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Simulation of Lithium Bromide- Water (LiBr-H2O) Vapor Absorption System (VAS) powered by Solar Flat Plate Collector (SFPC)

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Abstract. Solar energy may probably prove to be best option for future in air conditioning system. With growing need of energy consumption, the solar air conditioning system stands as a useful alternative. The objective of this work is to simulate a single effect LiBr-H2O absorption system, coupled with solar flat plate collector (SFPC), to supply heat to the generator of Vapor Absorption System (VAS). Case studies have been taken from India, particularly New Delhi and Mumbai, which are, respectively, known for their hot and humid climate. The influence of different parameters like inlet generator temperature, heat supplied to the generator and cooling load have been investigated. The design day of 15th of April, May and June have been considered. The thermodynamic analyses have also been carried out. An outlet solar collector temperature between 68°C and 78°C was maintained for New Delhi, whereas between 67°C and 79°C for Mumbai. The maximum efficiency of SFPC was found to be 50 percent and 51 percent in case of New Delhi and Mumbai, respectively, on 15th April and 15th of May. A coefficient of performance of 0.857 was obtained at 4.1033 kW of heat supplied to the generator, at an inlet generator temperature of 68°C and cooling load of 3.5167 kW. It was observed that at constant $\tau$, any increase in supply heat, increases the flow rate of vapor and cooling load. Furthermore, the analysis for various stages of single effect LiBr-H2O (VAS) is presented including the design of the evaporator, absorber, condenser, heat exchanger and generator.

1. Introduction
Vapor Absorption System (VAS) is an attractive method for utilizing low grade energy directly for cooling. The lithium bromide- water (LiBr-H2O) absorption system mainly constitutes evaporator, absorber, generator, condenser, solution pump, storage tank and expansion valve [1]. When powered by flat plate collector, the water is taken as refrigerant and Lithium Bromide (LiBr) as absorbent. Since the system is generally applicable for air conditioning purposes [2], the evaporator temperature is kept above 0°C, to avoid freezing of water, which is taken as refrigerant [3].

MATLAB which stands for MATrixLABoratory, is a very powerful technical language for mathematical programming [4]. In equation-solver based simulation, users need to compiling all the equations related to developing software tools to carry out various types of analysis then write the code on software and modify it to analysis the data entered accurately. Users need to ordering the equations for all possible states in which the circuit may operate. There may be many such states [5].
2. System Description

Figure 1 elucidates the schematic diagram of LiBr- H₂O absorption refrigeration system, powered by solar flat plate collector, combined with basic vapor absorption refrigeration cycle [6]. Firstly, the solar radiation energy received by the flat plate collectors is converted into thermal energy [7] that heats up the water (heat transfer fluid) being circulated between the storage tank and collectors (17 - 18). The hot water in the storage tank heats up the LiBr- H₂O solution (1) passing through the generator (9-10), converting the water in the LiBr- H₂O solution into vapor (2), and thereby leaving concentrated LiBr-H₂O solution. The strong solution in the generator first passes to the heat exchanger and then moves to the absorber (3a) via expansion valve whereas, the superheated water in the generator passes through the condenser (2), whereby it transforms into saturated liquid state (6) after condensation. The pressure of the liquid refrigerant is reduced by throttling process (7), across the expansion valve, followed by evaporation at low pressure, thereby absorbing heat from the cooling water, responsible for producing the refrigeration effect required by the building to be air conditioned (16 - 15). The refrigerant leaving the evaporator in nearly saturated vapor form (8), passes to the absorber and is mixed with the concentrated LiBr- H₂O solution. The exothermic heat produced in the absorber due to absorption of vapor by the strong solution, is rejected to the secondary cooling water supplied by the cooling tower (14 - 13). Now, the low-pressure Lithium Bromide dilute solution (4) is pumped (4a) through the heat exchanger (1a) to high pressure solution (1) in the generator. At the same time, the secondary water refrigerant from the cooling tower is returned to the condenser to cool the water vapor (11-12) and through the absorber (14-13) to receive the absorption heat.

