

Potentials evaluation for circular solar collector, humidifier and dehumidifier with close water open air (CWOA) air heated system humidification – dehumidification process

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Abstract — The humidification and dehumidification process has several attractive features, which include operation at lower temperature, ability to use sustainable energy sources, where solar radiation with high intensity is available, During day time a part of solar radiation striking the solar collector is converted into heat energy. Circular solar collectors' air heater both theoretically and experimentally have been investigated. Also formulae for the calculation of their efficiency have been developed. The value and the intensity of solar isolation over a year, strongly depend on the latitude and weather conditions of the place. The heat energy produced by a solar collector air heater is utilized by humidifier and convert dry air in to humidified air. Air cooled dehumidifier absorbed heat from air and moisture which is passing through inside condenser tube ,air release from it and leave in to atmosphere and pure water collected in collecting tank.. The results of the investigation have shown that the system productivity increases with the increase in the mass flow rate of air through the unit.

Keywords- Humidification; Solar Radiation; Circular Solar Collector; Dehumidification; Air Heater, Dehumidifier

1. Introduction

A study of humidification dehumidification processes were carried out to investigate a solar desalination method. The desalination system consists of a solar air heater, humidifier, dehumidifier, and air-driving component blower. The study covers different environmental parameters like solar intensity, ambient temperature, and wind speed. The heater , the humidifier, and the dehumidifier effectiveness also influence on water production of the system. Operational constrain such as feed water rate, temperature, and air circulation flow rate. The results indicated that solar air heater efficiency significantly influences the system's productivity. Increasing the solar intensity and ambient temperature and decreasing wind velocity increase system productivity. Increasing the air flow rate up to 0.7 kg/s increases the productivity, after which it has no significant effect. The feed water flow rate and temperature have an insignificant influence on the system's productivity. The surprising result is that dehumidifier effectiveness also has an insignificant influence on system productivity, which has very important implications since the cost of the dehumidifier (air cooled heat exchanger) is a major part of the system's cost. 1] The air after being heated in the solar collector (line 1–2) Air humidified in the evaporator (line 2–3) It is dehumanized in the condenser

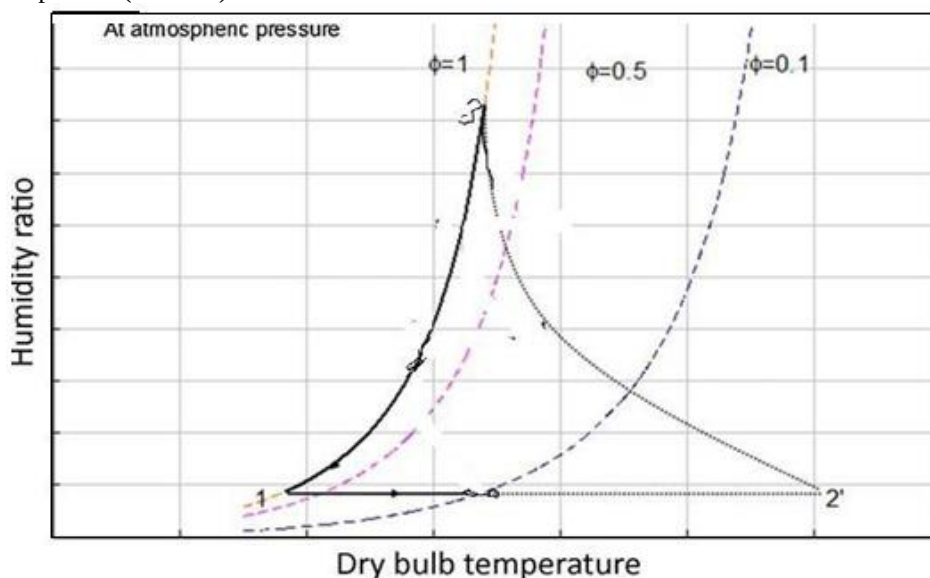


Figure 1 air-heated CWOA HDH process on psychometric chart

2 constructions of Components

There are three main component circular solar collector air heater ,humidifier, dehumidifier in project .solar circular heater made from 1500mmlong borosilicate glass tube whose inner diameter is 56mm and outer diameter is 60mm.aluminium tube is used for absorber tube ,black dull colour applied on outer surface with the help of spray printing machine with one layer .it is also 1600mm in length. Assembly is done by neoprene rubber on both side ,absorber tube keep centrally and make it air tight Four collector prepared ,120mm distance kept between them and fix on the frame by clamp properly Blower used to suck the air through circular solar collector . Another end blower is connected with humidifier by flexible rubber pipes. Humidifier is a galvanized iron tank constructed from 2mm thick sheet having dimension are length 914 mm width 305 mm height 610 mm. Arc welding is used to manufacture tank . galvanized iron sheet is cut on hydraulic press according to dimension. Steel net used for supporting the grass pad .submersible pump ,sensor ,water inlet connection and water drained are provided on humidifier. air-cooled dehumidifier attached with humidifier by bolts and nuts fasteners .dehumidifier is made from aluminums capillary tube which are join by TIG welding process because of 1mm thickness wall .Aluminums tube welded both end with two main fold .dehumidifier connected with reservoir tank.

4 Equations for Humidifier

When air is passing through the air heater the relative humidity of air will reduce due to sensible heating which is shown in fig. 2 When the hot air having mass flow rate 'm' kg/sec with temperature t_2 and specific humidity ω_2 kg/kg of dry air passing through falling water drops, it absorb the water vapors m_v result in increase relative humidity of air and get specific humidity ω_3 .

Which mass balance is given by,

$$\begin{aligned}\omega_3 m &= \omega_2 m + m_v \\ m_v &= m(\omega_3 - \omega_2)\end{aligned}$$

Where specific humidity

$$\omega = \frac{0.622 P_v}{1 - P_v}$$

And relative humidity ϕ

$$\phi = \frac{P_v}{P_{vs}}$$

Where P_{vs} saturated vapor is pressure at corresponding temperature, and P_v is partial vapor pressure in dry air.

