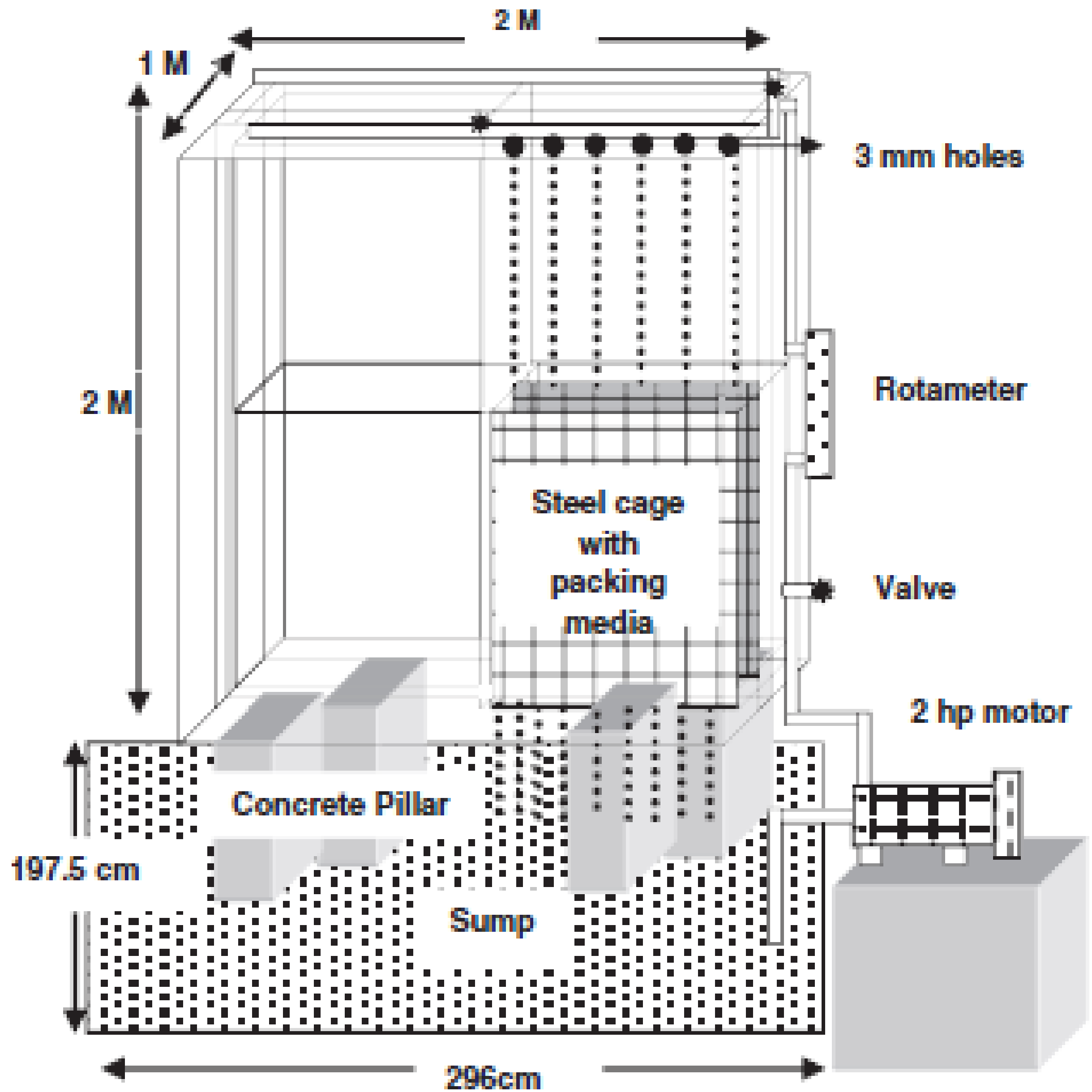

Air vent
Solar collector field
Storage Tank
Circulating pump 2
Heat exchanger
Circulating pump 1
Drain
Evaporator
Bottom collection tank

METHODOLOGY

Experimental Setup:

The natural evaporator has the following components:

1. **A structure made of steel pipes give the structural stability to hold the packing media.**
2. **The water distribution system at the top is made up of two PVC pipelines with evenly distributed 24 holes of 3mm to drip the water on to the structure uniformly.**
3. **A collection tank at the bottom for collecting water dripping from the evaporator.**
4. **A recirculation tank for collecting concentrated water from the evaporator, preheat and pump the water to the distribution system.**
5. **A solar collector field for utilizing solar energy for pre heating the water.**
6. **2HP Pumps, appropriate controls and measuring instruments like rotameter, control valve.**


2 M
1 M
3 mm holes
2 M
Rotameter
Steel cage with packing media
Valve
2 hp motor
Concrete Pillar
197.5 cm
Sump
296cm


sunrise
sunrise

Effect of Various Parameters on Evaporation

1. **Wind velocity**
2. **Relative humidity in the ambient air**
3. **Temperature of water in the recirculation tank for different design parameters.**

Different wind velocities are obtained in the model by adjusting the blower speed. Evaporation loss was measured in terms of increased TDS/volume reduction in the collection tank.

Wind Velocity/ Relative Humidity

The wind velocity was maintained constant by using an industrial fan, but the constant wind was affected by ambient air flow.

This was prevented by using a wind shield made of tarpaulin with bamboo stick supports. Wind velocity was measured by using an anemometer.

Relative humidity in the ambient air was measured using a humidity meter and the values are cross checked with dry bulb and wet bulb thermometers.

Experiment with a cage loaded with dense spiral ring synthetic packing media

This synthetic packing media due to its high packing density and highly irregular shape, didn't allow air to pass through the media.

It acted as a barrier against wind.

The rate of evaporation was very low. Hence, this packing media was not selected

Technical data for spiral ring packing media

S.no	Size	Surface area	Void ratio	Packing Factor	Weight	Material
1.	26mm	500 Sq.m/cu.m	87%	210 sft/cft	140gm/l	PVC
2.	55mm	350 sq.m/cu.m	92%	83sft/cft	110gm/l	PVC
3.	Permissible temperature – 75 °C					

A new less dense pall ring tower packing media was loaded in the cage

Physical & chemical properties of plastic tower packing

Performance / Material	PE	PP	RPP	PVC	CPVC	PVDF
Density (g/cm^3)	0.94-0.96	0.89-0.91	0.93-0.94	1.32-1.44	1.50-1.54	1.75-1.78
Operating Temp. (°C)	90	>100	>120	>60	>90	>150
Chemical corrosion resistance	Good	Good	Good	Good	Good	Good
Compression Strength (Mpa)	>6.0	>6.5	>7.0	>6.0	>8.0	>10.0

Sizes mm	**Surface m^2/m^3**	**Free Vol. %**	**Number per m^3**	**Weight kg/ m^3**
16*16*1	260	91	230000	141
25*25*1.2	210	90	53500	82
38*38*1.4	140	89	13500	54
50*50*1.5	100	90	6500	51
76*76*2.6	73	92	1930	58

Experiments

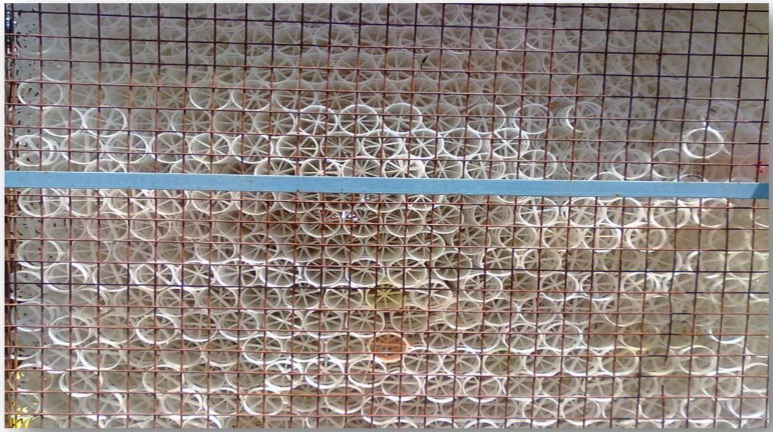
- Type of packing media (pall ring / thorny sticks).
- Type of packing (random / structured).
- Number of panels (one / two)
- Arrangement of panels (side by side / back to back)
- Thickness of panel (50 cm / 25 cm)
- Water flow rate (200 LPH / 400 LPH / 600 LPH / 800 LPH).
- Variation occurred only in terms of air (ambient) temperature, water temperature, and relative humidity.
- Wind velocity is mostly kept constant at 15 km/h, except in few cases

Experiment with a cage loaded with pall ring packing media (randomly) with 400 LPH and 10 Km/h wind

Steel cage with pall ring packing media

Experimental setup with a cage loaded with pall ring plastic packing media

Various Configurations



Results and Inferences

- Experimental data obtained from the pilot scale natural evaporator was analyzed for the trends through empirical correlation development.
- evaporation rate strongly depends on the difference between the vapor pressure of water at the water temperature (e_{sw}) and the partial pressure of water vapor in the air above the water surface (e_a).
- the evaporation rate will be minimal on those days when the relative humidity is very high, and there is not much difference between the temperatures of water and air.
- It is emphasized that Chennai, being a coastal city is inherently prone to high humid conditions and hence when water is also at near ambient conditions, the vapor pressure was not high.
- One way to increase the evaporation rate is to increase the value of (e_{sw} - e_a) by increasing the water temperature.
- This can be accomplished by preheating the water using solar power, as demonstrated in the present pilot scale experiments.
- evaporation rate, E strongly depends upon the wind velocity, *V*.
- High evaporation rate can be achieved in regions with high wind velocity.

Trend Analyses

- Evaporation rate, E linearly depends upon the wind velocity, V.
- Evaporation from water surfaces that the evaporation rate strongly depends on the difference between the vapor pressure of water at the water temperature (E_{sw}) and the partial pressure of water vapor in the air above the water surface (E_a).
- Therefore, variable E/V is plotted as a function of ($E_{sw} – E_a$) and the equation for a best fit curve is obtained.
- It is hypothesized that (E/V) varies with ($E_{sw} – E_a$) as per a power function.
- In some of the experiments, the water temperature and the ambient temperature (those experiments where the water is not pre-heated using the solar power) were same.
- For those experiments, (E/V) is plotted as a function of T*(1-Rh), where T is the temperature in ^{0}C and Rh is the relative humidity in fraction.
- In the trend analysis, V is taken in Km/h, E is taken in mm/h, E_{sw} and E_a are taken in N/m^2 abs.

