Transient Performance of a Liquid Desiccant Solar Regenerator

By

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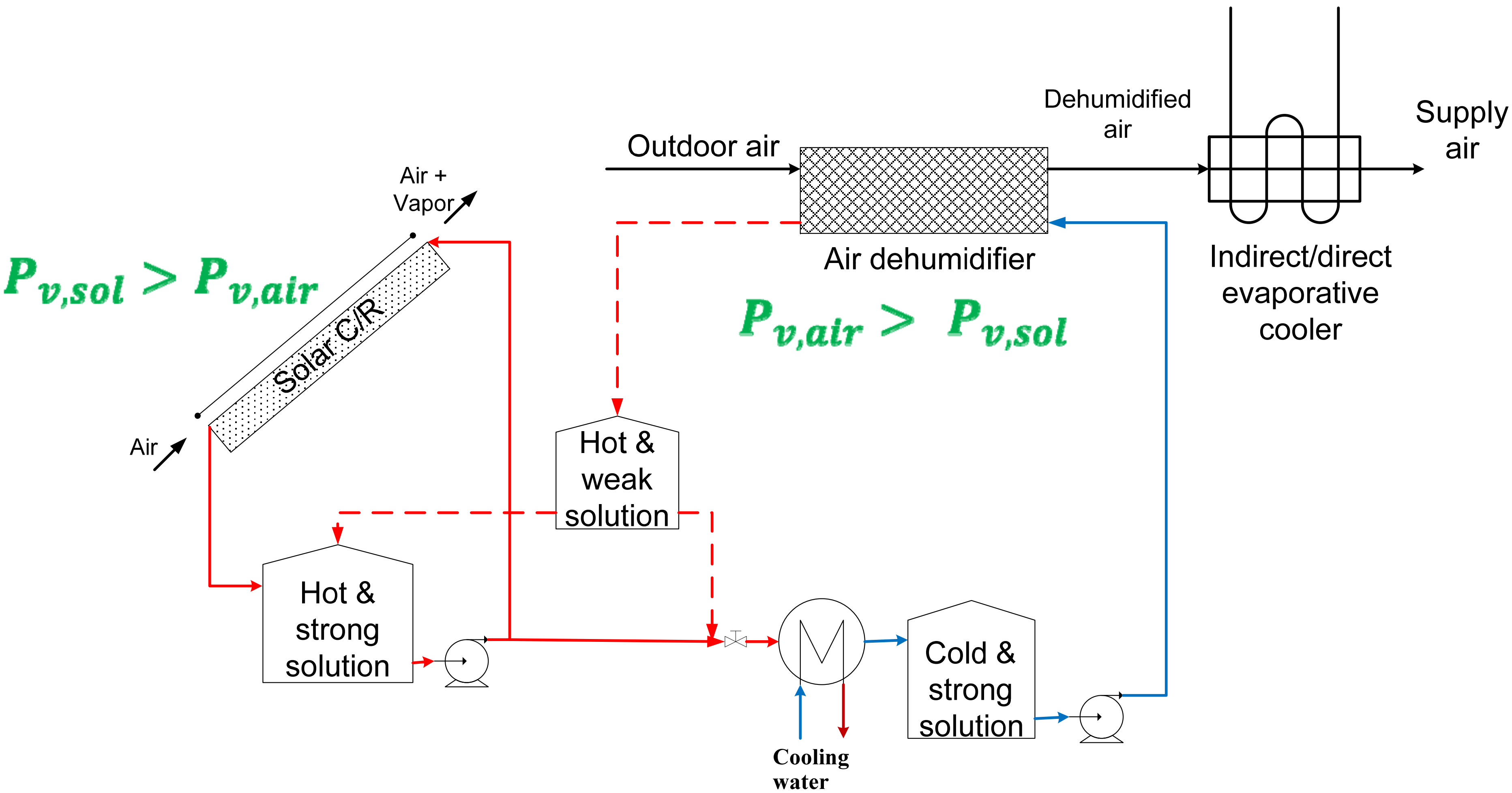
Presentation outline

- Introduction
- Literature review
- Objectives of the research
- Experimental setup and instrumentation
- Data analysis
- Transient performance of solar C/R
- Conclusions
- Acknowledgements