Figure 1. Schematic diagram of Solar Vapor Absorption Refrigeration System (SVAS)
3. Mathematical Modeling

Various mathematical models on vapor absorption system and their analyses are available in literature [8]-[10]. In this work, mathematical model of solar flat plate collector -powered LiBr-H2O absorption cooling system has been developed. The values of various input parameters required for analysis of flat plate solar collector system have been shown in Table1.

| Input Parameters                  | Symbols in simulation | Value       |
|-----------------------------------|-----------------------|-------------|
| Length of absorber plate          | L                     | 2.00m       |
| Width of absorber plate           | D                     | 0.98m       |
| Thermal conductivity of plate     | $T_{cp}$              | 350W/m-k    |
| Plate thickness                   | $P_{thic}$            | 0.15mm      |
| Plate absorptive for solar radiation | $P_{afsr}$          | 0.94        |
| Outer diameter of the tube        | $D_o$                 | 13.7mm      |
| Inner diameter of the tube        | $D_i$                 | 12.5mm      |
| Tube center- to- center distance  | W                     | 11.3cm      |
| Date                              | N                     | 15April /15May/ 15Jun |
| Fluid to tube heat transfer coefficient | $F_i$               | 205w/m²-k   |
| Reflectivity of the surrounding surface | $R_o$              | 0.2         |
| Location of the collector         | /                     | New Delhi (19º 07’N, 72º 51’E), Mumbai (28 º 35’N, 77 º12’) |
| Hourly beam radiation             | $I_b$                 | 725 w/m² at 12pm |
| Hourly diffuse radiation          | $I_d$                 | 230 w/m² at 12pm |
| Mass flow rate                    | $m$                   | 1.16 Kg/min |
| Ambient temperature               | $T_a$                 | 298 K       |
| Overall loss coefficient          | $U_l$                 | 4 w/m²-k    |
| specific heat capacity of water   | $C_p$                 | 4.18(kJ/kg. K) |

The complete analysis of the system has been divided into two main parts: the first part contains the analysis of Flat Plate Collector (FPC), while the results of the first part has been used as input to perform SVAS analysis in the second part.

3.1. Analysis of Flat Plate Collector (FPC)

The rate of useful energy gain ($Q_u$) delivered by the solar flat plate collector can be calculated using Eq. (1) [11] and Eq. (2) [12]:

$$Q_u = A_c I_r \eta_c$$  \hspace{1cm} (1)

$$Q_u = A_p S - q_l$$  \hspace{1cm} (2)

The incident solar flux absorbed in the absorber plate is given by Eq. (3) [11]:
$$S = I_b r_b (ta) b + (I_a r_a + (I_b + I_a) r_r)(ta) d$$  \hspace{1cm} (3)$$

Instantaneous collector efficiency \( \eta_c \) is given by the following Eq. (4) [11]:

$$\eta_c = F_p (\tau a) - F_R U_e \frac{(T_{j, in} - T_a)}{I_T}$$  \hspace{1cm} (4)$$

Where is \( F_R \) is the Collector heat removal factor

$$F_R = \frac{c P}{U} \left[ 1 - \exp \left\{ - \frac{F' U (A_p)}{\dot{m} c P} \right\} \right]$$  \hspace{1cm} (5)$$

Where is \( F' \) is the Collector efficiency factor

$$F' = \frac{1}{W U} \frac{\frac{1}{U_i} [W - D_o] \frac{1}{n - D_o}] + \frac{\delta_o}{k_0 D_o} + \frac{1}{\pi D_h F}$$  \hspace{1cm} (6)$$

The hourly total solar radiation \( I_T \) falling on the tilted collector surface is given by the following eq. (7) [12]:

$$I_T = I_b R_b + I_a R_a + (I_b + I_a) R_r$$  \hspace{1cm} (7)$$

The tilt factor for the beam radiation \( R_b \) and it is given by following eq (8) [12]:

$$R_b = \frac{\sin \delta \sin (\phi - \beta) + \cos \delta \cos \omega \cos (\phi - \beta)}{\sin \phi \sin \delta + \cos \phi \cos \delta \cos \omega}$$  \hspace{1cm} (8)$$

The declination angle \( \delta \) which is given by eq (9) [12][13]:

$$\delta = 23.45 \sin \left( 360 \frac{284 + n}{365} \right)$$  \hspace{1cm} (9)$$

The time used for calculating the hour angle \( \omega \) is the local apparent time.