. The most common way to express performance of the humidifier is its efficiency given by equation[2]

$$\eta = \frac{(\omega_{out} - \omega_{in})}{(\omega_{out,sat} - \omega_{in})}$$

where

ω_{out} is outlet humidity ratio; ω_{in} is inlet humidity ratio; and $\omega_{out,sat}$ is outlet humidity ratio at saturation

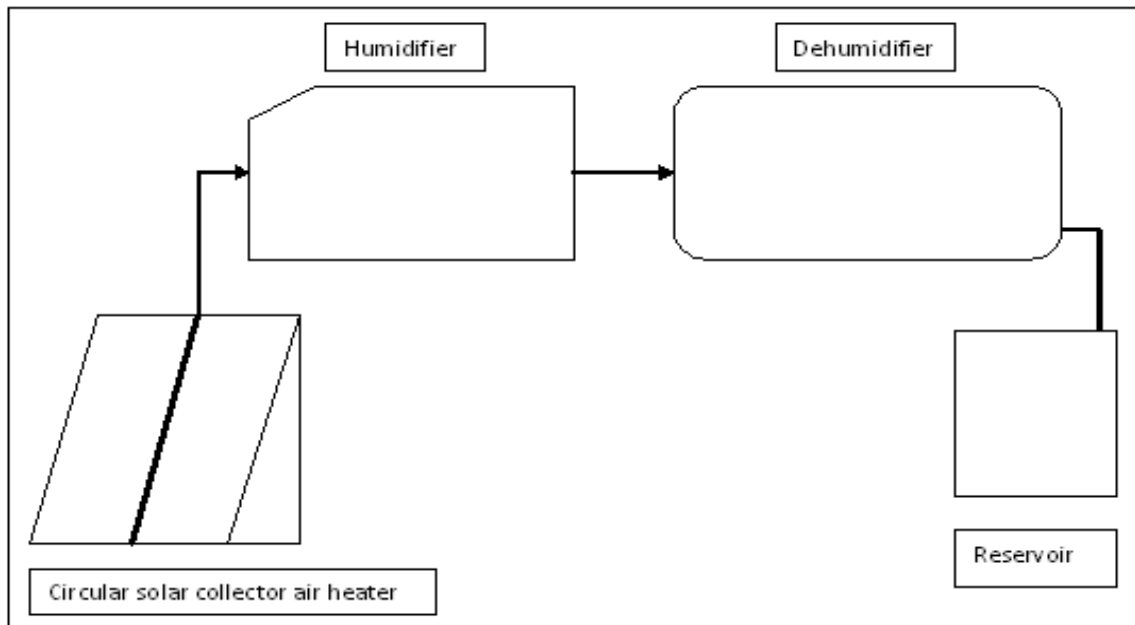


Figure 2 Diagram of circular solar collector air heater, humidifier and dehumidifier for (CWOA) humidification-dehumidification process

5 Equations for Dehumidifier

Energy and mass balances are applied to a segment of height Δy

$$M_{cw}Cp_{cw}(T_{cwo} - T_{cwi}) = M_a(H_o - H_c) \quad (1)$$

$$M_{cw}Cp_{cw}(T_{cwo} - T_{cwi}) = U_c A_c LMTD_c \quad (2)$$

The logarithmic mean

$$LMTD_c = \frac{(T_{ac} - T_{cwo})(T_{ac} - T_{cwi})}{\ln\left(\frac{(T_{ao} - T_{cwo})}{(T_{ac} - T_{cwi})}\right)}$$

The production of distilled water is given by the following balance equation

$$M_d = M_a(W_o - W_c)$$

Dehumidifier effectiveness

$$\eta = \frac{T_3 - T_4}{T_3 - T_{amb}}$$

6 Instrumentation

The measured variables in the experiment include inlet and outlet air and water temperatures in each unit components, inlet and outlet relative humidity in the humidifier, ambient temperature, air velocity and the solar irradiation incident on the circular collector's plane. The air and water solar collectors were instrumented with Pt100 thermistors for measuring the outlet and the inlet of air and water temperatures and ambient temperature. The Pt 100, which measured the ambient

temperature, was kept in a shelter to protect the sensor from direct sunlight. The outlet and the inlet of both relative humidity and air temperatures in the humidifier were measured using the TH100 transmitter and the water temperatures were measured using the thermistors type 1... However, the inlet and the outlet air temperatures in both the dehumidifier were measured using, respectively, the thermistors type 1 and the thermistors type 2. The air flow rate was calculated from the air velocity, measured by a multifunction anemometer with screw probe at the humidifier outlet. A pyranometer was used to measure the total solar irradiation placed on a solar circular collector plane. All sensors, which were calibrated before using to determine the probes sensibility.



Figure 3 Practical model of humidifier & dehumidifier for (CWOA) using circular solar collector of humidification-dehumidification process

7 Result and discussion

During experimentation, all the parameters were measured and recorded every 60 min. All measurements started at 8:00 a.m. and finished at 6.00pm from 21 Jan 2016 to 25 may 2016.