Introduction

- ❖ Air conditioning:
  - is becoming a necessity in modern life
  - consumes high grade energy produced from fossil fuels and contributes to release of pollutant gases like CO_2, CO, SO_2, during production of electricity
  - is adversely affecting the environment due to use of ODP, GWP, inflammable and toxic refrigerants
- ❖ Clean refrigerant and Renewable Energy based AC technologies are necessary such as solar liquid desiccant cooling system which uses natural refrigerant and solar thermal-energy

Typical solar liquid desiccant cooling system



Solar regeneration of liquid desiccants

❖ Solar regeneration of liquid desiccants using solar C/R is a photo-thermo-physical process of concentrating diluted desiccant solution that involves:

- Conversion of solar energy into heat through absorption by the absorber plate and the solution;
- Evaporation of liquid water in the solution into vapor through the heat absorbed;
- Increase in vapor pressure of vapor on the surface of the solution;
- Active transport of vapor (and heat due to vapor transferred) from the solution surface into the ventilation air gap;
- Increase in concentration of desiccant in the solution due to loss of water by evaporation ;

Advantages of solar C/R

❖Compared to indirect solar liquid desiccant regenerators (ETC/FPC) a solar C/R has the following advantages

- Simplicity in design and compactness
- Collection of solar energy and regeneration is achieved in the same device (Mullick & Gupta,1974)
- No need of hot water tank and accessories

Literature review

There are about 28 papers on solar C/R

❖Experimental

- glazed solar C/R with corrugated GI absorber plate (Mullick & Gupta,1974; Elssarag,2008)
- Unglazed roof as C/R made of asphalt shingles (Hawlader et al.,1993)
- Concrete slab as C/R (Kaushik et al., 1985)
- glazed solar C/R with flat plate absorber (Alizadeh & Saman,2002a,2002b, Kabeel,2004)

Literature review (cont.)

❖ Theoretical work

- Analytical (Collier, 1979; Kaushik et al., 1985,1986)
- Simplified simulation (Gandidasan,1983; Fagbenle & Karayiannis, 1998)
- Using a code developed for modular simulation (Haim et al., 1992)
- Non-dimensional numerical model (Johansen & Grossman, 1983; Kaushik et al., 1985)
- Artificial neural network (Aly, 2011).

Literature review (cont.)

- Haim et al. (1992) has identified solar C/R to be the most complicated component of open cycle vapor absorption cooling system
- Hawlader et al. (1993) reported that attempts to analyses the solar C/R met with rather limited success due to simplified assumptions of the heat and mass transfer parameters

Literature review(cont.)

- Performance indices of solar C/R
  - Mass of water evaporated
  - Energy rate of evaporated water
  - Solution temperature
  - Concentration of the liquid desiccant
  - Mass transfer coefficient
  - Heat & mass transfer coefficients
  - Figure of merit
  - Exergetic efficiency
  - Efficiency
  - Collector efficiency
  - Regeneration efficiency

Objectives

❖ To **experimentally** investigate the transient performance of a solar regenerator (on regeneration of LiCl and $CaCl_2$ solutions) under the weather conditions of Delhi in terms of:

- **Increase in concentration,**
- **Mass of water evaporated, and**
- **Solar collector cum regenerator efficiency**.