Local Apparent Time = Standard time ± 4 (Standard time longitude– longitude of location) + (Equation of time correction)  \hspace{1cm} (10)$$

The equation of time correction (in minutes) can also be calculated from the following empirical relation.

$$E = 229.18 (0.000075 + 0.001868 \cos B)$$
$$- 0.032077 \sin B$$
$$- 0.014615 \cos 2B$$
$$- 0.04089 \sin 2B$$  \hspace{1cm} (11)$$

where \( B = (n - 1)360/365 \) and \( n \) is the day of year.
The tilt factor for the diffuse radiation \( R_d \) and the reflected radiation \( R_r \) can be obtained by Eqs. (12) and (13), [14]-[16] respectively:

**Beam Radiation:**

\[
R_d = \frac{1 + \cos \beta}{2}
\]  

**Diffuse Radiation:**

\[
R_r = \rho \left( \frac{1 - \cos \beta}{2} \right)
\]

### 3.2. Analysis of Lithium Bromide-Water (LiBr-H\(_2\)O) of VAS

The operating conditions for lithium bromide–water plant for air conditioning [17], are considered as follows:

- **Generator temperature variable in our case** (Temp outlet of solar collector 68°C to 80°C)
- **Condenser temperature**, \( T_c \) = 34°C
- **Evaporator temperature**, \( T_e \) = 6°C
- **Absorber temperature**, \( T_a \) = 24°C

The water vapor pressures are obtained for the condenser and evaporator pressures [18][19], which are:
- **Condenser and generator pressures at** (34°C) \( P_c \) = 5.32 kPa
- **Evaporator and absorber pressure at** (6°C) \( P_a \) = 0.935 kPa

(1) Now, from lnp-1/T diagram we get first the concentration \( \xi \). From the Enthalpy of water- Lithium bromide solution. Table 2. Shows states conditions at varies state points.

- **State 1**: saturated cold solution from absorber at \( P = 0.935 \) kPa and \( T = 24\)˚C \( \xi \) \( \xi \text{Libr}_2 = 0.45 \)
  \[ h_4 = 45.15 \text{ kJ/kg} \text{ (from } h- \xi \text{ diagram)} \]
- **Rich solution concentration of water (refrigerant)**
  \( \xi = 1 - \xi \text{Libr}_2 = 1 - 0.45 = 0.55 \)
- **State 2**: saturated hot solution from generator at \( P = 5.32 \) kPa and \( T = 68\)˚C
  \( \xi \text{Libr}_2 = 0.55 \)
  \[ h_2 = 148.7 \text{ kJ/kg} \]
- **Poor solution concentration of water (refrigerant)**
  \( \xi_a = 1 - 0.55 = 0.45 \)
- **State 3**: saturated solution at condenser pressure \( P = 0.935 \) kPa and \( \xi \) \( \xi \text{Libr}_2 = 0.55 \)
  \[ T_3 = 35\)˚C and } h_3 = 85.5 \text{ kJ/kg} \]
- **State 3a**: have the same temperature enthalpy and composition as state 3. But it is at the condenser pressure.
  \[ T_3 = 34\)˚C and } h_4 = 45.15 \text{ kJ/kg} \]

Now specific solution circulation rates

\[ \dot{F} = \frac{1 - \xi_a}{\xi_a} = 5.5 \text{ kJ/kg vapor} \]

- **Heat available in hot solution for transfer**
  \[ = (\dot{F} - 1) (h_2 - h_3) = 261.9KJ \]
- **Heat required by cold solution for heating**
  \[ = \dot{F}(h_1 - h_4) = 379.7kJ > 261.9kJ \]
Hence, cold solution at 4a cannot be heated to 1. Then will heated to 1a.

State 1a: Energy balance of the heat exchange gives

\[ F (h_{1a} - h_4) = (h_2 - h_3) \]

\[ h_{1a} = h_4 + \left( \frac{F - 1}{F} \right) (h_2 - h_3) = 96.85 \text{ kJ/kg} \]

State 5: It is the water vapor at condenser pressure and generator temperature and its find from the empirical relation:

\[ h = (2501 + 1.88T)kj/kg h = 2628 \text{ kJ/kg} \]

State 6: saturated water at 34°C \( h_6 = 4.1868 \) (T) = 142.35 kJ/kg

State 7: \( h_7 = h_6 = 142.35 \text{ kJ/kg} \)