Table 1:6/5/2016 Volume flow rate =0.033 m³/s

Time, hr	Air inlet temp. °C	Air outlet temp. °C	Solar radiation W/m ²	Mass flow rate	Ac *IT	m*cp*ΔT	Collector efficiency
8	30	36	325	0.033698	213.33	203.19894	95.2509914
9	33	43	531	0.032886	348.5484	330.5043	94.8230719
10	35	46	711	0.032364	466.7004	357.78402	76.6624627
11	36	49	824	0.032074	540.8736	419.04681	77.4759223
12	41	54	844	0.031871	554.0016	416.394615	75.1612658
1	42	55	835	0.031813	548.094	415.636845	75.8331317
2	42	52	658	0.031958	431.9112	321.1779	74.3620216
3	41	51	585.2	0.031552	384.1253	317.0976	82.5505679
4	41	49	457	0.031552	299.9748	253.67808	84.5664636
5	40	47	365.58	0.032016	239.9667	225.23256	93.8599184
6	38	43	256.2	0.032112	168.1697	161.3628	95.9523738

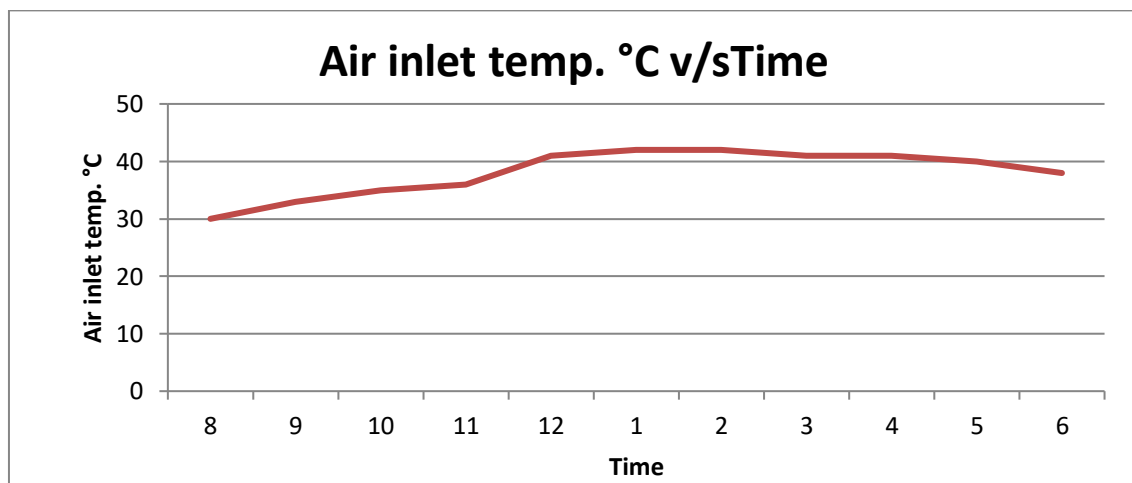


Figure 4 6/5/2016 Volume flow rate =0.033 m³/s

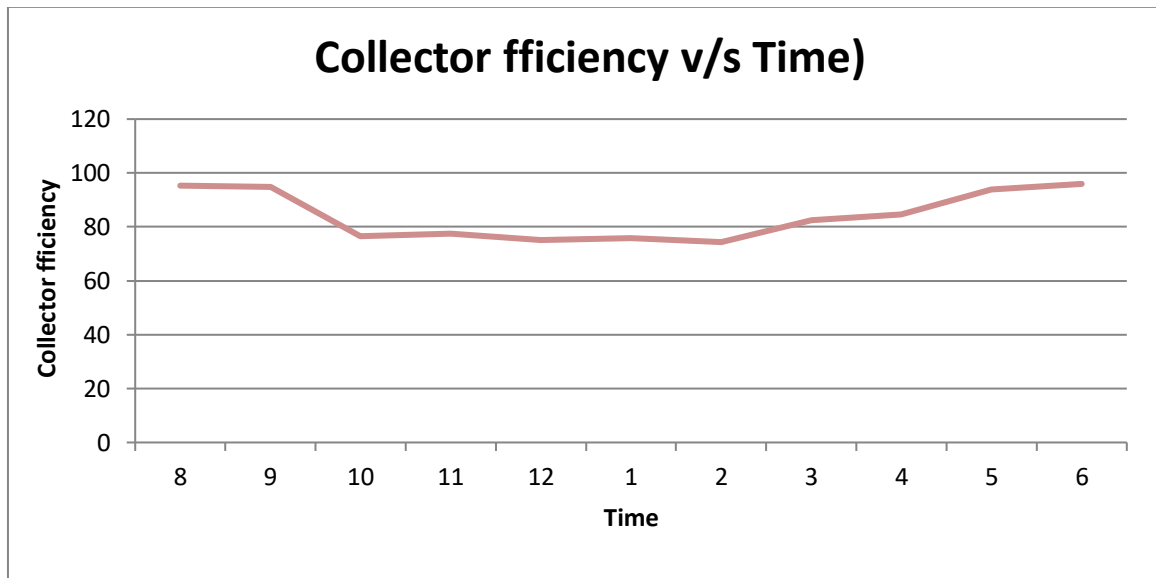


Figure 5 6/5/2016 Volume flow rate =0.033 m³/s