Set No.	Description	Equation	R^2 Value
1	Flexi rings; Random packing; Single cage (Exposed surface area = 1 m^2); Depth = 0.50 m; No wind shield; Q = 400 L – 500 L/h; V = 10.0 – 15.0 Km/h	$E = 0.429[V(e_{sw} - e_a)]/1000$	0.58
2	Flexi rings; Random packing; Two cages Back to Back with 22 cm gap (Exposed surface area = 1 m^2) Depth = 1.0 m; No wind shield; Q = 600 / 800 L/h; V = 15 Km/h	(a) Q = 600 L/h $E = 0.363[V(e_{sw} - e_a)]/1000$	0.94
		(b) Q = 800 L/h $E = 0.751[V(e_{sw} - e_a)]/1000$	0.77
3	Flexi rings; Random packing; Single cage (Exposed surface area = 1 m^2); Depth = 0.5 m; Wind shield in place Q = 400 L/h ; V = 15 Km/h	$E = 0.86[V(e_{sw} - e_a)]/1000$	0.81
4	Flexi rings; Structured packing; Single cage (Exposed surface area = 1 m^2); Depth = 0.5 m; Wind shield in place, Q = 400 L/h; V = 15 Km/h	$E = 0.451[V(e_{sw} - e_a)]/1000$	0.88
5	Flexi rings; Random packing; Single cage (Exposed surface area = 1 m^2); Depth = 0.25 m; Wind shield in place; Q = 400 L/h; V = 15 Km/h	$E = 0.542[V(e_{sw} - e_a)]/1000$	0.72

Trend Analyses

6	Flexi rings; Structured packing; Two cages side by side (Exposed surface area = 2 m^2) Depth = 0.50 m; Wind shield in place; Q = 800 L/h; V = 15 Km/h	$E = 0.902[V(e_{sw} - e_a)]/1000$	0.69
7	Flexi rings; Structured packing; Two cages back to back (22 cm gap) (Exposed surface area = 1 m^2); Depth = 1.0 m; Wind shield in place; Q = 800 LPH; V = 15 Km/h	$E = 0.851[V(e_{sw} - e_a)]/1000$	0.86
8	Thorny sticks; Single cage (Exposed surface area = 1 m^2) Depth = 0.50 m; Wind shield in place; Q = 400 LPH; V = 15 Km/h	$E = 0.152[V(e_{sw} - e_a)]/1000$	0.77
9	Flexi rings; Structured packing; Single cage (Exposed surface area = 1 m^2); Depth = 0.50 m; Wind shield was in place; Q = 400 L/h; V = 15 Km/h Salt water	$E = 0.192[V(e_{sw} - e_a)]/1000$	0.86

CONCLUSIONS

- Among the various synthetic media tried, Flexi ring was found to be most effective.
- Random packing was more effective compared to structured packing, as long as the air flow is not significantly obstructed by the packing.
- The important parameters which affect the evaporation rate are humidity of the ambient air, temperature of water, temperature of ambient air and the wind velocity.
- The most important variable which affects the evaporation rate is the difference between the vapor pressure at water temperature and the partial pressure of water vapor at air temperature.
- Natural media like thorny sticks were also found to be suitable packing media though the evaporation rate was lower than the structured Flexi ring media.
- The exposed surface area is the most important dimension of the natural evaporator.
- Larger depth of packing of the evaporator had a positive effect on evaporation.
- Rate of evaporation was significantly reduced when the ambient relative humidity was high and solar pre heating significantly increased the evaporation rate.

Typical Design Examples

- The empirical equations proposed in this study can be used for the design of cross-flow natural evaporators, as described below.
- Consider Flexi ring media with structured packing. The equation for evaporation rate from 1 m^2 of evaporator (exposed surface area perpendicular to wind direction) is

$$E = 0.451[V(e_{sw} - e_a)]/1000$$

where E is in L/h; V is in m/h, e_{sw} and e_a are in KN/m^2 abs.

Case(i): Provision of Solar Heating

- It is assumed that the water temperature due to solar heating is 60^0 C (corresponding e_{sw} value is 20 KN/m^2)
- Ambient air temperature is 30^0 C (corresponding vapor pressure = 4.25 KN/m^2)
- Prevailing wind velocity is 15 Km/h and the Relative humidity, Rh is 50% (corresponding e_a at air temperature of 30^0 C is 2.125 KN/m^2).
- It is required to evaporate 100 KL of water per day.
- Evaporation rate, E is 120.9 L/h or 2902 LPD.
- Hence the area required for evaporating 100 KLD = $10^5/2902$ = 34.5 m^2

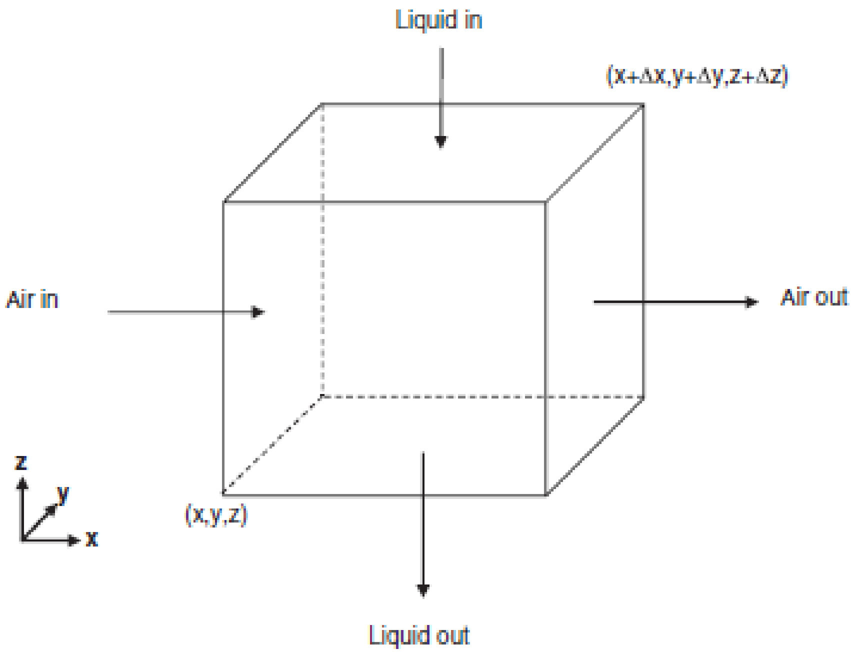
Case (ii): No Provision for Solar Heating

- It is assumed that the water temperature is 30^0 C (corresponding e_{sw} value is 4.25 KN/m^2)
- Ambient air temperature is 30^0 C (corresponding vapor pressure = 4.25 KN/m^2).
- Prevailing wind velocity is 15 Km/h and the Relative humidity, Rh is 50% (corresponding e_a at air temperature of 30^0 C is 2.125 KN/m^2).
- It is required to evaporate 100 kL of water per day.
- Evaporation rate, E is 14.37 L/h or 345 LPD.
- Hence, area required for evaporating 100 KLD is $10^5/345 = 289\ m^2$.

Case(iii): No Provision for Solar Heating and Low Wind Velocity and high Relative Humidity

- It is assumed that the water temperature is 30^0 C (corresponding e_{sw} value is 4.250 KN/m^2).
- Ambient air temperature is 30^0 C (corresponding vapor pressure = 4.250 N/m^2).
- Prevailing wind velocity is only 5 Km/h and the Relative humidity, Rh is 85% (corresponding e_a at air temperature of 30^0 C is 3.6125 N/m^2).
- It is required to evaporate 100 kL of water per day.
- Evaporation rate, E is 1.438 L/h or 34.5 LPD/m^2.
- Hence, area required for evaporating 100 KLD is $10^5/34.5 = 2898$ m^2

PROCESS BASED MODEL



Control volume depicting air and water phases in cross flow.

Equations

- Conservation of mass
- Conservation of Energy
- Interphase Transport

SHELL BALANCE APPROACH

Material Balance

Rate of loss of water due to evaporation = Rate of gain in moisture by air

$$\frac{\partial G^*}{\partial Z} = \frac{\partial \omega}{\partial X}.$$

$$G^* = \frac{G_w}{G_a}; \; X = \frac{x}{B}; \; Z = \frac{z}{B}$$

G_a= Mass Flux of air

G_w= Mass Flux of water

W = Humidity in mass ratio basis

B = Width in the air flow direction

Interfacial Flux Expression

$$\frac{\partial G^*}{\partial Z} = NTU(\omega_i - \omega_G).$$

$$NTU = \frac{k_\omega a}{G_a} B.$$

W_i= saturation humidity at inteface, based on liquid T
w_G= humidity of bulk air stream
K_w= Mass transfer coefficient

NTU: Important performance Indicator
High value indicates more evaporation
So better cooling

OVERALL ENERGY BALANCE

Decrease in water enthalpy = Increase in air enthalpy

$$G^{*}\frac{\partial t_w}{\partial Z} = \frac{1}{C_{PW}}\frac{\partial H_a}{\partial X} - NTU\left[t_w(\omega_i - \omega_G)\right].$$

t_w = water temperature
C_{pw} = Specific heat capacity
H_a = Air enthalpy

HEAT FLUX ACROSS INTERPHASE

Convective heat flux water interphase to bulk air

Heat flux associated with water evaporation

$$\frac{\partial H_a}{\partial X} = NTU \left\{ (H_{ai} - H_a) + (Le - 1)[(H_{ai} - H_a) - (\omega_i - \omega_G) H_{vi}] \right\}.$$

H_{ai}= Enthalpy of air at air water interface
H_{vi}= Enthalpy of water vapor at interface temperature
Le = Lewis number

$$Le = 0.9078 \frac{\left(\frac{\omega_i + 0.622}{\omega_G + 0.622} - 1\right)}{\ln\left(\frac{\omega_i + 0.622}{\omega_G + 0.622}\right)}.$$

Equation for Water Temperature

$$\frac{\partial t_w}{\partial Z} = \frac{1}{G^* C_{Pw}} (NTU)\{(H_{ai} - H_a) + (Le - 1)[(H_{ai} - H_a) - (\omega_i - \omega_G) H_{vi}] - C_{Pw} T_W (\omega_i - \omega_G)\}.$$