State 8: at evaporator temperature 6°C \( h_8 = 4.1868 \) (T) = 2512.28 kJ/kg

| State Points | Temp (ºC) | Pressure (kpa) | Enthalpy \( h \) (kJ/kg) | Concentration (ξ) |
|--------------|----------|----------------|---------------------------|------------------|
| 4            | 24       | 0.935          | 45.15                     | 0.45             |
| 2            | 68       | 5.32           | 148.7                     | 0.55             |
| 1            | 55       | 5.32           | 114.2                     | 0.45             |
| 3            | 35       | 0.935          | 90.5                      | 0.55             |
| 3a           | 35       | 5.32           | 90.5                      | 0.55             |
| 4a           | 24       | 5.32           | 45.15                     | 0.45             |
| 1a           | 42       | 5.32           | 96.85                     | 0.40             |
| 5            | 68       | 5.32           | 2628                      | 0.55             |
| 6            | 34       | 5.32           | 142.35                    | 0.35             |
| 7            | 6        | 0.935          | 142.35                    | 0.35             |
| 8            | 6        | 0.935          | 2512                      | 0.35             |

(2) The refrigerating effect is:

\[ R_E = h_8 - h_7 = 2369.9 \text{ kJ/kg} \]

Heat added to the generator

\[ q_d = h_5 - h_2 + (h_2 - h_{1a}) = 2765 \text{ kJ/kg} \]

Coefficient of performance \( COP = \frac{R_E}{q_d} = 0.857 \)

(3) water vapor distilled per the capacity of the system.

\[ D = \frac{211}{R_E} = 0.0890 \text{ kg/min} \]

Mass flow rate of cold solution from absorber \( F = FD = 0.489 \text{ kg/min} \)

Mass flow rate of hot solution from generator \( F- = 0.400 \text{ kg/min} \)

(4) Heat rejected in the condenser \( Q_c = \frac{D}{60} (h_5 - h_6) = 3.68 \text{ kW} \)

(5) Heat rejected in the absorber \( Q_A = Dq_A = [(h_6-h_3) + F(h_3-h_4)] = 3.93 \text{ kW} \)

(6) Heat supplied in the generator \( Q_G = Dq_d = 4.1022 \text{ kW} \)

4. Results and Discussion

4.1. Result of solar Energy of FPC

The mathematical expressions provided in the analysis section have been solved in MATLAB 17a.

The results of the numerical analysis of the solar- Flat plate collector, carried out in MATLAB have been shown in the current section. The two case studies have been taken from India, particularly New Delhi and Mumbai with respective locations as: (28° 35’N, 77° 12’) and (19° 07’N, 72° 51’E). The input data for the analysis was taken on every 15 of April, May and Jun. In order to simulate the system, the initial conditions listed in Table 1 were used.
4.1.1. Result of case study in New Delhi

A. Case study in New Delhi on 15 of April

Table 3. Performance of a flat-plate collector over a whole day on 15 of April in New Delhi

| IST(h) | 0900 | 1000 | 1100 | 1200 | 1300 | 1400 | 1500 | 1600 |
|--------|------|------|------|------|------|------|------|------|
| \(I_t (W/m^2)\) | 543.63 | 713.48 | 832.48 | 893.15 | 886.26 | 817.50 | 685.93 | 513.14 |
| \(T_a (\degree C)\) | 69.01 | 73.45 | 76.55 | 78.14 | 77.95 | 76.13 | 72.68 | 68.17 |
| \(Q_u (W)\) | 444.82 | 663.88 | 816.82 | 895.35 | 885.69 | 795.96 | 625.99 | 403.55 |
| \(Q_l (W)\) | 381.97 | 425.43 | 455.78 | 471.37 | 469.45 | 469.45 | 417.92 | 373.78 |
| \(\eta_t\) | 0.41 | 0.47 | 0.50 | 0.51 | 0.50 | 0.49 | 0.46 | 0.40 |