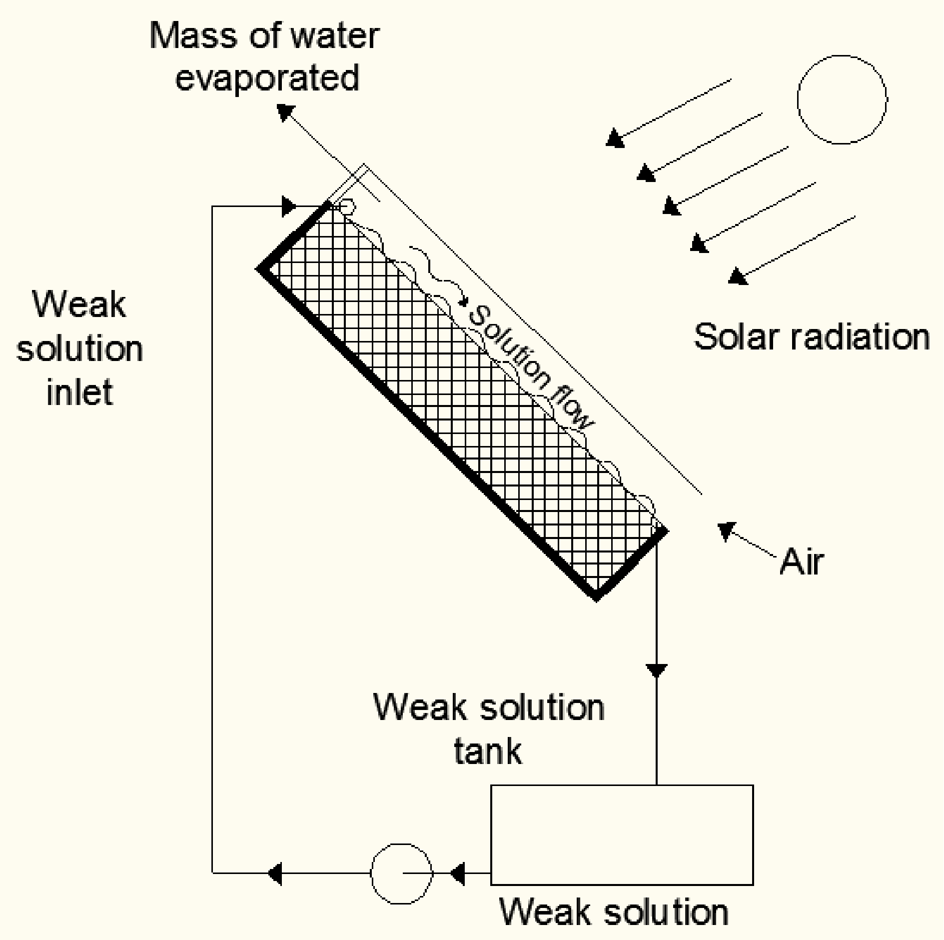
Experimental setups

Absorber area= 2.2 m x 1.84 m = 4.048 m

Aperture area= 2.6 m x 2 m = 5.2 m^2

Experimental setups(cont.)

Experimental procedure



Desiccants studied

- Calcium chloride, and
- Lithium chloride

Regeneration analysis method

- Time integral analysis of first law of thermodynamics

Instrumentation

Instruments

- Pyranometer (Kipp and Zonen) for measuring (radiation)
- Thermocouple wires(T- type) for measuring absorber surface temperature
- RTDs(4 wire) for detecting solution temperature in the tank
- Digital hand held solution density measuring instrument
- Measuring scale/tape rule (initial solution height in the tank)

Calibration

RTDs, Thermocouple wires were calibrated at ice and boiling point of water

Densitometer was calibrated against density of water according to the manufacturer guideline

Uncertainty analysis

S. No.	Instrument	Uncertainty
1	Densitometer	$\pm 0.001\ g/cm^3$
2	Pyranometer	$\pm 3\ \%$ of pyranometer reading
3	Thermometer	$\pm 0.5^o C$
4	Thermocouple wire	$\pm 0.5^o C$
5	RTD	$\pm 0.5^o C$
6	Tape rule / Scale	$\pm 1\ mm$

General uncertainty analysis method was used (Dunn, 2005):

$$U_R^2 = \sum_i^N \left(\frac{\partial R}{\partial x, i} U_{x,i} \right)^2$$

❖ **Uncertainty in calculated:**

- **concentration of desiccant was 0.0014 kg/kg**
- **mass of water evaporated was in range of 0.02-0.04 kg (%error < 2%)**
- **solar C/R efficiency was in the range of 1.2-1.4% (% error <4%)**

Data analysis

Starting time: 9 am	LiCl	$CaCl_2$
Measured		
Initial volume of solution	38.4 litre,	38.4 litre
Initial density of solution	1193 kg/m^3	1289 kg/m^3
Initial temperature of solution	49^oC	37^oC
Calculated		
Initial concentration	0.33	0.31
Initial mass of solution	45.8 kg	49.4 kg
Initial mass of desiccant in solution	15.2 kg	15.3 kg

Data analysis (cont.)