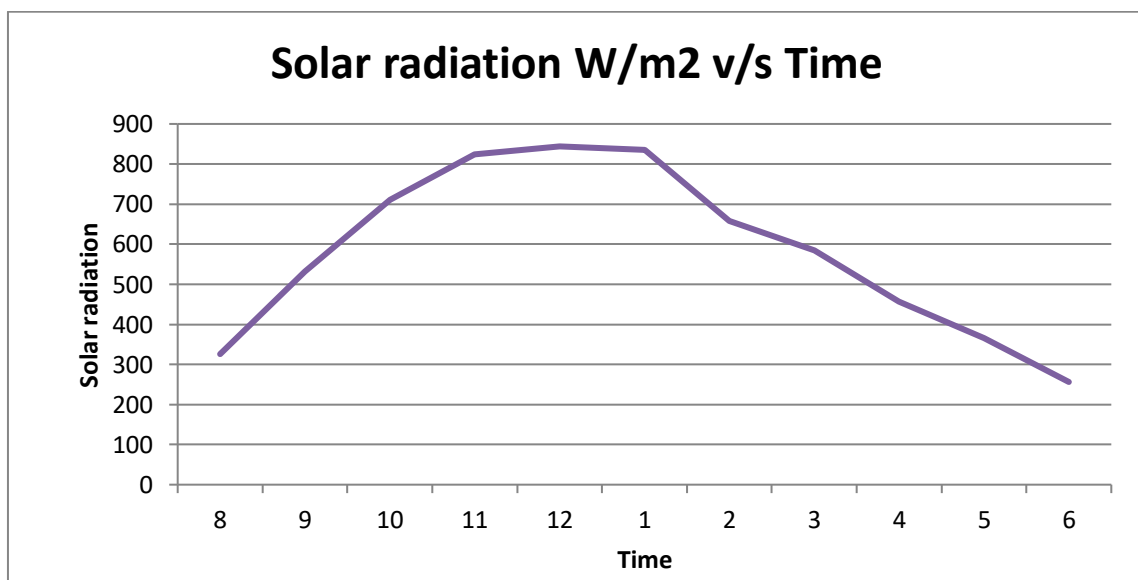


Figure 6 6/5/2016 Volume flow rate =0.033 m³/s

Table 2 7/5/2016 Volume flow rate =0.029 m³/s

Time, hr	Air inlet temp. °C	Air outlet temp. C	Solar radiation W/m ²	Mass flow rate	Ac *IT	m*cp*ΔT	Collector efficiency
8	27	32	232.36	0.029008	152.5211	145.7642	95.56985307
9	32	39	340.5	0.029125	223.5042	204.89438	91.67361284
10	36	45	479.38	0.02906	314.66503	262.85132	83.53369179
11	39	51	647.78	0.029159	425.20279	351.66236	82.7046225
12	42	54	743.32	0.029078	487.91525	350.67586	71.87228877
1	43	55	766.1	0.029177	502.86804	351.8698	69.97259082
2	42	54	730.35	0.029396	479.40174	354.51335	73.94911583
3	42	54	657.29	0.029412	431.44516	354.70872	82.21409258
4	41	51	526.78	0.029119	345.77839	292.64595	84.63396116
5	40	48	389.41	0.029019	255.60872	233.31276	91.27730711
6	38	45	325.28	0.029247	213.51379	205.75265	96.36503716