Equations are solved for

Water flow rate
Air humidity
Air enthalpy
Water Temperature

At any location in the tower

x: Direction of air flow
z: Direction of water flow

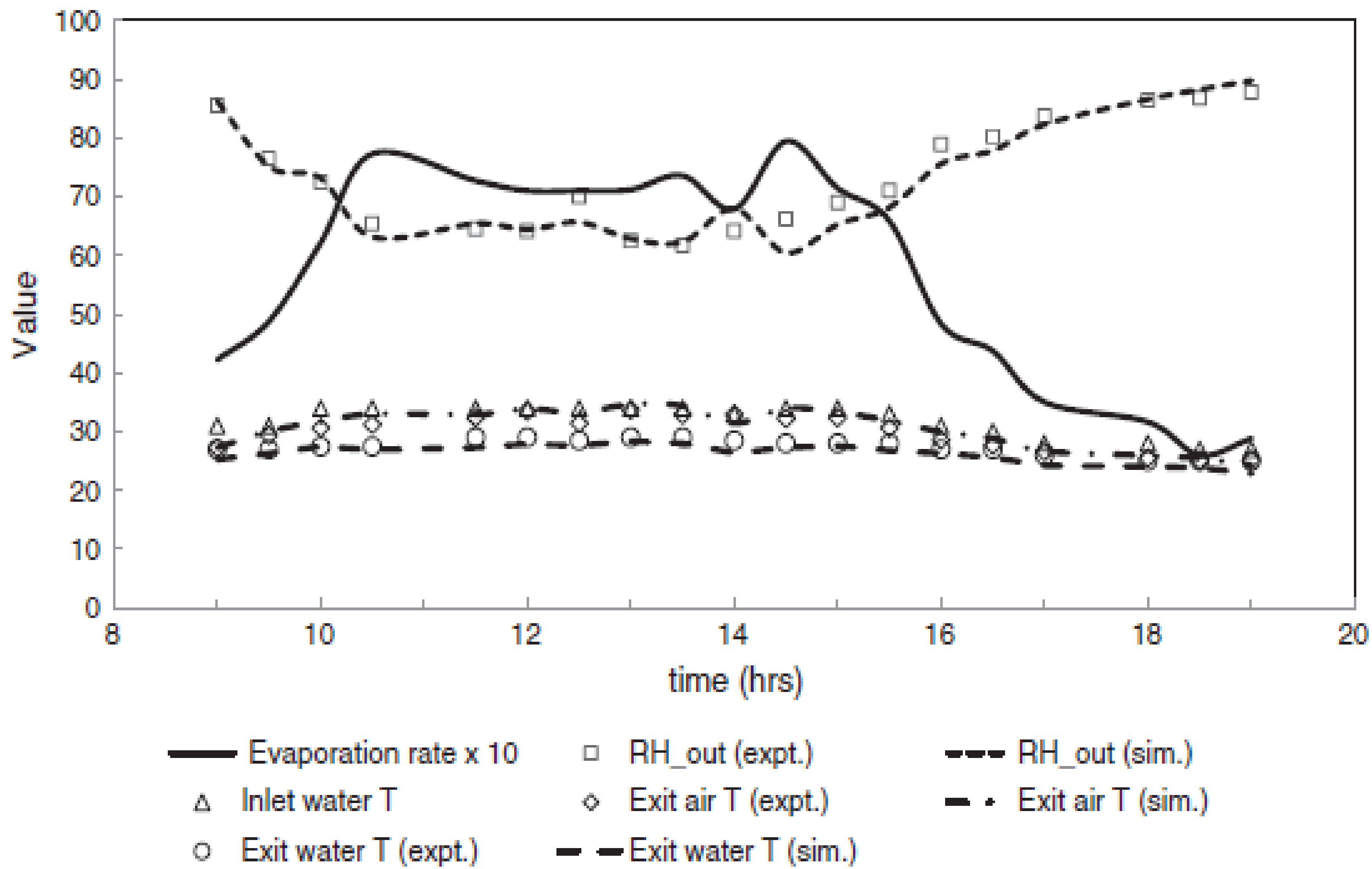


Fig. 3. Evaporator performance with arranged packing media (depth: 50 cm, air flow rate = 2.136 kg/s, water flow rate = 400 LPH, *NTU* = 0.2). Temperatures are in °C and evaporation rate is in kg/h.

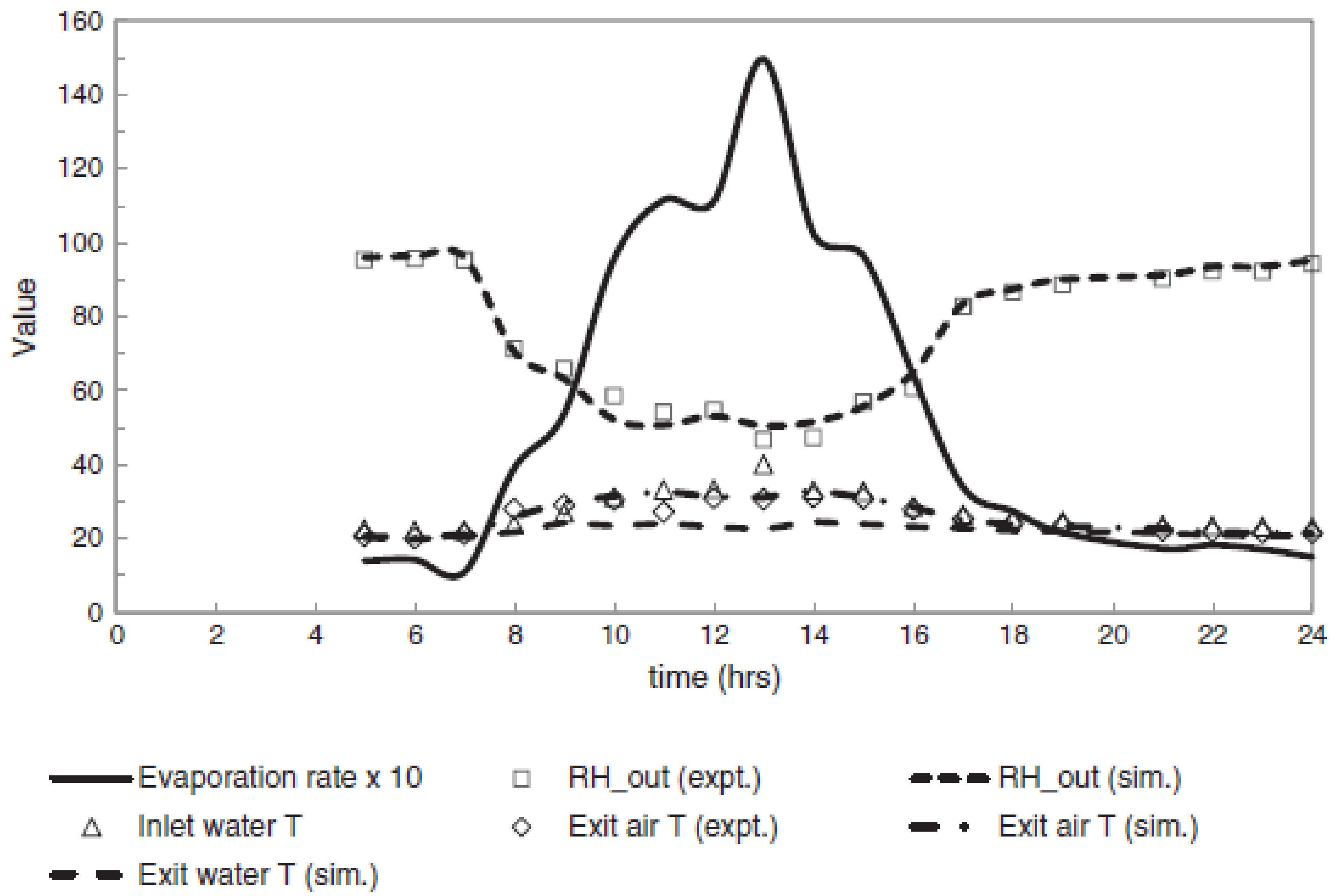


Fig. 4. Evaporator performance with arranged packing media (depth: 50 cm, air flow rate = 2.329 kg/s, water flow rate = 400 LPH, *NTU* = 0.2). Temperatures are in °C and evaporation rate is in kg/h.

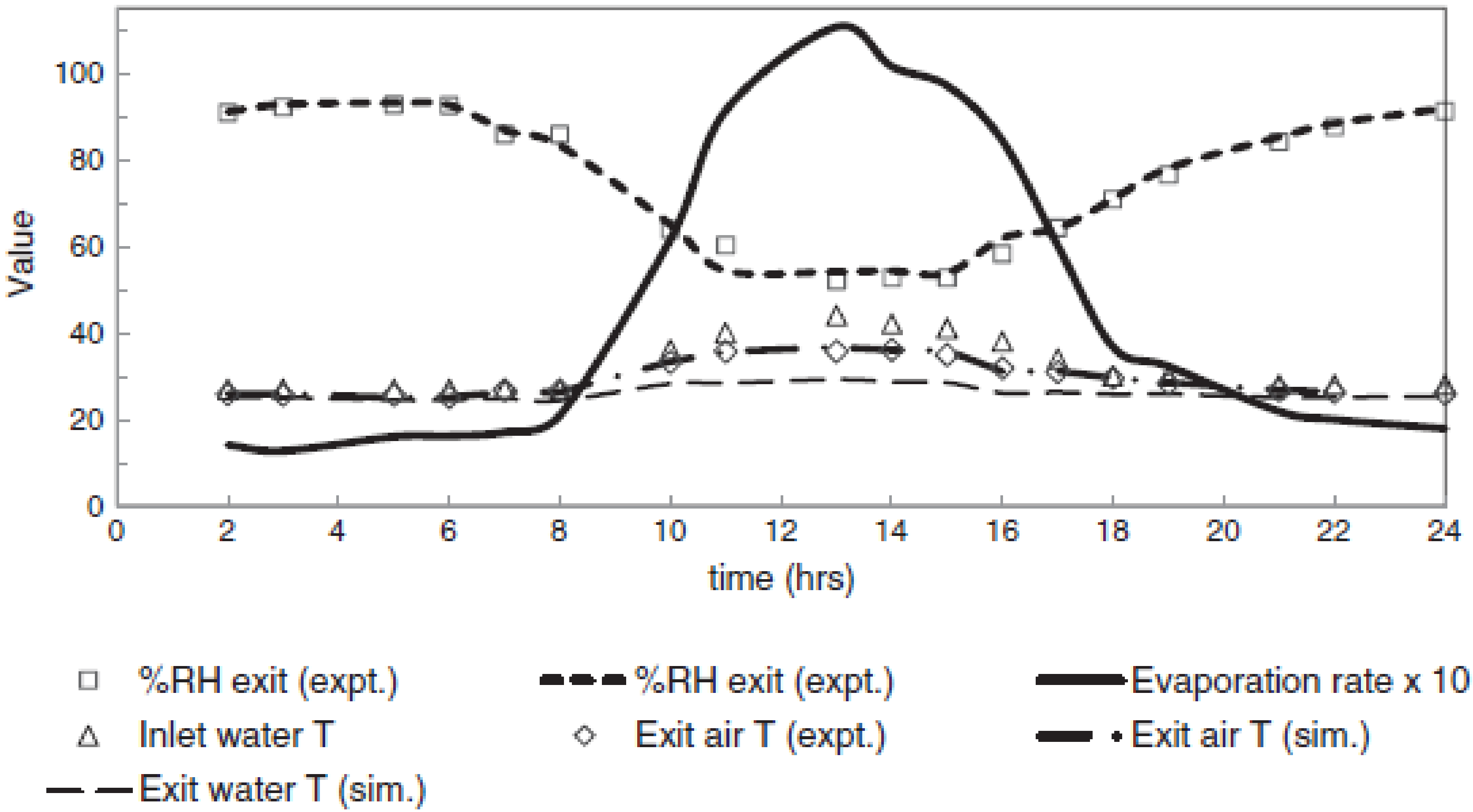
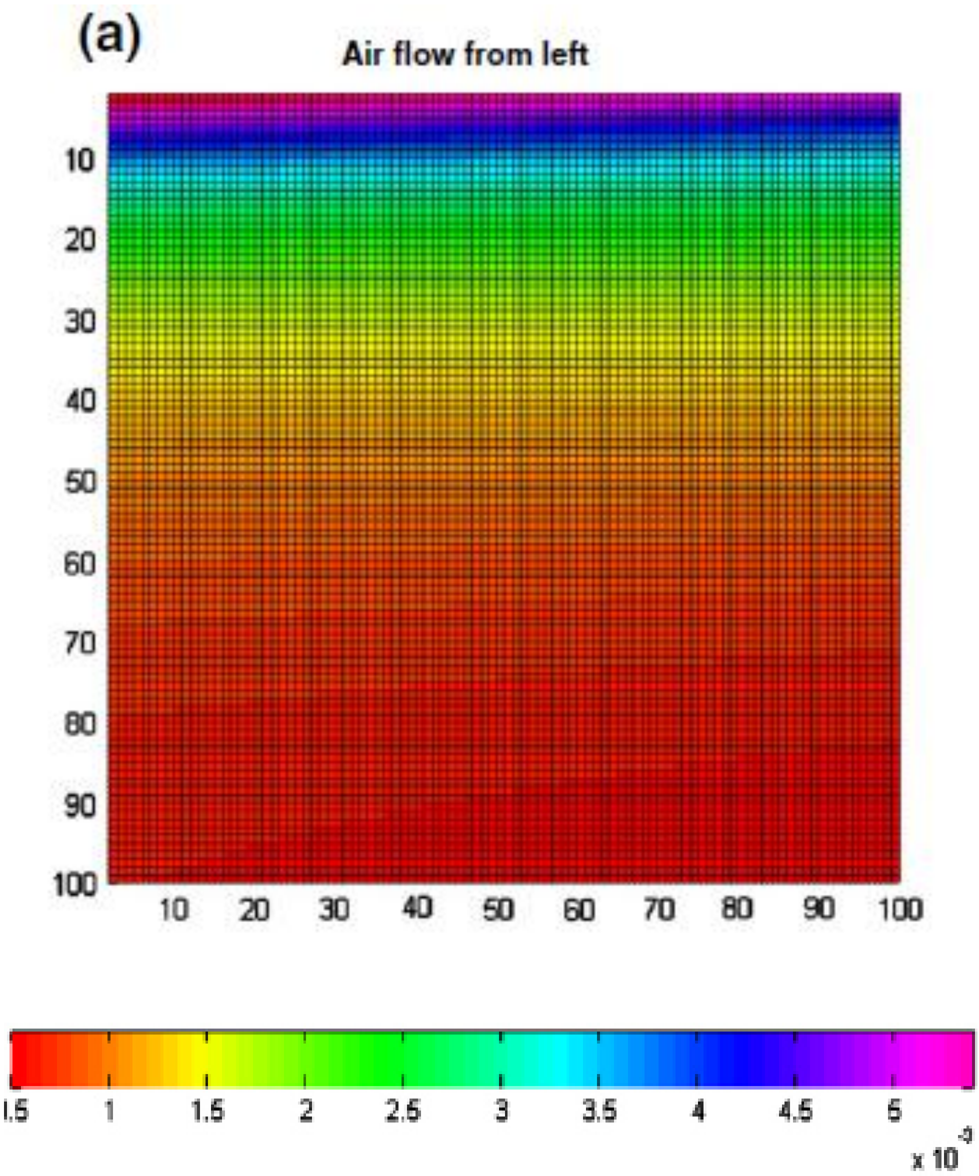