B. Case study in New Delhi on 15 of May

Table 4. Performance of a flat-plate collector over a whole day on 15 of May in New Delhi

| IST(h) | 0900 | 1000 | 1100 | 1200 | 1300 | 1400 | 1500 | 1600 |
|--------|------|------|------|------|------|------|------|------|
| \(I_t (W/m^2)\) | 545.60 | 698.18 | 808.13 | 863.56 | 859.22 | 789.36 | 676.05 | 514.87 |
| \(T_a (\degree C)\) | 68.965 | 72.94 | 75.81 | 77.25 | 77.13 | 75.29 | 72.33 | 68.13 |
| \(Q_u (W)\) | 442.33 | 638.56 | 780.12 | 851.50 | 845.43 | 754.87 | 608.41 | 401.59 |
| \(Q_l (W)\) | 381.47 | 420.41 | 448.50 | 462.66 | 461.46 | 443.49 | 414.43 | 373.39 |
| \(\eta_t\) | 0.41 | 0.46 | 0.49 | 0.50 | 0.50 | 0.48 | 0.45 | 0.39 |

C. Case study in New Delhi on 15 of Jun

Table 5. Performance of a flat-plate collector over a whole day on 15 of Jun in New Delhi

| IST(h) | 0900 | 1000 | 1100 | 1200 | 1300 | 1400 | 1500 | 1600 |
|--------|------|------|------|------|------|------|------|------|
| \(I_t (W/m^2)\) | 481.51 | 612.00 | 703.95 | 751.38 | 754.90 | 697.29 | 595.96 | 452.66 |
| \(T_a (\degree C)\) | 67.15 | 70.49 | 72.84 | 74.06 | 74.15 | 72.67 | 70.07 | 67.40 |
| \(Q_u (W)\) | 353.05 | 517.74 | 633.72 | 693.99 | 698.61 | 625.58 | 496.92 | 316.00 |
| \(Q_l (W)\) | 363.76 | 396.44 | 419.45 | 431.41 | 432.33 | 417.83 | 392.30 | 356.41 |
| \(\eta_t\) | 0.37 | 0.43 | 0.45 | 0.47 | 0.47 | 0.45 | 0.42 | 0.35 |

As seen in the Table 3, Table 4 and Table 5, The result of Case study in New Delhi on 15 of April, May and Jun the values of the outlet temperature and useful heat gain (Figure.2.) increase sharply from 0900 to 1200 h, touch a peak around noon and then drop sharply after 1300 h. The outlet temperature increasing from 0900 to 1200 h was 78˚C and at around 1600 it was 68 ˚C. and the comparison between three months shown that the month of April was highest heat gain because of solar flux incident on collector.
4.1.2. Result of Case study in Mumbai

A. Case study in Mumbai on 15 of April

Table 6. Performance of a flat-plate collector over a whole a day on 15 of April in Mumbai

| IST(h) | 0900 | 1000 | 1100 | 1200 | 1300 | 1400 | 1500 | 1600 |
|--------|------|------|------|------|------|------|------|------|
| I_r(W/m²) | 479.11 | 676.33 | 821.98 | 911.20 | 928.56 | 868.24 | 738.07 | 547.70 |
| T_o(°C) | 67.29 | 72.46 | 76.30 | 78.68 | 79.16 | 77.61 | 74.19 | 69.19 |
| Q_d(W)  | 359.92 | 614.93 | 804.25 | 921.71 | 945.73 | 868.89 | 700.39 | 453.54 |
| Q_u(W)  | 365.12 | 415.72 | 453.29 | 476.59 | 481.36 | 466.11 | 432.68 | 383.70 |
| η_l     | 0.38  | 0.46  | 0.49  | 0.51  | 0.51  | 0.48  | 0.45  | 0.42  |

B. Case study in Mumbai on 15 of May

Table 7. Performance of a flat-plate collector over a whole a day on 15 of May in Mumbai

| IST(h) | 0900 | 1000 | 1100 | 1200 | 1300 | 1400 | 1500 | 1600 |
|--------|------|------|------|------|------|------|------|------|
| I_r(W/m²) | 455.33 | 654.49 | 792.19 | 870.34 | 878.47 | 821.30 | 702.98 | 531.04 |
| T_o(°C) | 67.58 | 71.80 | 75.44 | 77.52 | 77.75 | 76.26 | 73.17 | 68.68 |
| Q_d(W)  | 324.93 | 582.48 | 761.95 | 864.50 | 876.14 | 802.72 | 650.05 | 428.61 |
| Q_u(W)  | 358.18 | 409.28 | 444.89 | 465.24 | 452.98 | 452.98 | 422.69 | 378.75 |
| η_l     | 0.37  | 0.45  | 0.49  | 0.50  | 0.50  | 0.49  | 0.47  | 0.41  |