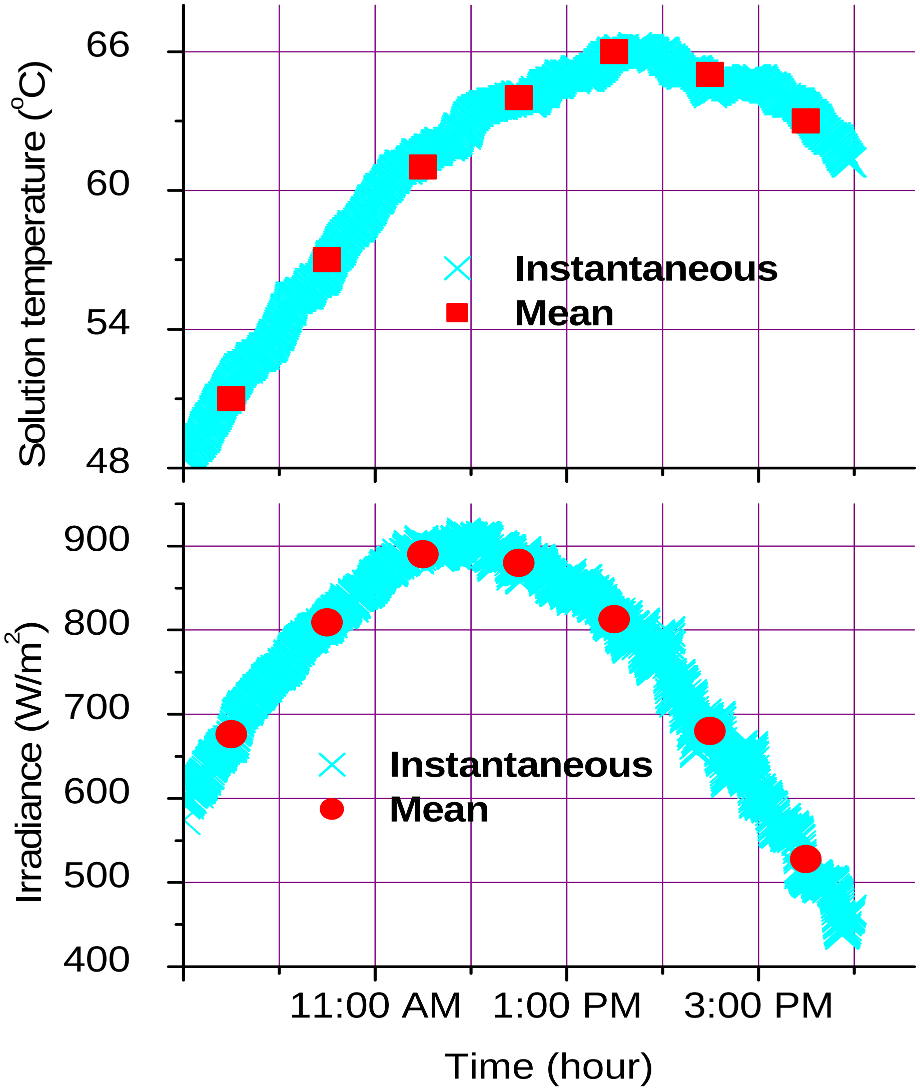


Fig.: Irradiance & solution temperature as scanned (every 10 seconds using DAQ system) and their 1 hour mean

$$T_{mean} = \frac{\sum_{i=1}^{N} T_i}{N}$$

$$I_{mean} = \frac{\sum_{i=1}^{N} I_i}{N}$$

Data analysis (cont.)