Fig. 6. Evaporator performance with arranged packing media (depth: 25 cm, air flow rate = 2.329 kg/s, water flow rate = 400 LPH, *NTU* = 0.1). Temperatures are in °C and evaporation rate is in kg/h.

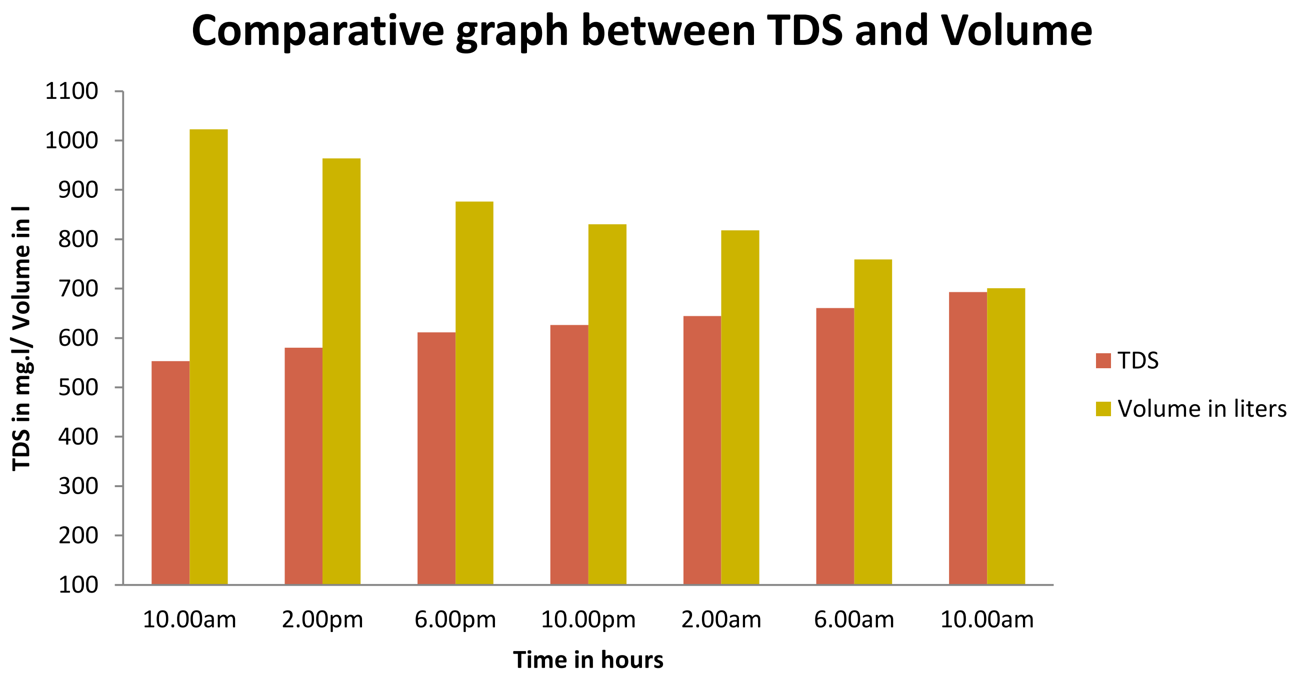
Water Evaporation rate in each element



THANK YOU

S. No	Parameters	AT 10 am	At 2 pm	At 6 pm	At 10 pm	At 2 am	At 6am	At 10am
1.	Wind speed before the cage Km/hr	10.5	11	10	10-11.3	10-12	10-11	10-12
2.	Wind speed after the cage Km/hr	1	1	2	2	1	0.8-1.2	1
3.	Humidity %RH	45.5	34.6	61.7	79	79.5	76.4	40
4.	Temperature ˚C	38	41	33	29.7	29.3	29.1	39.5
5.	Water flow LPH	400	400	400	400	400	400	400
6.	Water depth cm	17.5	16.5	15	14.2	14	13	12
7.	Experiment TDS mg/l	553.4	580.6	611.2	626	644.3	660.4	692.7
8.	Blank TDS mg/l	553.4	562.5	574.4	585.3	589.8	594.1	602.3

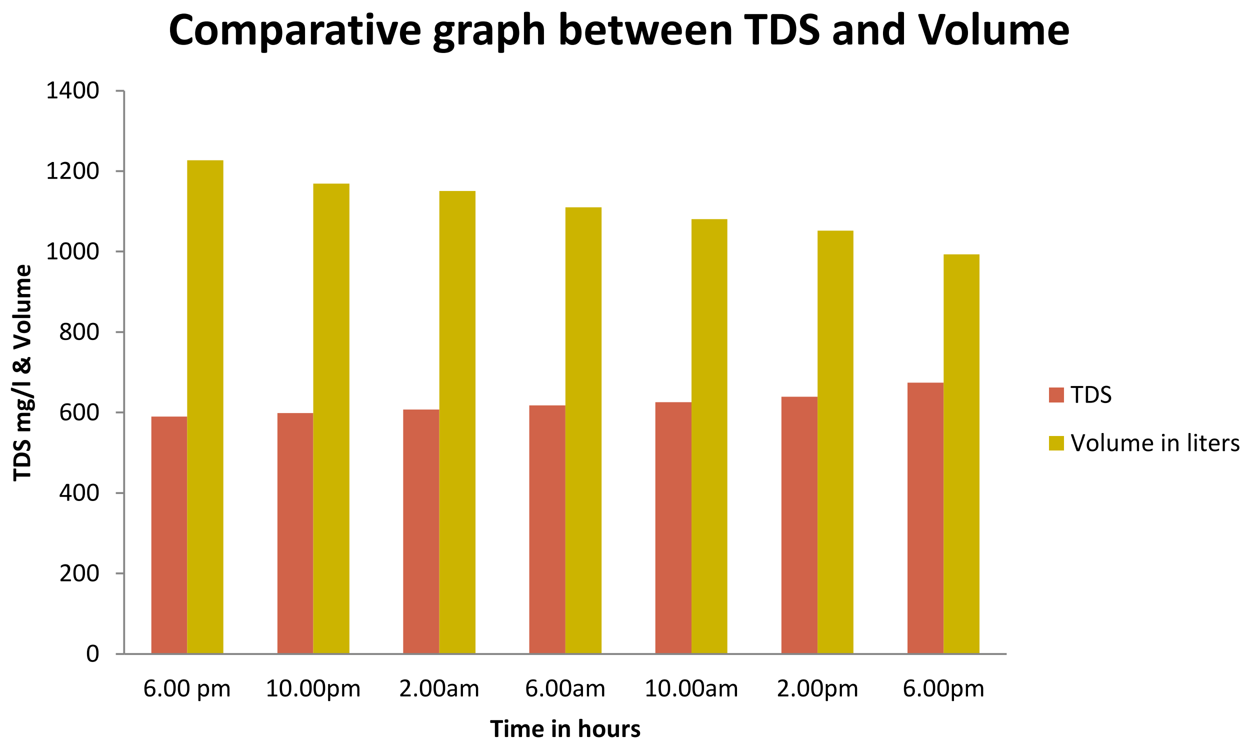
Evaporation for Experiment	**= 30 %**
Evaporation for Blank	= 10%
Volume of water at initial stage	= LxWxd
	=1023 L
Volume of water at final stage	= LxWxd
	=701 L
Total evaporation	= Initial volume – Final volume
	= 322 L
30 % of 1023(Total volume)	**= 306.6 L**



Experiment repeated without changing any parameter

S. No	Parameters	AT 6pm	At 10 pm	At 2am	At 6apm	At 10 am	At 2pm	At 6pm
1.	Wind speed before the cage Km/hr	10-12	10-12	10-11.5	10- 12	10-12	10-12	10-12
2.	Wind speed after the cage Km/hr	2-4	2	0-1	1-2	1 -2	1-2	1-1.8
3.	Humidity %RH	66	77	80.6	80.7	49	49	65.4
4.	Temperature ˚C	31 ˚ C	30.1	28.6 ˚ C	27.8	35	35	31.6
5.	Water flow LPH	400	400	400	400	400	400	400
6.	Water depth cm	21	20	19.7	19	18.5	18	17
7.	Experiment TDS mg/l	590.1	598.8	607.2	617.7	625.8	639.0	674.3
8.	Blank TDS mg/l	590.1	592.2	592.7	596.2	601.5	622.2	624.0

Evaporation for Experiment	**= 20 %**
Evaporation for Blank	= 10%
Volume of water at initial stage	=1227 L
Volume of water at final stage	= 993L
Total evaporation	= Initial volume – Final volume
	= **234 L**
20% of 1227(Total volume)	**=245.4 L**