C. Case study in Mumbai on 15 of Jun

Table 8. Performance of a flat-plate collector over a whole a day on 15 of Jun in Mumbai

| IST(h) | 0900 | 1000 | 1100 | 1200 | 1300 | 1400 | 1500 | 1600 |
|--------|------|------|------|------|------|------|------|------|
| I_r(W/m²) | 341.29 | 471.91 | 559.14 | 614.74 | 623.99 | 586.95 | 505.70 | 362.83 |
| T_o(°C) | 64.08 | 67.47 | 69.74 | 71.18 | 71.45 | 70.50 | 68.39 | 64.71 |
| Q_d(W)  | 201.6171 | 368.60 | 480.81 | 551.64 | 564.97 | 518.31 | 414.09 | 232.32 |
| Q_u(W)  | 300.65 | 330.51 | 350.58 | 363.24 | 365.63 | 357.28 | 338.65 | 306.21 |
| η_l     | 0.30  | 0.39  | 0.43  | 0.45  | 0.46  | 0.45  | 0.41  | 0.32  |
As seen in the Table 6, Table 7 and Table 8, the result of Case study in Mumbai on 15 of April, May and Jun the values of the useful heat gain and the efficiency (Figure 3) increase sharply from 0900 to 1200 h, touch a peak around noon and then drop sharply after 1400 h. The outlet temperature increasing from 0900 to 1200 h was 79°C and at around 1600 it was 69°C. and the comparison between three months shown that the month of April was highest heat gain and outlet temperature because of solar flux incident on collector.

4.2. Results of Lithium Bromide-Water (LiBr-H₂O) system powered by solar collector

In this section, we have carried out the development method of analysis that is based on analytical data which relate the thermodynamic variable of the lithium bromide water fluid couple, and the simulation date of flat plate collector, the coefficient of performance (COP) of the system for the different parameters is analysis to be 0.857 at generator inlet temperature. The result has shown when generator inlet temperature increases the heat supplied in generator increase. When we take the COP as constant the parameters of cooling load ($Q_8$) and water vapor distilled ($D$) per cooling load amount increases, the poor solution concentration of water leaves the generator ($ξ_a$) decrease slightly and rich solution was constant 0.55% ($ξ_r$). The result has shown in Table 9 and Table 10.

| $T_G$ (°C) | $h_4$ (kJ/kg) | $h_2$ (kJ/kg) | $h_1$ (kJ/kg) | $h_3$ (kJ/kg) | $F_1$ | $h_5$ (kJ/kg) | $h_6$ (kJ/kg) | $h_8$ (kJ/kg) | $ξ_a$ | $ξ_r$ |
|----------|---------------|---------------|---------------|---------------|------|---------------|---------------|---------------|------|------|
| 68       | 45.15         | 148.7         | 114.2         | 85.5          | 5.5  | 2628          | 0.45          |               |      |      |
| 70       | 45.15         | 155.6         | 114.2         | 87.5          | 5.45 | 2632          | 0.449         |               |      |      |
| 72       | 45.15         | 159.7         | 114.2         | 89.5          | 5.36 | 2636          | 0.447         |               |      |      |
| 74       | 45.15         | 163.84        | 114.2         | 93.5          | 5.32 | 2640          | 0.446         |               |      |      |
| 76       | 45.15         | 168.2         | 114.2         | 97.6          | 5.24 | 2643          | 0.444         |               |      |      |
| 78       | 45.15         | 172.08        | 114.2         | 101.7         | 5.12 | 2647          | 0.441         |               |      |      |
| 80       | 45.15         | 176.2         | 114.2         | 105.8         | 5.09 | 2651          | 0.44          |               |      |      |

The parameters listed in Table 10 are affecting on the performance of the system.
### Table 10.