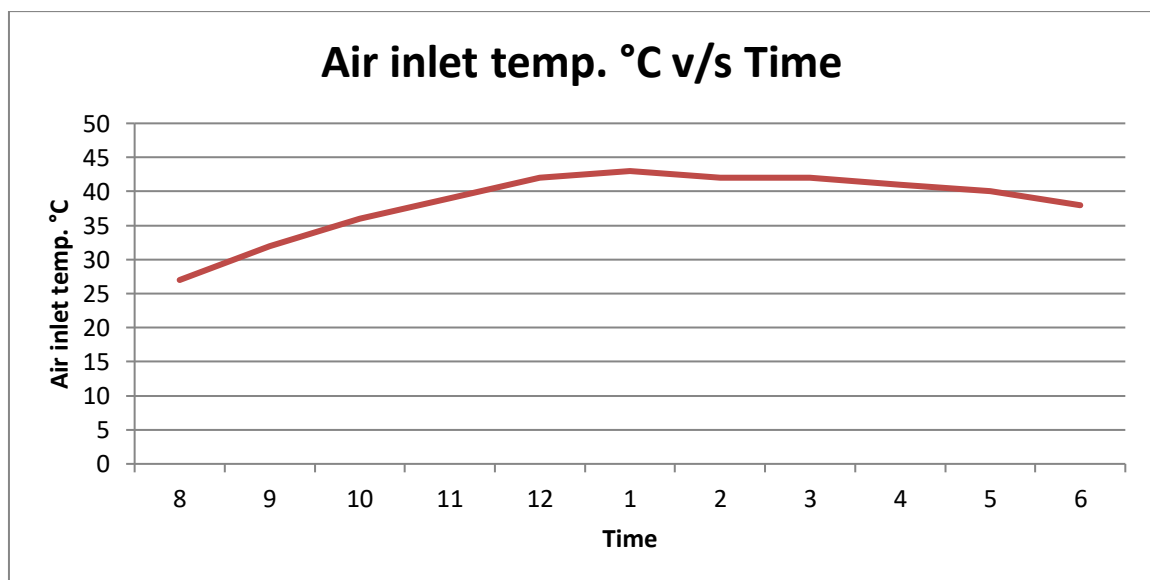


Figure 7: 7/5/2016 Volume flow rate =0.029 m³/s

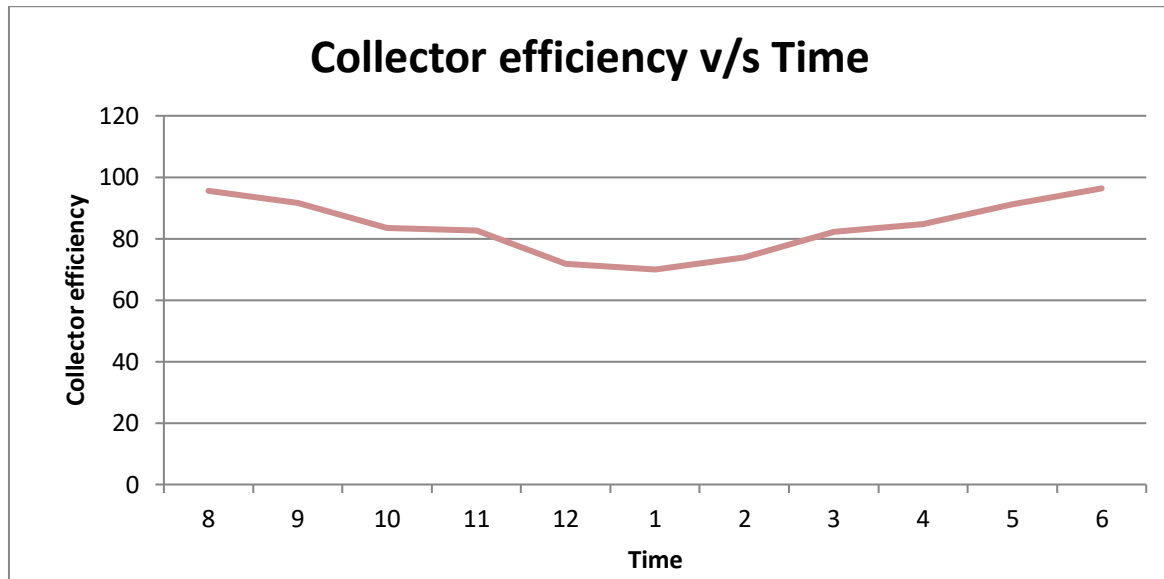


Figure 8: 7/5/2016 Volume flow rate =0.029 m³/s

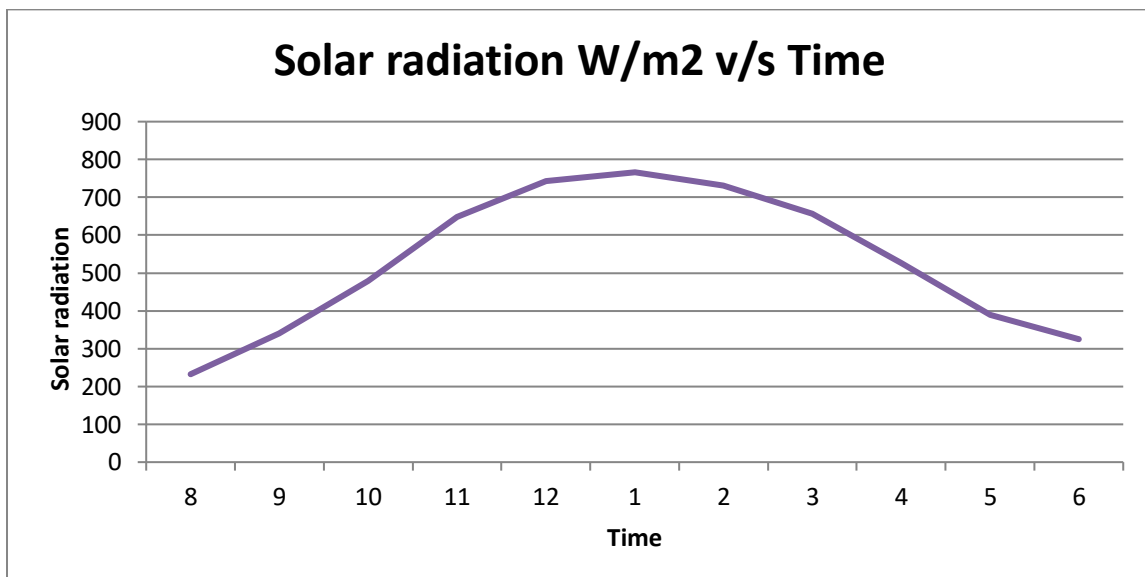


Figure 9: 7/5/2016 Volume flow rate =0.029 m³/s

Table 3:8/5/2016 Volume flow rate =0.026 m³/s

Time, hr	Air inlet temp. °C	Air outlet temp. °C	Solar radiation W/m ²	Mass flow rate	Ac *IT	m*cp*ΔT	Collector efficiency
8	31	36	215.51	0.026008	141.4608	130.6892	92.38547
9	33	41	362.28	0.026125	237.8006	210.045	88.32821
10	36	46	522.36	0.026004	342.8771	261.3402	76.21979
11	40	54	779.07	0.026159	511.3815	368.06276	71.9742
12	41	56	851.16	0.026078	558.7014	393.11982	70.36313
1	43	57	889.65	0.026277	583.9663	369.71176	63.31047
2	44	59	860.9	0.026196	565.0948	394.90169	69.88238
3	43	57	731.78	0.026012	480.3404	365.98884	76.19364
4	42	53	561.21	0.026111	368.3782	288.65711	78.35889
5	40	48	395.211	0.026109	259.4165	209.91636	80.91866
6	38	45	299.19	0.026247	196.3883	184.64765	94.02171