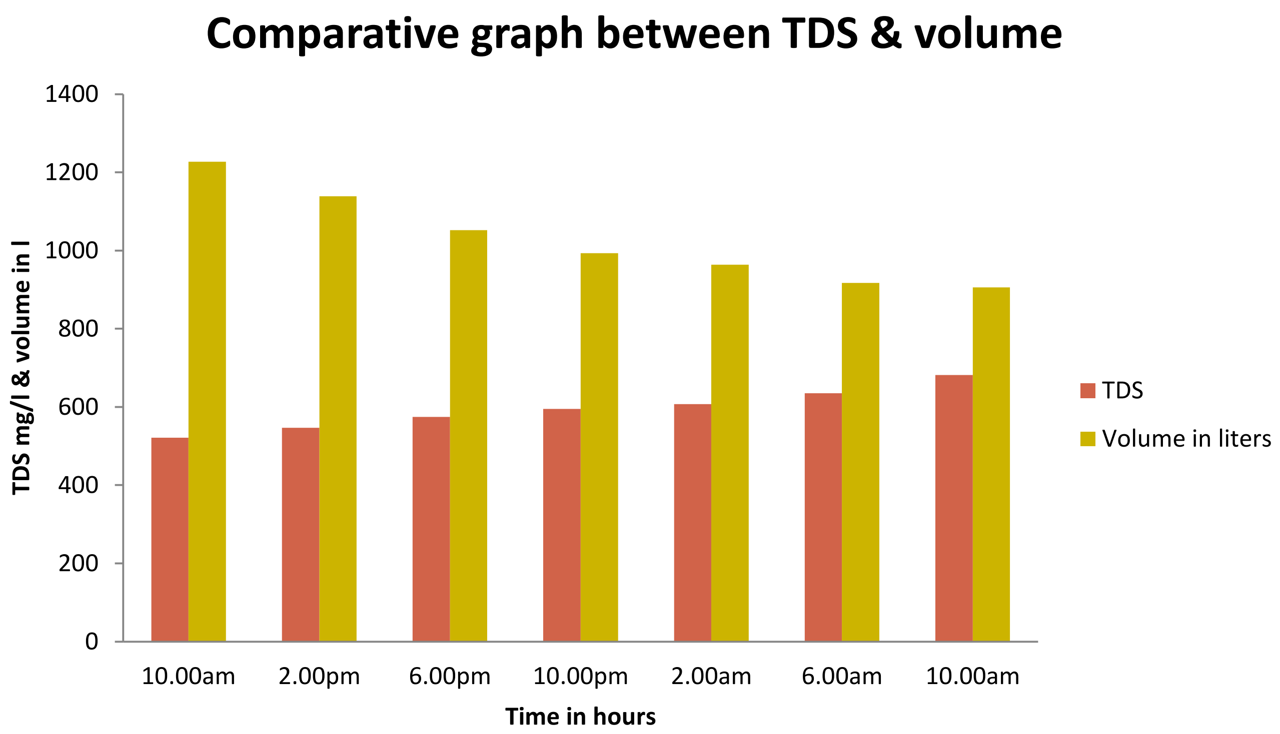


Date: 21/06/11

Experiment with a cage loaded with pall ring packing media (randomly) with 400 LPH and 15 Km/hr.

S. No	Parameters	At 10am	At 2 pm	At 6pm	At 10pm	At 2 am	At 6am	At10am
1.	Wind speed before the cage Km/hr	15	15	15	15	15	15	15
2.	Wind speed after the cage Km/hr	2	2-4	2-3	1	1	1	1-2
3.	Humidity %RH	33.5	26	32.2	75	60	54	34
4.	Temperature ˚C	41.8	43	32.2	30	30	29.6	40
5.	Water flow LPH	400	400	400	400	400	400	400
6.	Water depth cm	21	19.5	18	17	16.5	15.7	15.5
7.	Experiment TDS mg/l	521.6	546.5	574.5	595.2	607	634.8	682
8.	Blank TDS mg/l	521.6	535.4	546.5	547.8	551	556	574.5

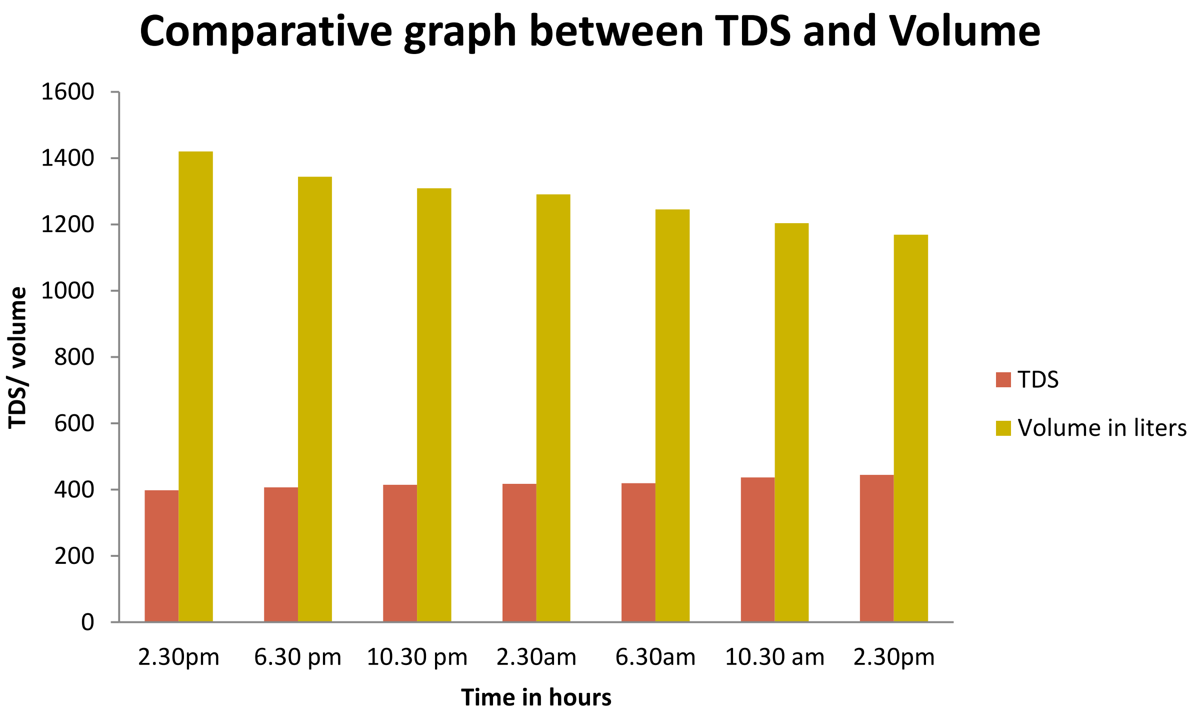
Evaporation for Experiment	= **30%**
Evaporation for Blank	**= 10%**
Volume of water at initial stage	=1227 L
Volume of water at final stage	= 906L
Total evaporation	= 321 L
30% of 1227(Total volume)	=368.1 L



1/8/11 **Experiment started at 2.30 pm, with a cage loaded with pall ring packing media. The water flow was increased to 500 LPH; wind speed was kept constant at 15 Km/hr.**

S. No	Parameters	At 2.30pm	At 6.30pm	At 10.30pm	At 2.30am	At 6.30am	At 10.30am	At 2.30Pm
1.	Wind speed before the cage Km/hr	15	15	15	15	15	15	15
2.	Wind speed after the cage Km/hr	1	0.1	1	1	1.3	2	1
3.	Humidity %RH	55.4	58.9	74.81	76.9	67.1	63.7	58
4.	Ambient humidity %RH	51	55.7	73.1	76.6	66.8	61	54.7
5.	Temperature ˚C	34.7	33.5	29.1	28.6	28.1	29.9	32.9
6.	Ambient temperature ˚C	35.2	33.6	29.6	28.8	28.4	30	33.2
7.	Water flow LPH	500	500	500	500	500	500	500
8.	Water depth cm	24.3	23	22.4	22.1	21.3	20.6	20
9.	Experiment TDS mg/l	397.8	406.5	414.2	418	419.5	437	444.2
10.	Blank TDS mg/l	397.8	401.6	403.3	404	405.1	407	410

Evaporation for Experiment	**= 20%**
Evaporation for Blank	**= 10%**
Volume of water at initial stage	=1420 L
Volume of water at final stage	= 1169L
Total evaporation	= 251 L
20% of 1420 (Total volume)	= 284 L



03/08/11 Experiment started at 2.00 pm with two cages, in back to back position with 6cm gap in between the cage. The flow rate was kept at 600 LPH. Wind speed was kept at 15km/hr.

S. No	Parameters	At 2pm	At 6pm	At 10pm	At 2am	At 6am	At 10am	At 2pm
1.	Wind speed before the cage Km/hr	15	15	15	15	15	15	15
2.	Wind speed after the cage Km/hr	2.5	2.5	1.5	1	0.2	2.5	1.2
3.	Ambient Humidity %RH	37.4	50.2	77.3	59.7	59.5	47.4	41.7
4.	Ambient temperature ˚C	39.6	33.3	30	29.8	30.2	34.7	37.7
5.	Humidity %RH	43.6	52.9	77.1	61.1	60.4	46.7	43.5
6.	Temperature ˚c	36.4	32.6	29.7	29.7	30.4	35.9	38.5
7.	Water flow LPH	600	600	600	600	600	600	600
8.	Water depth cm	27.5	26.2	25.6	25.2	24	23	21.8
9.	Experiment TDS mg/l	400	409	416	424	434	438	446.5
10.	Blank TDS mg/l	400	404.9	406	408	410.4	412.4	417.9