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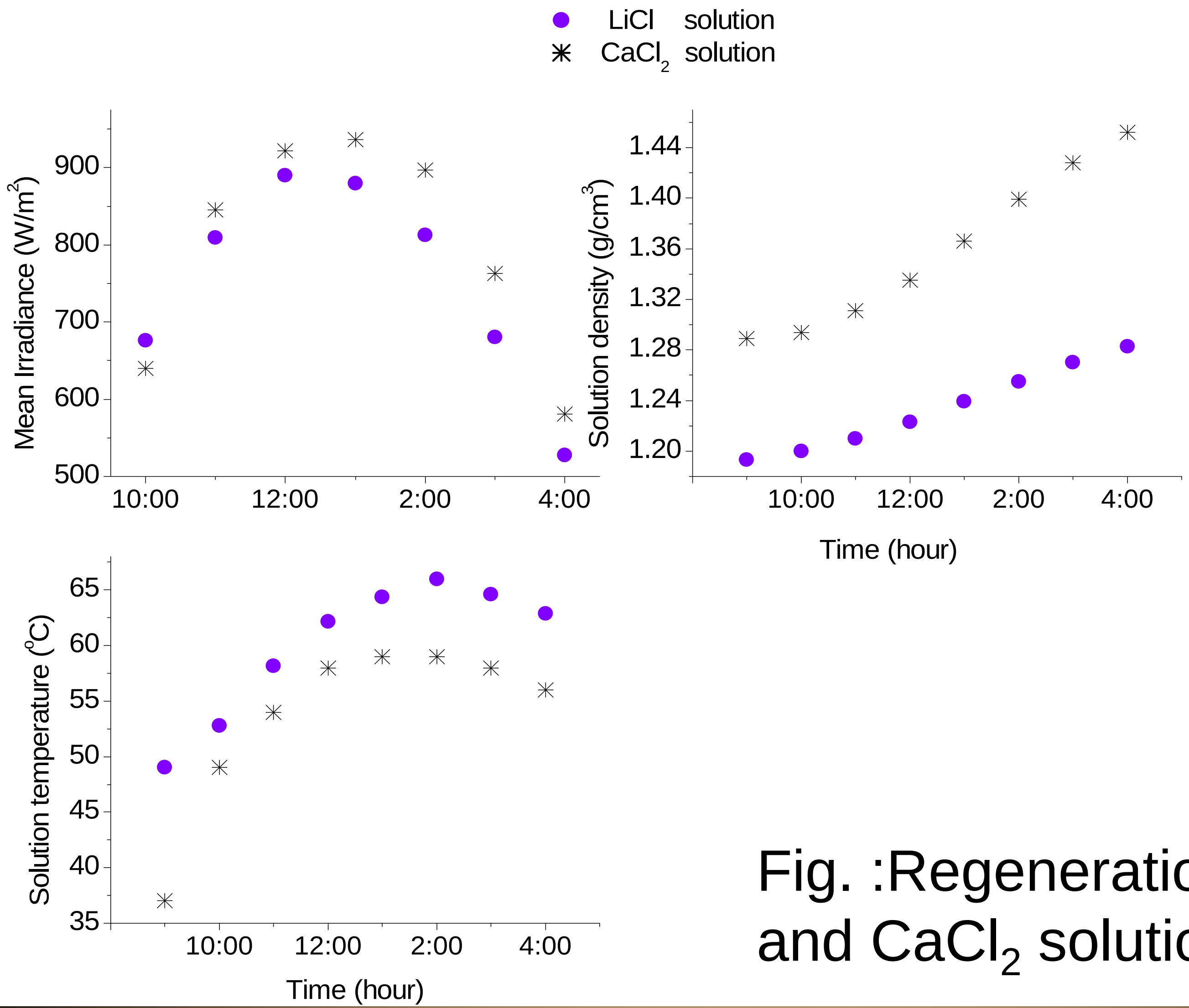


Solution density was measured every 30 minute

Fig. :Regeneration data for LiCl and $CaCl_2$ solutions

Performance analysis (cont.)

❖ **Concentration** (Conde, 2004)

- **Calcium chloride**

$$0.105642\left(\frac{\xi}{1-\xi}\right)^3 - 0.4363\left(\frac{\xi}{1-\xi}\right)^2 + 0.836014\left(\frac{\xi}{1-\xi}\right) + 1 - \frac{\rho_{sol(\xi,T)}}{\rho_{H_2O(T)}} = 0$$

- **Lithium chloride**

$$0.100791\left(\frac{\xi}{1-\xi}\right)^3 - 0.303792\left(\frac{\xi}{1-\xi}\right)^2 + 0.540966\left(\frac{\xi}{1-\xi}\right) + 1 - \frac{\rho_{sol}\left(\xi, T_{sol}\right)}{\rho_{H_2O}\left(T_{sol}\right)} = 0$$