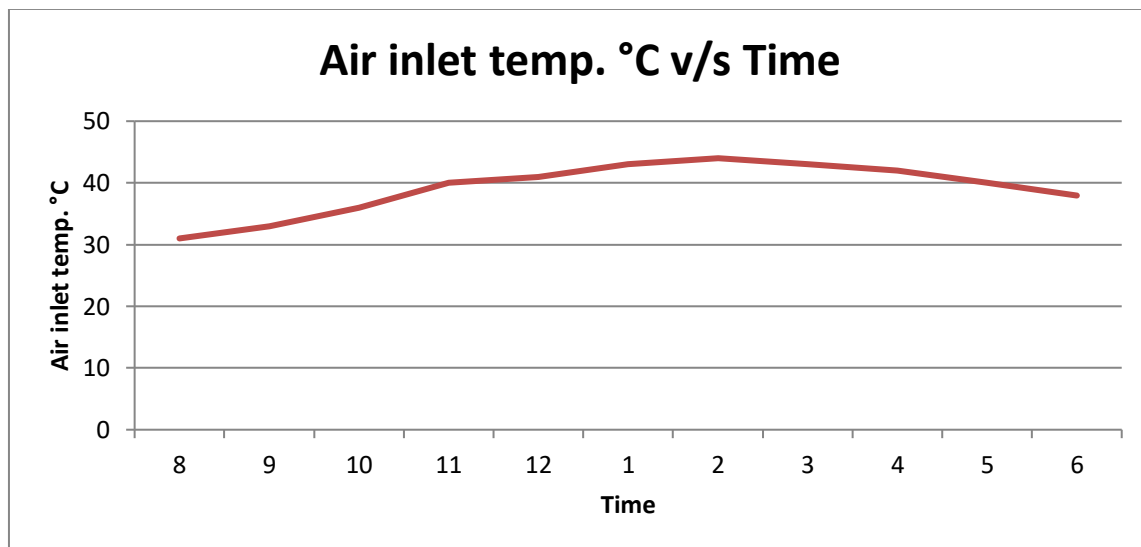


Figure 10: 8/5/2016 Volume flow rate =0.026 m³/s

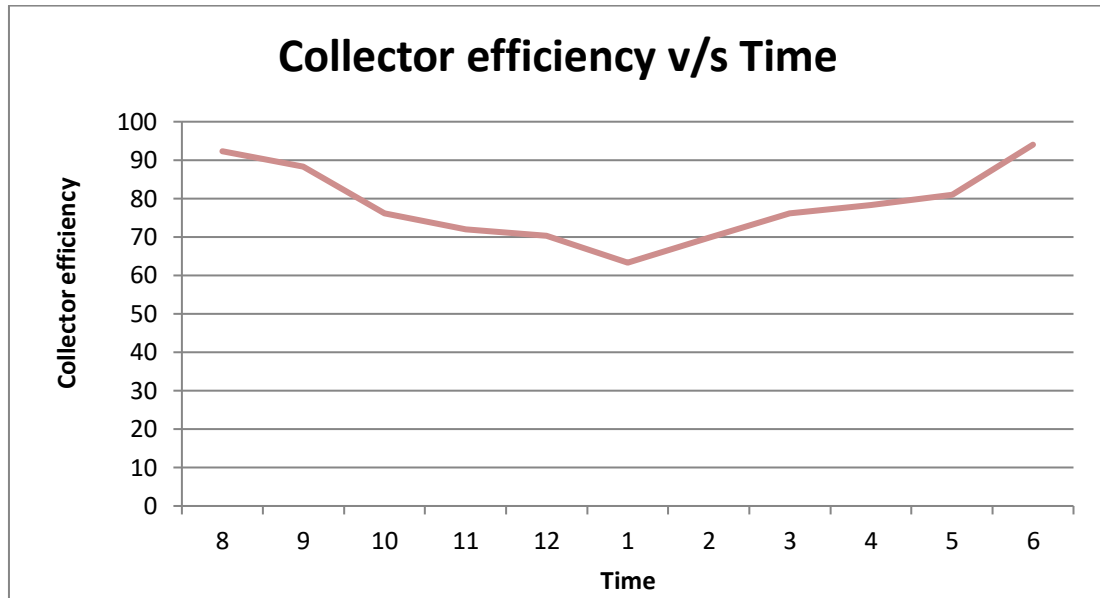


Figure 11: 8/5/2016 Volume flow rate =0.026 m³/s

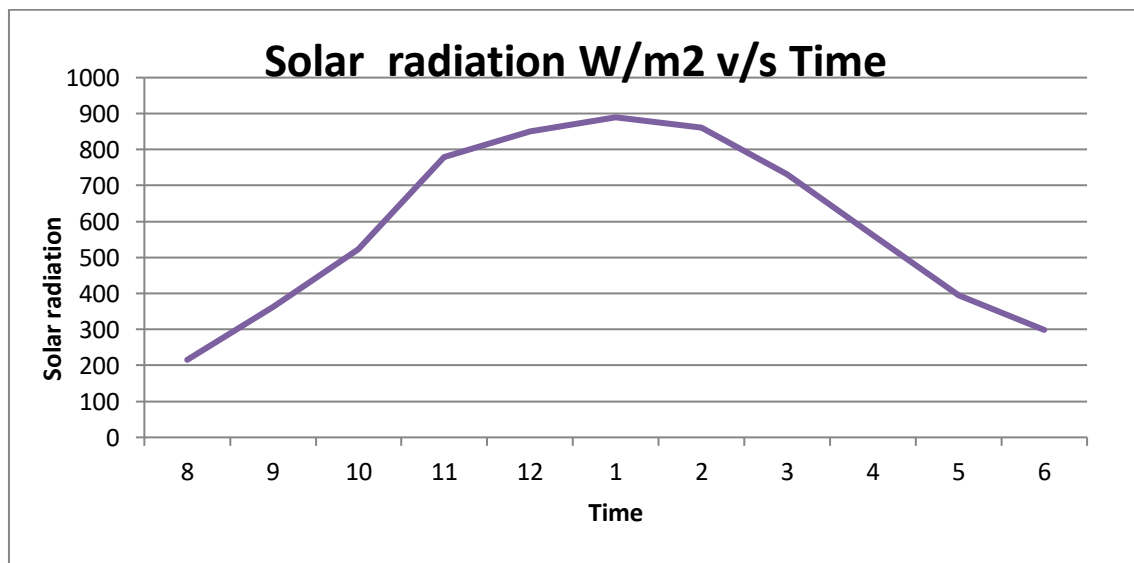


Figure 12: 8/5/2016 Volume flow rate =0.026 m³/s

Table 4:9/5/2016 Volume flow rate =0.0202 m³/s

Time, hr	Air inlet temp. °C	Air outlet temp. °C	Solar radiation W/m ²	Mass flow rate	Ac *IT	m*cp*ΔT	Collector efficiency
8	33	40	297.51	0.023008	195.2856	161.85987	82.8836857
9	34	46	516.47	0.022725	339.0109	274.0635	80.842089
10	38	53	703.86	0.02226	462.0137	335.57553	72.6332416
11	40	55	833.82	0.022159	547.3194	334.05296	61.034366
12	42	57	877.62	0.021978	576.0698	331.31232	57.5125338
1	43	61	844.2	0.021877	554.1329	395.74769	71.4174719
2	43	59	721	0.021796	473.2644	350.47646	74.0551083
3	42	56	599.4	0.021412	393.4462	301.26684	76.5713001
4	42	50	355.08	0.022119	233.0745	177.83676	76.3003893
5	41	48	296	0.022119	194.2944	155.60717	80.0883427
6	40	45	212	0.022247	139.1568	111.79118	80.3346836