Evaporation for Experiment = **20%**

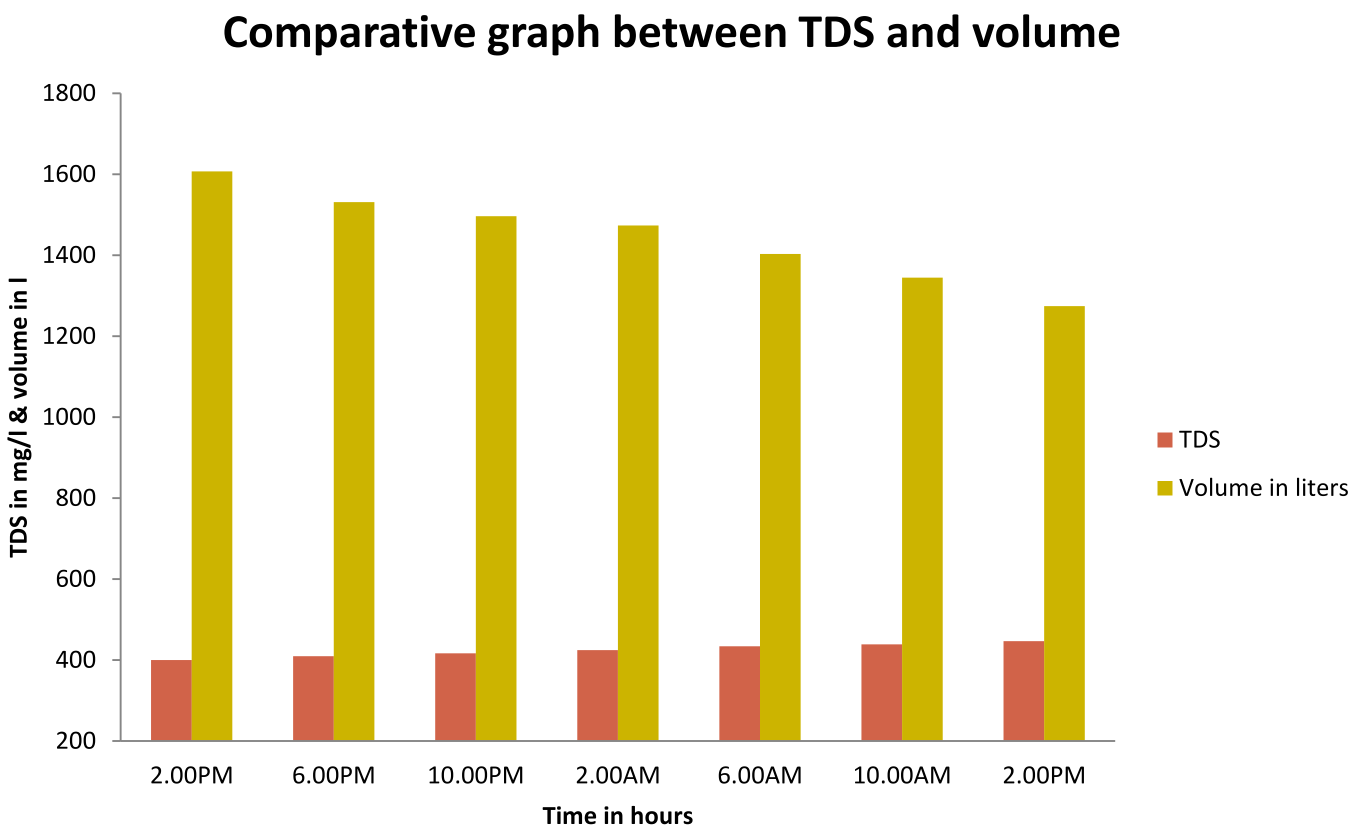
Evaporation for Blank = **10%**

Volume of water at initial stage =1607 L

Volume of water at final stage = 1274L

Total evaporation = 333 L

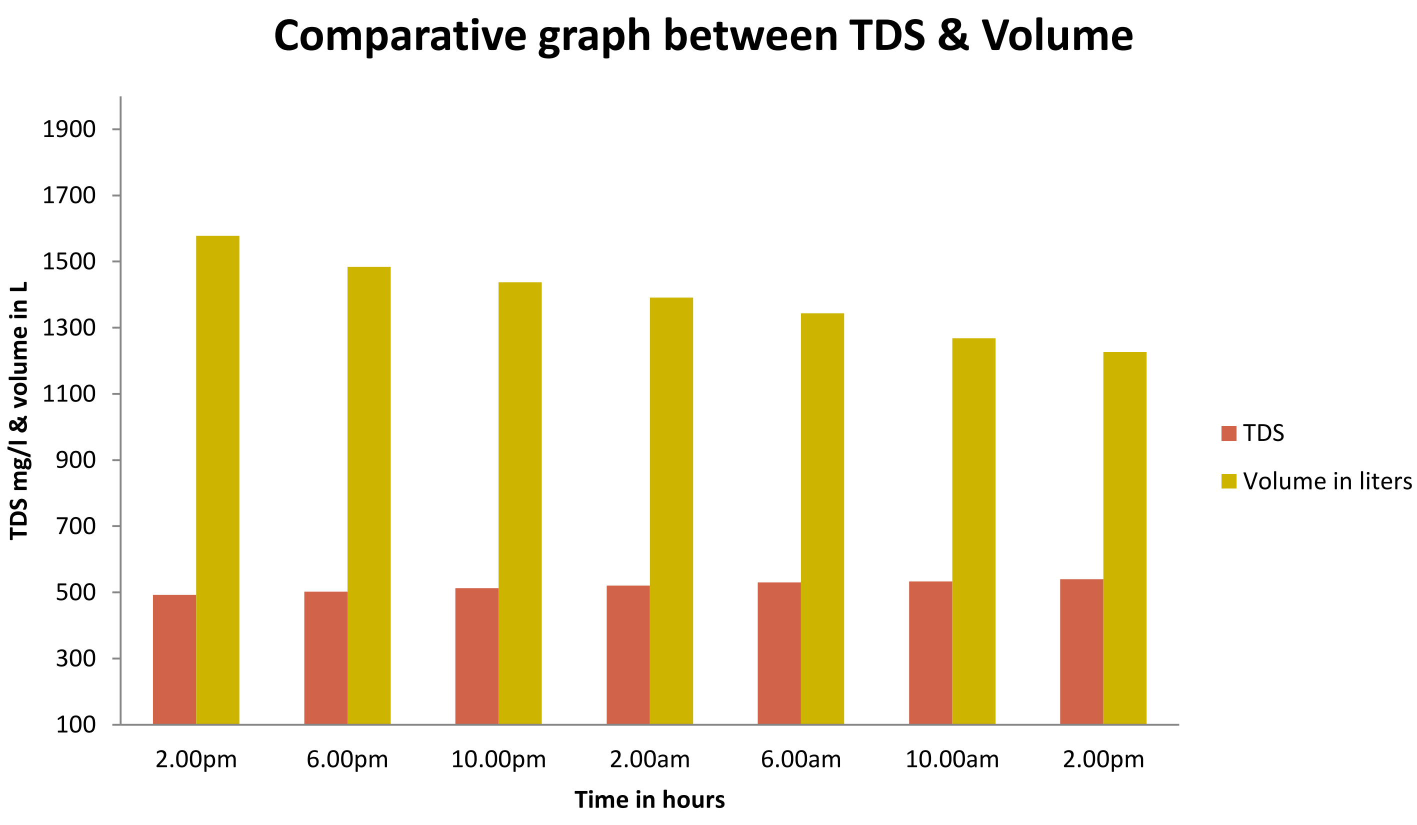
20% of 1607 (Total volume) = 321.4



11/8/11 **Experiment started at 2 pm with 2 cage in back to back position with 6cm gap and the flow rate was increase to 800 LPH, wind speed was maintained at 15 km/hr.**

S. No	Parameters	At 2pm	At 6pm	At 10pm	At 2am	At 6am	At 10am	At 2pm
1.	Wind speed before the cage Km/hr	15	15	15	15	15	15	15
2.	Wind speed after the cage Km/hr	1.8	0	1.5	3.5	0	1.5	2.1
3.	Ambient Humidity %RH	44	74	77.3	76.1	82.7	55.1	49.7
4.	Ambient temperature ˚C	40	30.8	30.3	27.4	26.6	35.7	37
5.	Humidity %RH	45.3	75.4	79.5	77.5	83.1	55.9	51.2
6.	Temperature ˚c	39.6	30.4	29.7	27.2	26.6	35.5	37
7.	Water flow LPH	800	800	800	800	800	800	800
8.	Water depth cm	27	25.4	24.6	23.8	23	22	21
9.	Experiment TDS mg/l	492.6	501.9	512.4	520.5	530.2	533	540
10.	Blank TDS mg/l	492.6	497.4	497.4	498.8	500	501.6	506.9

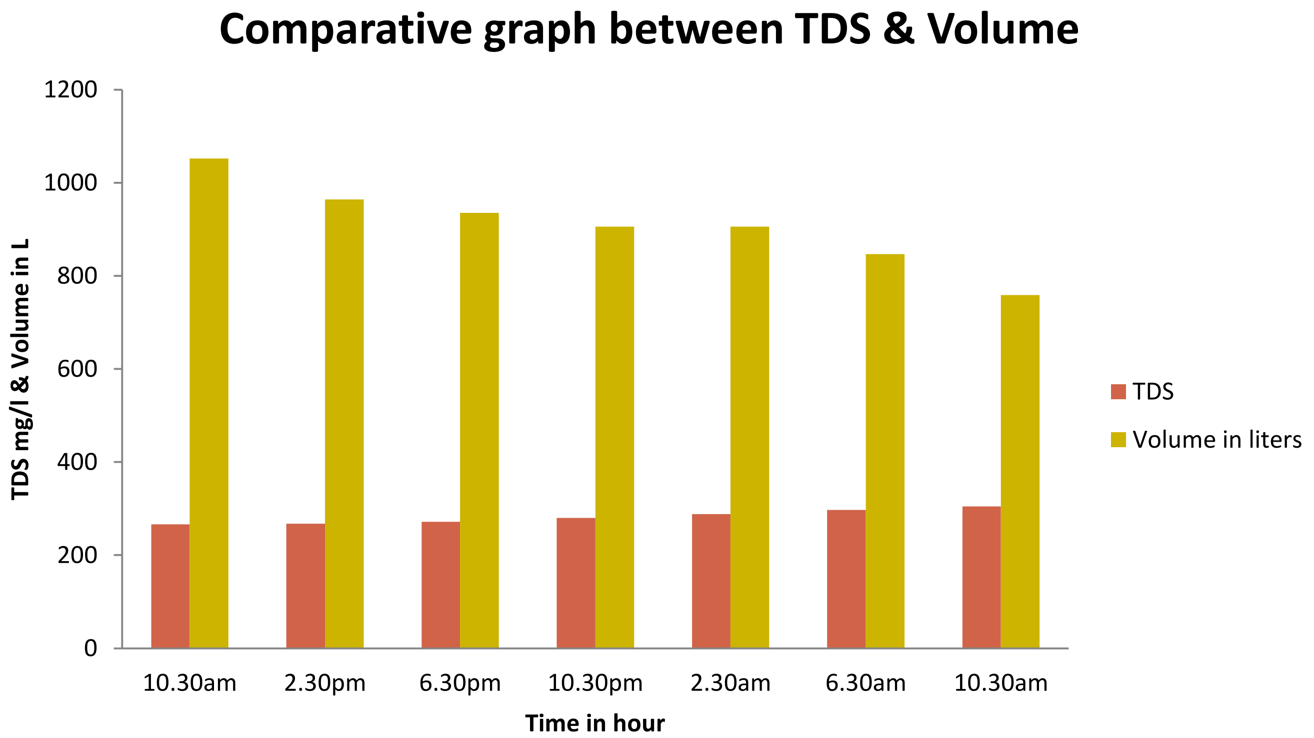
Evaporation for Experiment	**= 10%**
Evaporation for Blank	**= 10%**
Volume of water at initial stage	=1578 L
Volume of water at final stage	= 1227L
Total evaporation	= 354 L
10% of Total volume 1578	= 157 L



23/8/11 **Experiment was started at10.30 am with two cages in back to back postion. The gap between the cages was increase to 27 cm. Flow rate was maintained at 800 LPH. Wind speed at 15 km/hr.**

S. No	Parameters	At 10.30am	At 2.30pm	At 6.30pm	At 10.30pm	At 2.30 am	At 6.30am	At 10.30am
1.	Wind speed before the cage Km/hr	15	15	15	15	15	15	15
2.	Wind speed after the cage Km/hr	1	0.5	0.1	1	0.7	2.5	1.5
3.	Ambient Humidity %RH	60.6	51.9	73	74.5	79.5	78.4	62
4.	Ambient temperature ˚C	35.1	38.5	31	29.1	27.4	28.4	35
5.	Humidity %RH	62.9	55.2	76.8	75.9	81.1	78.8	62.2
6.	Temperature ˚c	34.3	37.6	30.1	28.9	27.3	28.2	34.8
7.	Water flow LPH	800	800	800	800	800	800	800
8.	Water depth cm	18	16.5	16	15.5	15.5	14.5	13
9.	Experiment TDS mg/l	266	267.6	271.6	280	288.5	296.9	304.6
10.	Blank TDS mg/l	266	271	271.0	275.9	276.0	277.6	285.0