Table showing the variation that have occurred to the system during change in the generator temperature

| $T_G$ (°C) | $Q_G$ (kW) | COP | $Q_E$ (kW) | $D$ (kg/min) | $Q_A$ (kW) | $q_d$ (kJ/kg) | $\dot{m}_e$ (kg/min) | $\dot{m}_h$ (kg/min) | $R_E$ (kJ/kg) |
|------------|------------|-----|------------|-------------|------------|--------------|---------------------|---------------------|------------------|
| 68         | 4.1022     |     | 3.5167     | 0.0890      | 3.9306     | 3.6896       | 2765                | 0.400              | 0.489            |
| 70         | 4.1200     |     | 3.5308     | 0.0894      | 3.9586     | 3.7092       | 2778                | 0.402              | 0.491            |
| 72         | 4.1379     |     | 3.5461     | 0.0897      | 3.9755     | 3.7306       | 2781                | 0.403              | 0.493            |
| 74         | 4.1611     | 0.8570 | 3.5660     | 0.0903      | 4.0385     | 3.7573       | 2812                | 0.406              | 0.496            |
| 76         | 4.2308     |     | 3.6257     | 0.0918      | 4.1355     | 3.8270       | 2834                | 0.413              | 0.504            |
| 78         | 4.3368     |     | 3.7166     | 0.0941      | 4.2663     | 3.9272       | 2857                | 0.423              | 0.517            |
| 80         | 4.4785     |     | 3.8380     | 0.0972      | 4.4374     | 4.0633       | 2879                | 0.437              | 0.534            |

### Figure 4.

Variation of the Cooling load and Vapor Distilled with the Generator Inlet Temperature

#### 5. Conclusion

The performance of the solar flat plate collector (FPC) system were compared at different locations and time. It was observed that the efficiency of the solar collector and the useful heat gain during the day greatly depended on the incident flux absorbed by absorber plate. The efficiency increases during the morning time due to increase in collector temperature, however it decreases during afternoon, due to the high heat loss to the surrounding. The efficiency of solar collector on 15 of April in Mumbai
observed highest, but generally the flat plate collector can power the lithium bromide water system
during the day because the outlet temperature of the collector was between 68°C to 79°C and this
temperature was sufficient to run it. There is no loss of temperature between the solar collector cycle
and generator because it is designed that the mass flow rate in solar collector is equivalent to twice the
mass flow rate in generator. While the COP of the solar vapor absorption system (SVAS) was 0.857
the vapor water distilled increases with increase the heat supplied to the generator and cooling load,
with constant COP. The poor solution concentration of water leaves the generator (ξa) decrease slightly
and rich solution concentration of water (ξr) was constant.

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| NOMENCLATURE | | |
|---------------|---------------|---------------|
| Ap            | Area of the absorber plate. [m²] | | |
| S             | Incident solar flux absorbed in absorber. | | |
| q_t           | Heat lost by convection and re-radiation from the top. | | |
| t             | Transmissivity of the glass cover system. | | |
| α             | Absorptivity of the absorber plate. | | |
| A_c           | Collector area. [m²] | | |
| I_T           | Total solar radiation. | | |
| η_c           | Instantaneous collector efficiency. | | |
| T_f,ln        | Collector fluid inlet temperature. [°C] | | |
| T_a           | Ambient temperature. [°C] | | |
| τα            | Transmitted-absorptivity product. | | |
| U_L           | Overall heat transfer coefficient [W/m²-k] | | |
| T_sky         | Effective temperature of the sky. [k] | | |
| ε_c           | Emissivity of the covers for long wavelength radiation | | |
| ε_p           | Emissivity of the absorber plate for long wavelength radiation | | |
| P             | Pressure [kPa] | | |
| h             | Specific enthalpy [kJ kg⁻¹] | | |
| T             | Temperature [°C] | | |
| k             | Thermal conductivity of the insulation [w/m-k] | | |
| δ_b           | Thickness of the insulation. | | |
| I_b           | Hourly beam radiation that the collector receives [W/m²] | | |
| I_d           | Hourly diffuse radiation that the collector receives [W/m²] | | |
| φ             | Latitude angle | | |
| β             | Collector tilt angle | | |
| ξ_poor        | Poor solution concentration of water [-] | | |
| ξ_rich        | Rich solution concentration of water [-] | | |
| D             | Vapor water distilled [kg/min] | | |
| Q_e           | Cooling load [kW] | | |
| Q_g           | Heat supplied to generator [kW] | | |
| Q_a           | Heat rejected in absorber[kW] | | |
| Q_c           | Heat rejected in condenser [kW] | | |
| F             | Specific solution circulation rates [kJ/kg vapor] | | |
| m_c           | Mass flow rate of cold solution from the absorber [kg/min] | | |
| m_h           | Mass flow rate of hot solution from the generator [kg/min] | | |
| R_R           | Refrigeration effect [kJ/kg] | | |
| COP           | Coefficient of performance [-] | | |