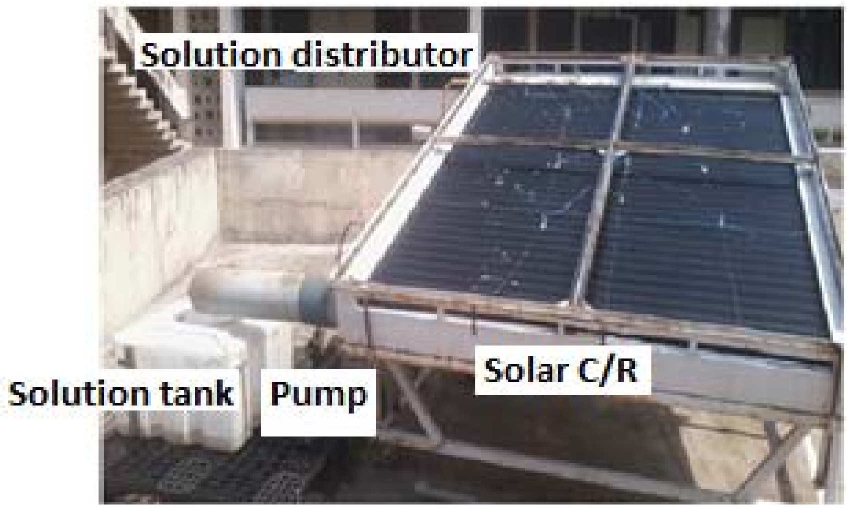
- **Density of water**

$$\rho_{H_2O}\left(T_{sol}\right) = 0.322\begin{pmatrix} 1 + 1.99377184\,30\,\tau^{1/3} + 1.09852116\,04\,\tau^{2/3} \\ -0.50944929\,96\,\tau^{5/3} - 1.76191242\,7\,\tau^{16/3} \\ -44.9005480\,267\,\tau^{43/3} - 723692.261\,8632\,\tau^{110/3} \end{pmatrix}$$

Performance analysis (cont.)

❖ **Mass of water evaporated (derived)**

$$m_{v,\Delta t} = m_d * \left(\frac{1}{\xi_{t_o+(n-1)\,.\Delta t}} - \frac{1}{\xi_{t_o+n\,.\Delta t}} \right) \qquad where \quad n = 1, 2, \ldots$$



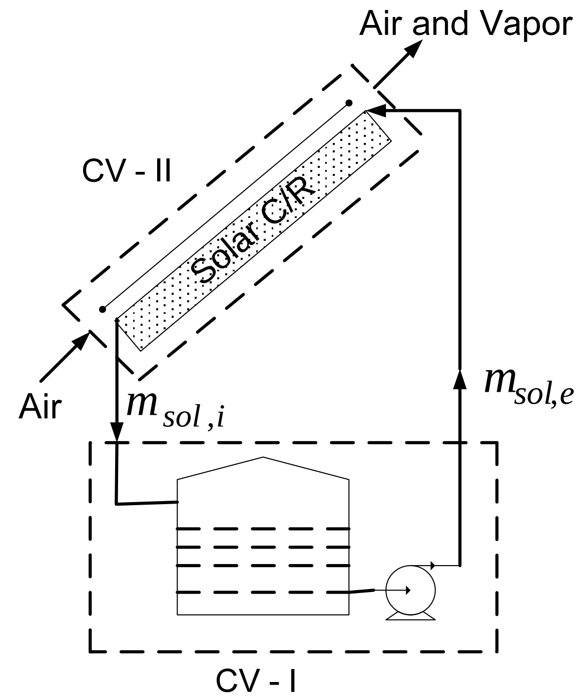


Fig. Actual experimental setup and its schematic diagram

Performance analysis (cont.)