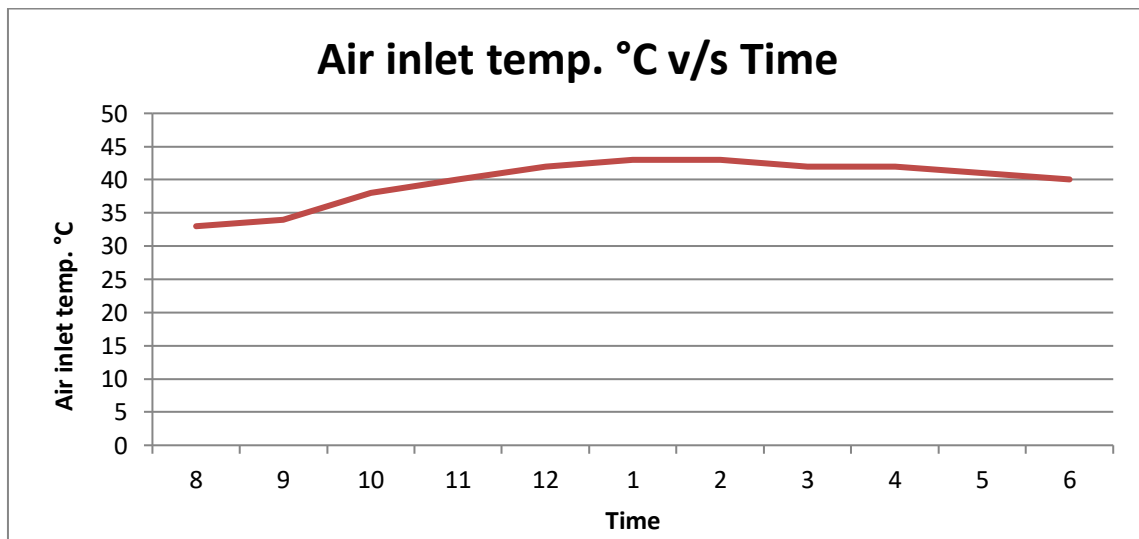


Figure 13 9/5/2016 Volume flow rate =0.0202 m³/s

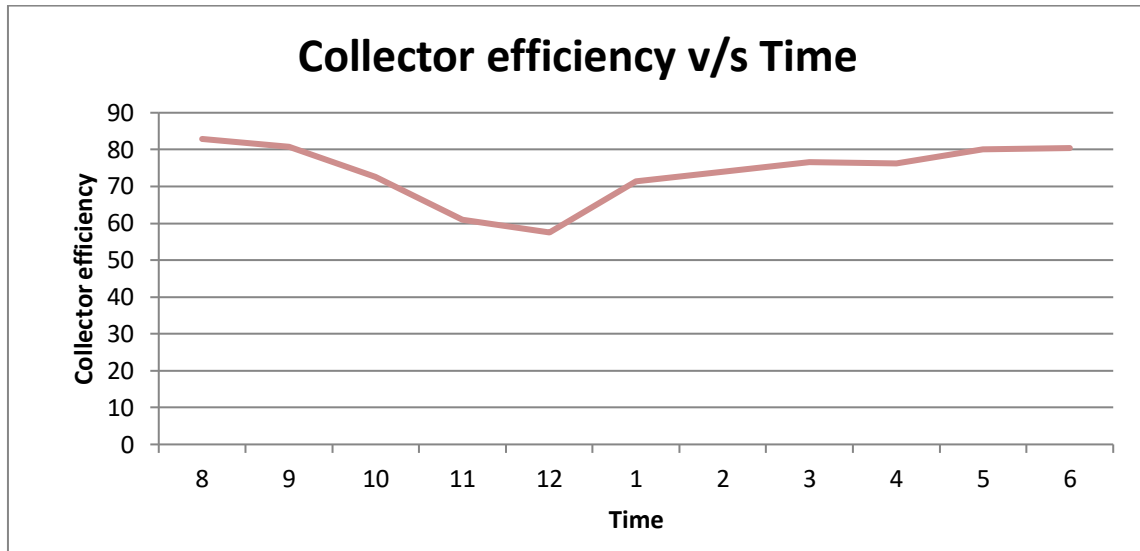


Figure 14 9/5/2016 Volume flow rate =0.0202 m³/s

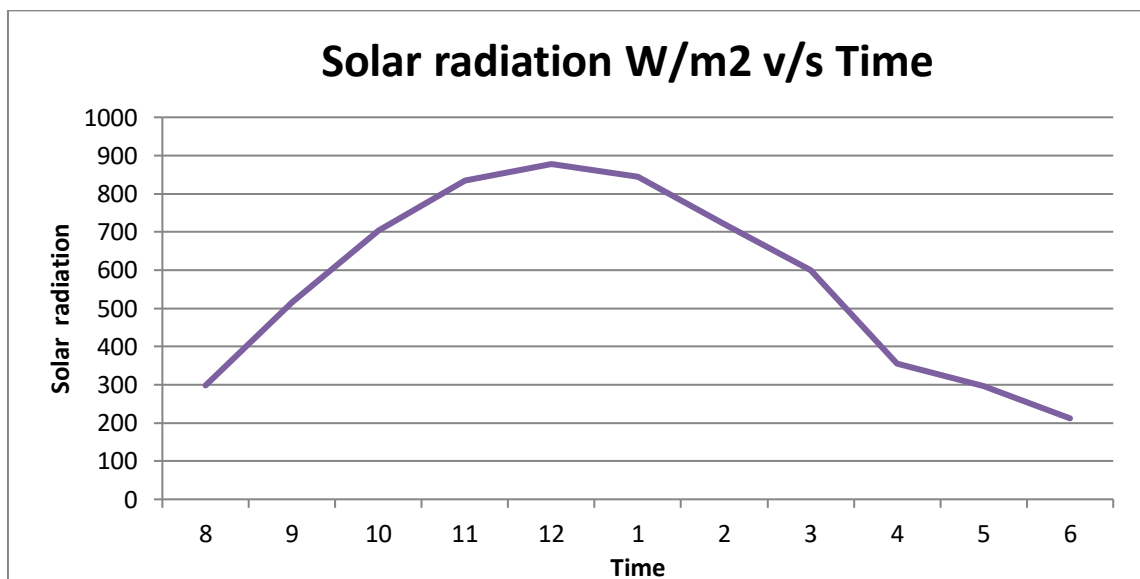


Figure 15 : 9/5/2016 Volume flow rate =0.0202 m³/s

Table 5:6/5/2016 Volume flow rate =0.033 m³/s

Sr.no	Time	Dry Bulb temperature At Humidifier Inlet	Wet Bulb temperature At Humidifier Inlet	DBT-WBT	Relative humidity	Dry Bulb temperature At Humidifier out let	Wet Bulb temperature At Humidifier outlet	DBT-WBT	Relative humidity	Efficiency
1	8	36	25	11	38	32	31	1	94	88.309196
2	9	43	30	13	35	36	34	2	88	75.751566
3	10	46	32	14	33	39	37	2	86	72.514524
4	11	49	34	15	32	43	40	3	84	70.627047
5	12	54	36	18	30	45	42	3	83	66.740709
6	1	55	36	19	27	47	43	4	80	65.093495
7	2	52	35	17	30	46	42	4	82	68.372066
8	3	51	34	17	30	44	41	3	85	72.716975