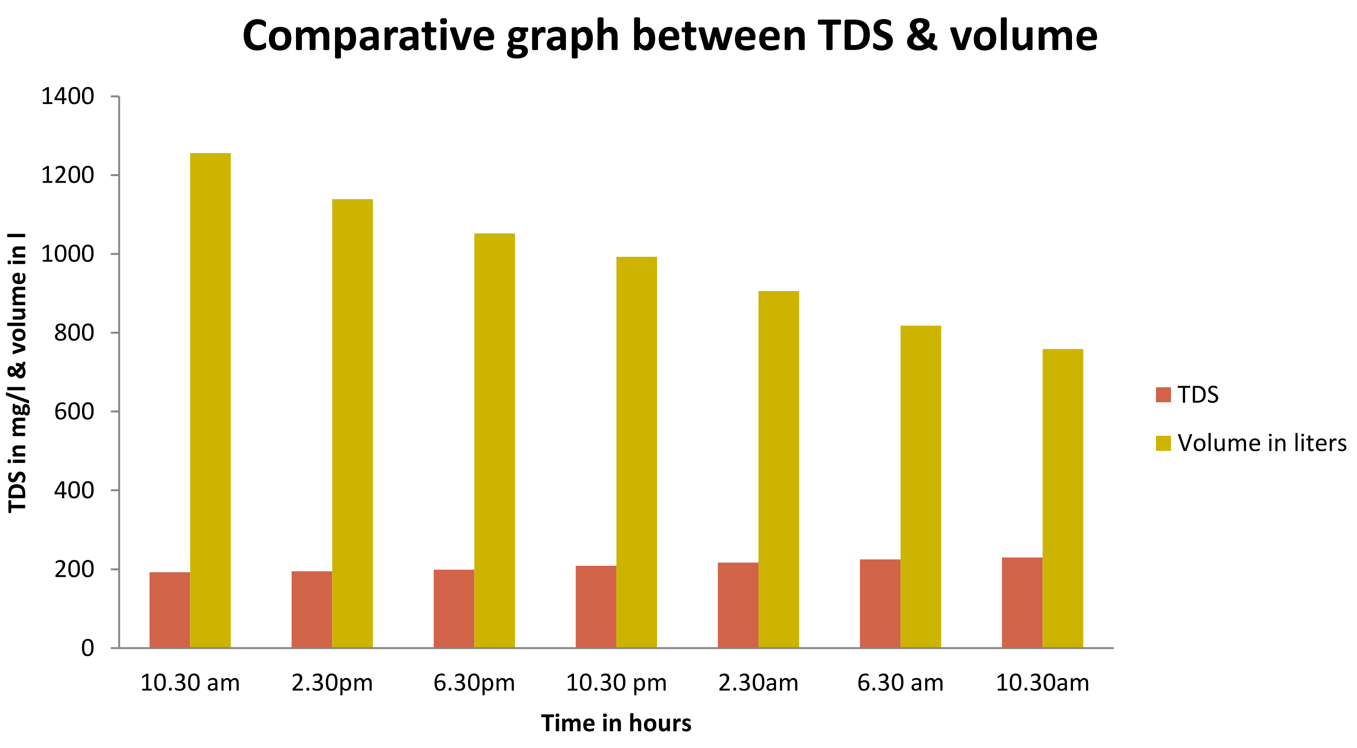
Evaporation for Experiment	**= 20%**
Evaporation for Blank	**= 10%**
Volume of water at initial stage	=1052 L
Volume of water at final stage	= 759
Total evaporation	= 293L
20% of total volume 1052	= 210 L



29/8/11 **Experiment started at 10.30 am without packing media, wire cage, wind shield. Water flow was maintained at 800 LPH, Wind speed at 15Km/hr.**

S. No	Parameters	At 10.30am	At 2.30pm	At 6.30pm	At 10.30pm	At 2.30 am	At 6.30am	At 10.30am
1.	Wind speed before the cage Km/hr	15	15	15	15	15	15	15
2.	Wind speed after the cage Km/hr	10-11	8-9	8	7	8-9	7	8-10
3.	Ambient Humidity %RH	61.6	60	64.8	66.4	67.4	70.7	53.7
4.	Ambient temperature ˚C	32	32.1	30.1	29.5	28.6	28	33.1
5.	Humidity %RH	62.1	63.3	68.2	67.5	71.3	75.1	54.2
6.	Temperature ˚c	31.6	31.5	29.6	29	27.7	27.1	33
7.	Water flow LPH	800	800	800	800	800	800	800
8.	Water depth cm	21.5	19.5	18	17	15.5	14	13
9.	Experiment TDS mg/l	192	195	199	209	217	225	230
10.	Blank TDS mg/l	192	193	194	197	197.9	198.5	201
11.	Temperature of water ˚c	29	30	29	28	28	26	31

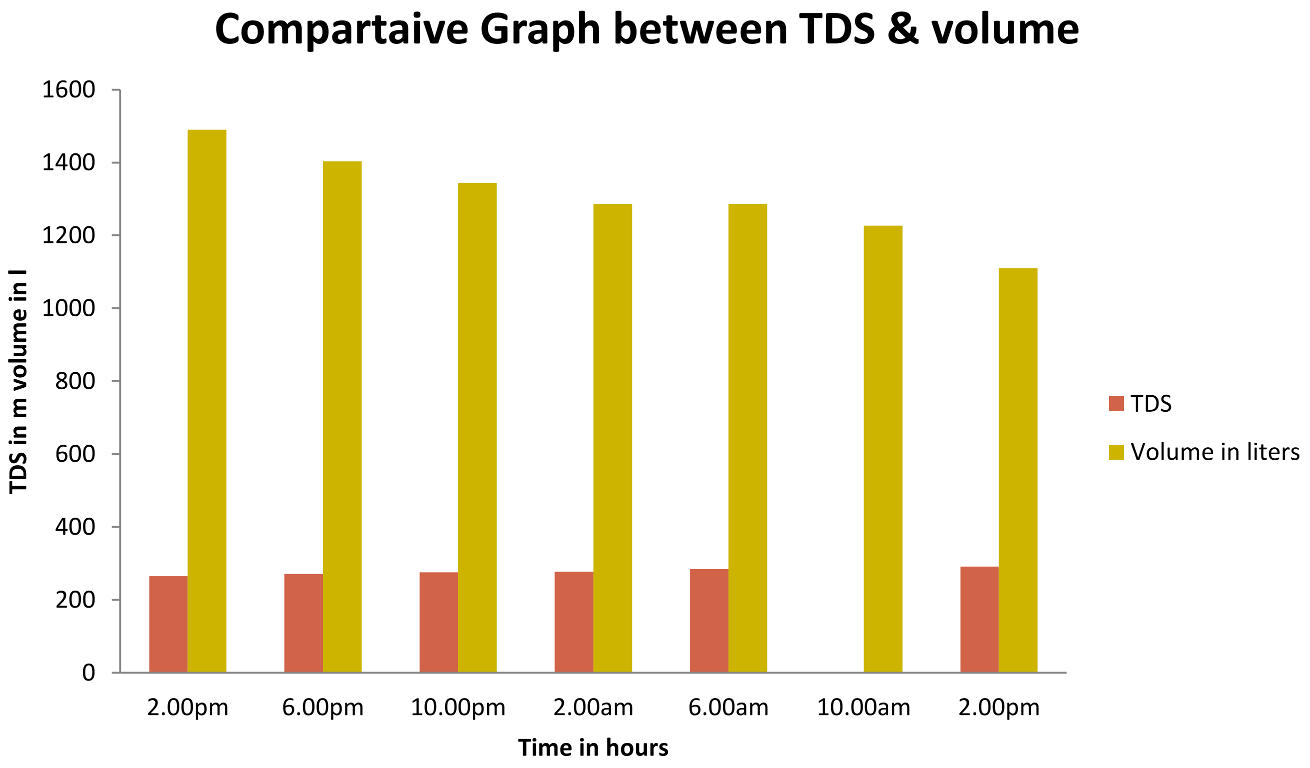
Evaporation for Experiment	**= 20%**
Evaporation for Blank	**= 10%**
Volume of water at initial stage	=1256 L
Volume of water at final stage	= 759
Total evaporation	= 497L
20 % of total volume 1256	= 251.2



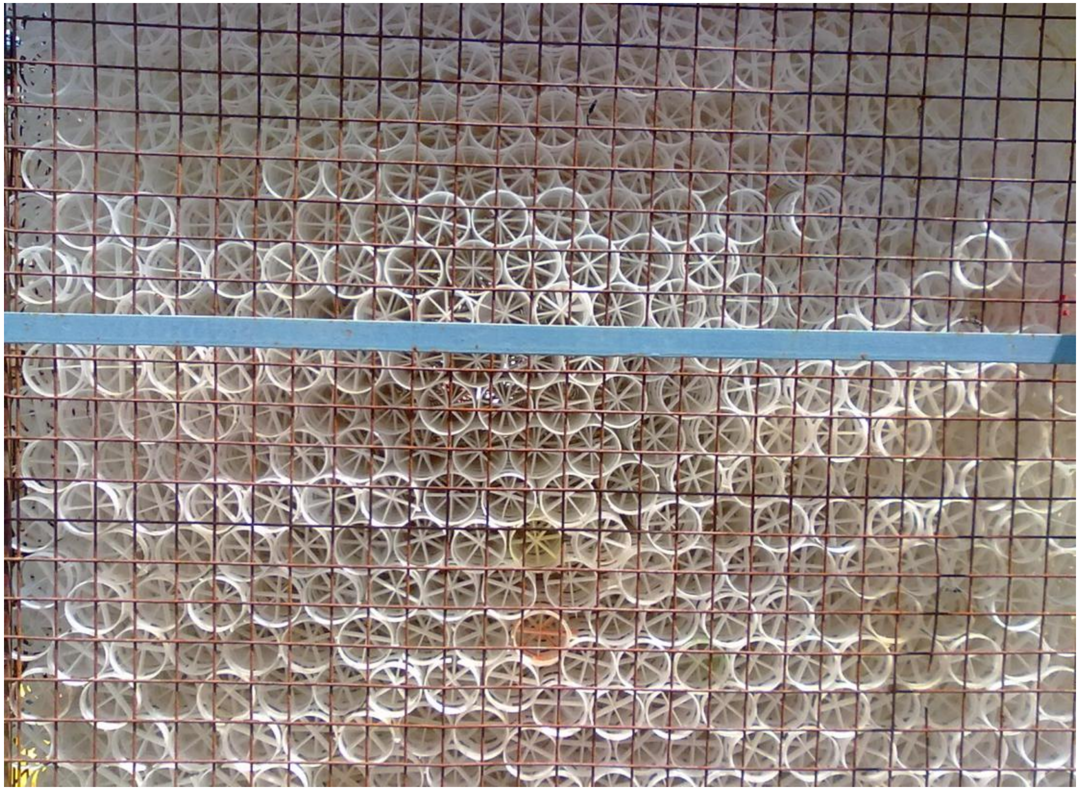
30/8/11 **Experiment with single cage and the setup was covered with a wind shield made up of tarpaulin. The Flow rate was maintained at 400 LPH, wind speed at 15 Km/hr**