❖ **Solar collector cum regenerator efficiency**

$$\eta_{CR} = \frac{Q_{eva}}{I.A_{ap}.\Delta t}$$

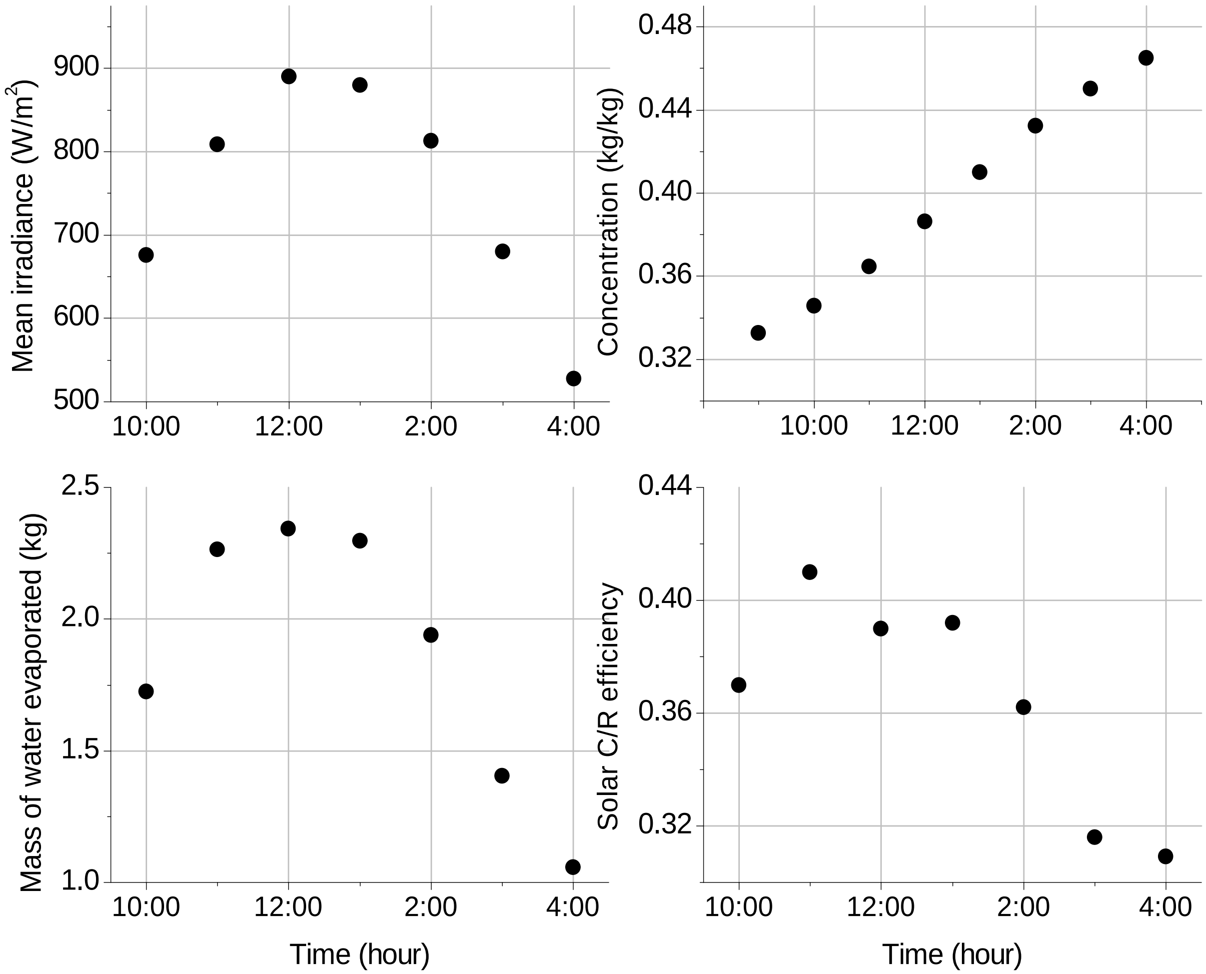
✓ **Heat transferred due to mass transferred or energy of evaporation is given by**

$$Q_{eva} = m_{v,\Delta t} h_{fg,av} = m_{v,\Delta t}\left(2551 + \Delta h_d\right)$$

$$\Delta h_d = (169.105 + 457.85\theta)\left[1 + \left(\frac{\xi}{0.845(0.6-\xi)}\right)^{-1.965}\right]^{-2.265}$$ (LiCl)

$$\Delta h_d = (-955.69 + 3011.974\theta)\left[1 + \left(\frac{\xi}{0.855(0.8-\xi)}\right)^{-1.965}\right]^{-2.265}$$ ($CaCl_2$)