S. No	Parameters	At2.00 pm	At 6.00pm	At 10.00pm	At 2.00am	At 6.00am	At 10.00am	At 2.00pm
1.	Wind speed before the cage Km/hr	15	15	15	15	15	15	15
2.	Wind speed after the cage Km/hr	2.2	0.2	0.5	1	0.5	1	1.5
3.	Ambient Humidity %RH	55.7	70.2	82.4	78.1	75.1	60	52.8
4.	Ambient temperature ˚C	33.3	31.1	29.3	27.9	28	31.2	34.9
5.	Humidity %RH	57.1	70.8	82.9	78.3	75.4	61.7	53.0
6.	Temperature ˚c	33.6	30.9	29.2	27.8	28.2	31	34.9
7.	Water flow LPH	400	400	400	400	400	400	400
8.	Water depth cm	25.5	24	23	22	22	21	19
9.	Experiment TDS mg/l	264.8	270.7	275.8	277.1	284.4	-	291.1
10.	Blank TDS mg/l	264.8	268.7	271.4	270.1	271.7	-	276.1
11.	Temperature of water ˚c	34	24	30	29	28	30	33

Evaporation for Experiment	**= 10%**
Evaporation for Blank	**= 10%**
Volume of water at initial stage	=1490 L
Volume of water at final stage	= 1110
Total evaporation	= 380L
10% of total volume1490	= 149 L

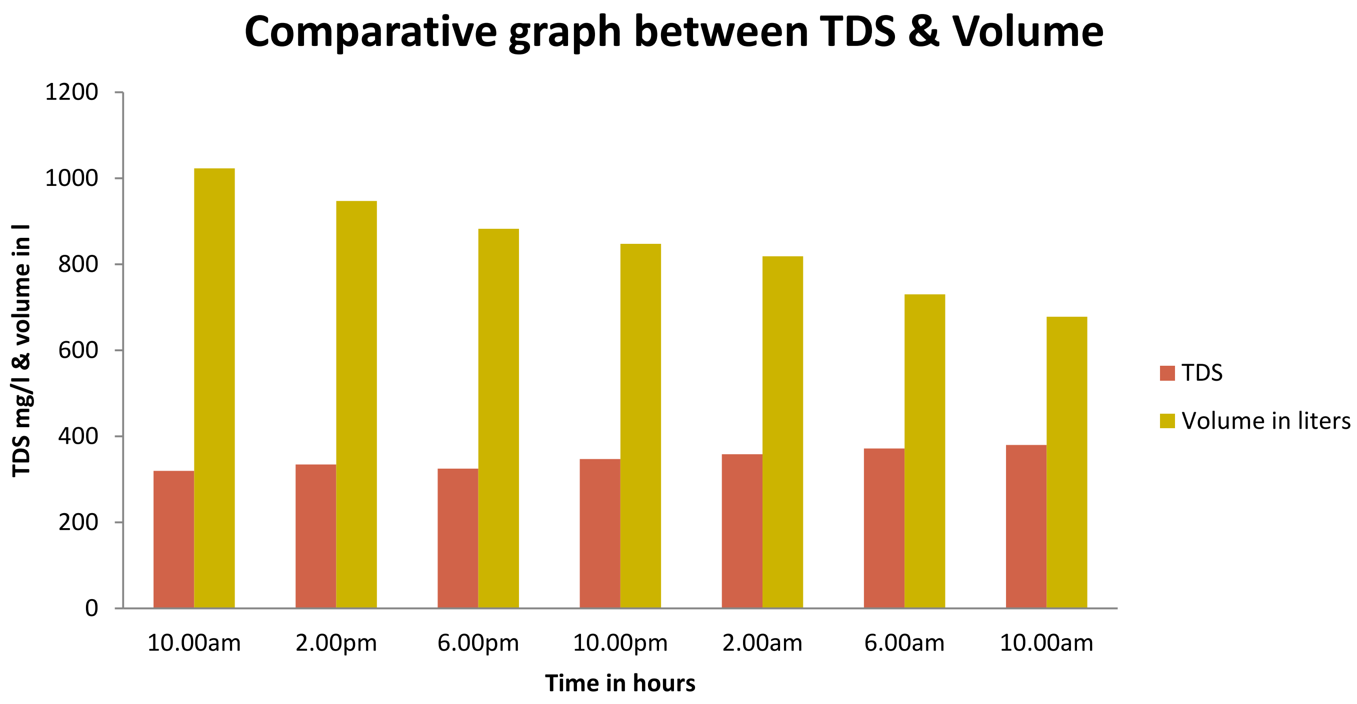


07/09/11**Experiment with a cage loaded pall ring packing media. The media are pasted in horizontal position to make a pipe like structure. This arrangement in packing media allowed air to pass through the media, more efficiently than the randomly packing method.**



S. No	Parameters	At 10.00am	At 6.00pm	At 2.00pm	At 10.00pm	At 2.00am	At 6.00am	At 10.00am
1.	Wind speed before the cage Km/hr	15	15	15	15	15	15	15
2.	Wind speed after the cage Km/hr	5.8	5	5	4	5.5	6.4	6
3.	Ambient Humidity %RH	52.3	70.5	44.7	80	79.6	70.4	57.9
4.	Ambient temperature ˚C	35.1	31.1	37.7	29	29.1	28.3	32.2
5.	Humidity %RH	54	71.8	49	83	82.3	74.7	61.0
6.	Temperature ˚c	35	30.9	37.5	28.6	24.4	27.5	32.8
7.	Water flow LPH	400	400	400	400	400	400	400
8.	Water depth cm	17.5	15.1	16.2	14.5	14	12.5	11.6
9.	Experiment TDS mg/l	319.3	333.9	324.4	346.6	357.9	371.6	379.4
10.	Blank TDS mg/l	319.3	330.7	325.9	331.8	332.6	335.3	338.3
11.	Temperature of water ˚c	33	33	34	30	30	28	33

Evaporation for Experiment	**= 20%**
Evaporation for Blank	**= 10%**
Volume of water at initial stage	=1023 L
Volume of water at final stage	= 678 L
Total evaporation	= 345L
20% of total volume1023	= 240.6 L

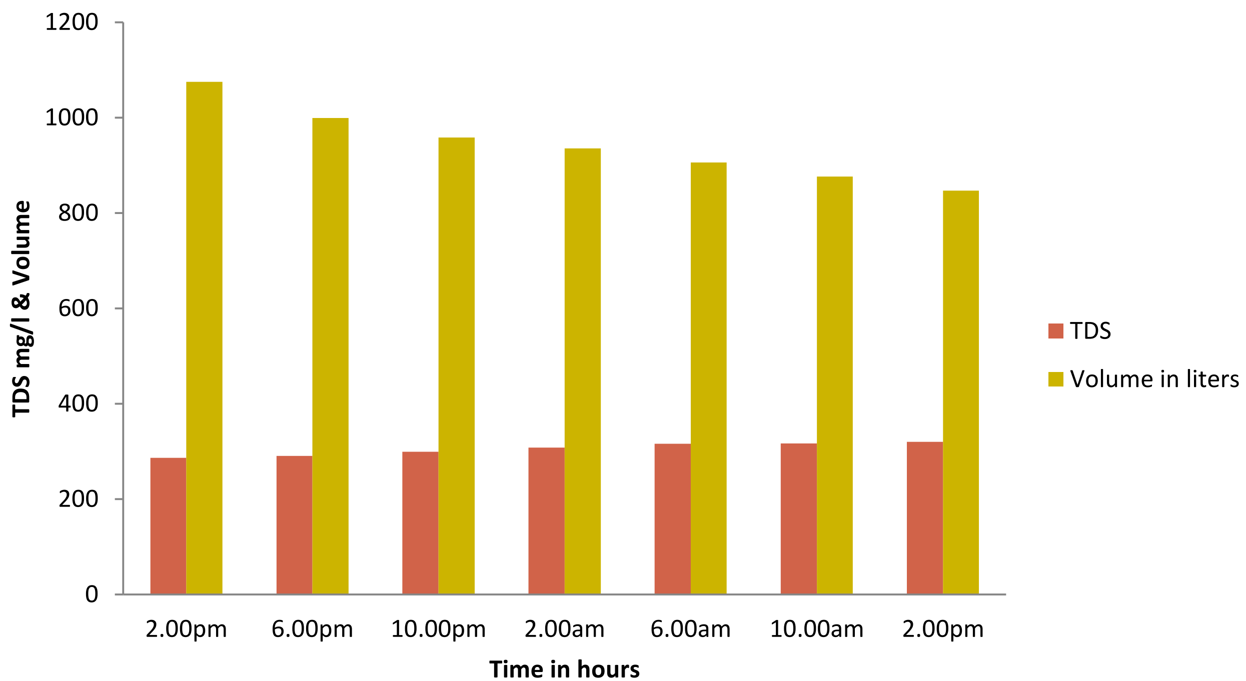


15/09/11 **Experiment with a cage loaded with horizontally arranged packing media, with wind shield and the top portion of the setup (1mtr) was covered using tarpaulin. Wind speed 15 Km/hr, water flow at 400 LPH**

S. No	Parameters	At 2.00pm	At 6.00pm	At 10.00pm	At 2.00am	At 6.00am	At 10.00am	At 2.00pm
1.	Wind speed before the cage Km/hr	15	15	15	15	15	15	15
2.	Wind speed after the cage Km/hr	4.5	6	5	5	4	5	5
3.	Ambient Humidity %RH	45	72	79.2	82.4	78.4	55	44
4.	Ambient temperature ˚C	39	31	29.3	26.7	27.6	33.6	40.5
5.	Humidity %RH	47	75	80.9	85	80	56.6	46.5
6.	Temperature ˚c	38	29.5	28.8	26	27.5	33.4	39
7.	Water flow LPH	400	400	400	400	400	400	400
8.	Water depth cm	18.4	17.1	16.4	16	15.5	15	14.5
9.	Experiment TDS mg/l	286.1	290.4	299.1	307.5	315.6	316.7	319.8
10.	Blank TDS mg/l	286.1	289.5	292.6	292.7	293.9	296	305.5
11.	Temperature of water ˚c	32	31	30	29	28	32	37

Evaporation for Experiment = **20%**
Evaporation for Blank = **10%**
Volume of water at initial stage =1075 L
Volume of water at final stage = 847 L
Total evaporation = 228L
20% of total volume1023 = 215 L

Comparative Graph between TDS & Volume



21/09/11 **Experiment with arranged packing media, with wind shield. Two solar heaters with 600 liters capacity are connected to the water inlet line to the evaporator. The solar heater gives water at an average of 45-50 ˚C, in midday sunlight.**

S. No	Parameters	At 6.00pm	At 10.00pm	At 2.00am	At 6.00am	At 10.00am	At 2.00pm	At 6.00 pm
1.	Wind speed before the cage Km/hr	15	15	15	15	15	15	15
2.	Wind speed after the cage Km/hr	5.5	5.5	5	6.5	6.4	6.4	6.3
3.	Ambient Humidity %RH	64.7	79.5	85.9	82.8	43	45	25
4.	Ambient temperature ˚C	32.3	28.6	27.3	26.5	36	38	34
5.	Humidity %RH	71.7	78.8	84.7	84.2	50	61	25.5
6.	Temperature ˚c	31.3	27.9	27.5	26.3	33	33	32
7.	Water flow LPH	400	400	400	400	400	400	400
8.	Water depth cm	22.7	21.5	21	20.5	20	18.5	17.5
9.	Experiment TDS mg/l	311	320	322	325.9	329.4	339.7	350
10.	Blank TDS mg/l	311	316	316.7	317.7	317.5	329.3	336
11.	Temperature of water ˚c	31	30	29	28.5	31	35	31
12.	Temperature of blank ˚c	31	30	29	27	33	39	35
13.	Temp of water before reaching the cage ˚c	38	30	29	28.5	40	46	35