Typical transient regeneration performance



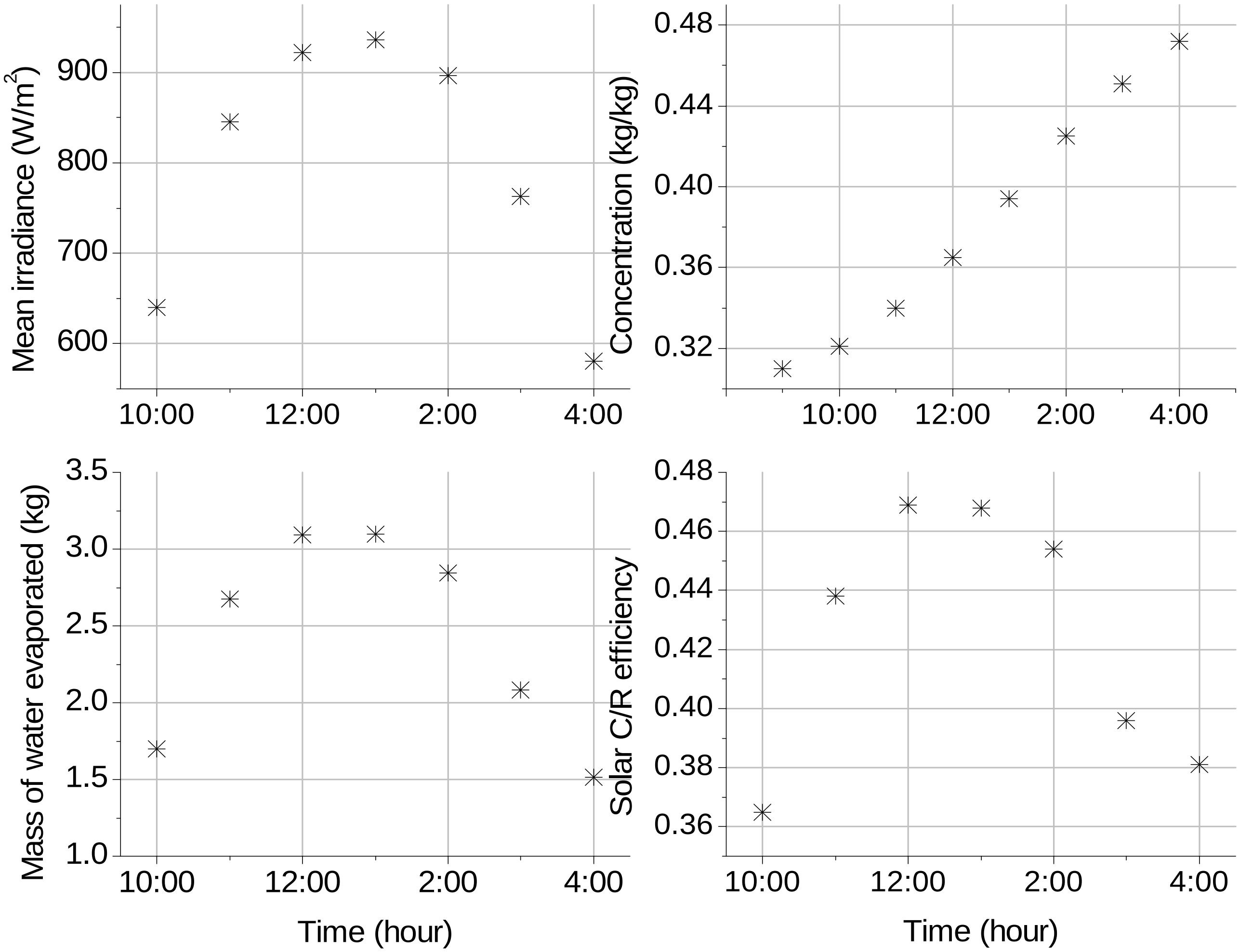
Peak evaporation per absorber area =0.57 kg/m^2

Evaporation flux over the day =0.13 g/(m^2.s)

Total mass of water evaporated = 13 kg

Fig.: Transient performance of the solar C/R (LiCl solution)

Typical transient regeneration performance (cont.)



Peak evaporation per absorber area =0.765 kg/m^2

Evaporation flux over the day =0.17 g/(m^2.s)

Total mass of water evaporated = 17 kg

Fig. Transient performance of the solar C/R ($CaCl_2$ solution)

Conclusions

- ❖ Transient experimental regeneration performance of a solar C/R was studied for solutions of $CaCl_2$ and LiCl for 43 days between 9 am to 4 pm under Delhi weather condition (natural convection regeneration)in terms of increasing in concentration, mass of water evaporated and solar C/R efficiency
- ❖ Typically mass of water evaporated in a day(9 am to 4 pm) using a 4 m^2 solar C/R were 14.2 kg for LiCl and 17 kg for $CaCl_2$ solutions in the month of May. The daily average evaporation flux was:
  - 0.17 g/(s.m^2) on regeneration of $CaCl_2$ solution (Cons. 0.31-0.47)
  - 0.13 g/(s.m^2) on regeneration of LiCl solution (Cons. 0.33-0.46)

Conclusions (cont.)

- Concentration of $CaCl_2$ in the solution increased from 0.31 to 0.47 kg/kg due to evaporation of 17 kg water between 9 am and 4 pm.
- Concentration of LiCl in the solution increased from 0.33 to 0.46 kg/kg due to evaporation of 13 kg water between 9 am and 4 pm.
- The transient solar collector cum regenerator efficiency was ranging in between 30.9 to 41% for LiCl and 36.5 to 49.6% for $CaCl_2$.

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