9	4	49	33	16	32	43	40	3	87	76.067597
10	5	47	32	15	35	42	40	2	91	82.878659
11	6	43	30	13	37	40	38	2	93	87.159507

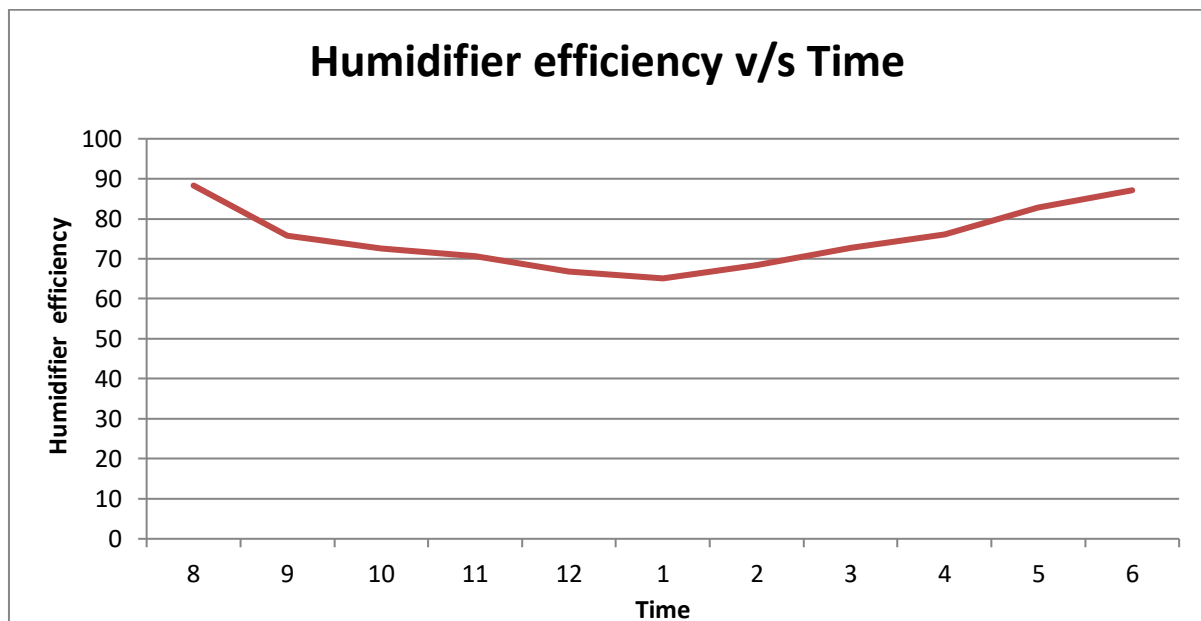


Figure 16: 6/5/2016 Volume flow rate =0.033 m³/s

Table 6:7/5/2016 Volume flow rate =0.029 m³/s

Sr.no	Time	Dry Bulb temperature At Humidifier Inlet	Wet Bulb temperature At Humidifier Inlet	DBT-WBT	Relative humidity	Dry Bulb temperature At Humidifier out let	Wet Bulb temperature At Humidifier outlet	DBT-WBT	Relative humidity	Efficiency
1	8	32	21	11	38	34	33	1	93	89.0498
2	9	39	26	13	36	38	36	2	88	79.96613
3	10	45	29	16	32	41	38	3	83	70.91801
4	11	51	32	19	29	45	41	4	80	65.69841
5	12	54	35	19	28	46	42	4	77	59.06066
6	1	55	36	19	27	47	41	6	72	51.58009
7	2	54	35	19	27	49	44	5	74	58.28212
8	3	54	33	21	24	48	44	4	82	71.80521
9	4	51	32	19	26	46	43	3	84	74.63242
10	5	48	30	18	28	44	42	2	88	80.75265
11	6	45	28	17	31	42	41	1	92	86.83389

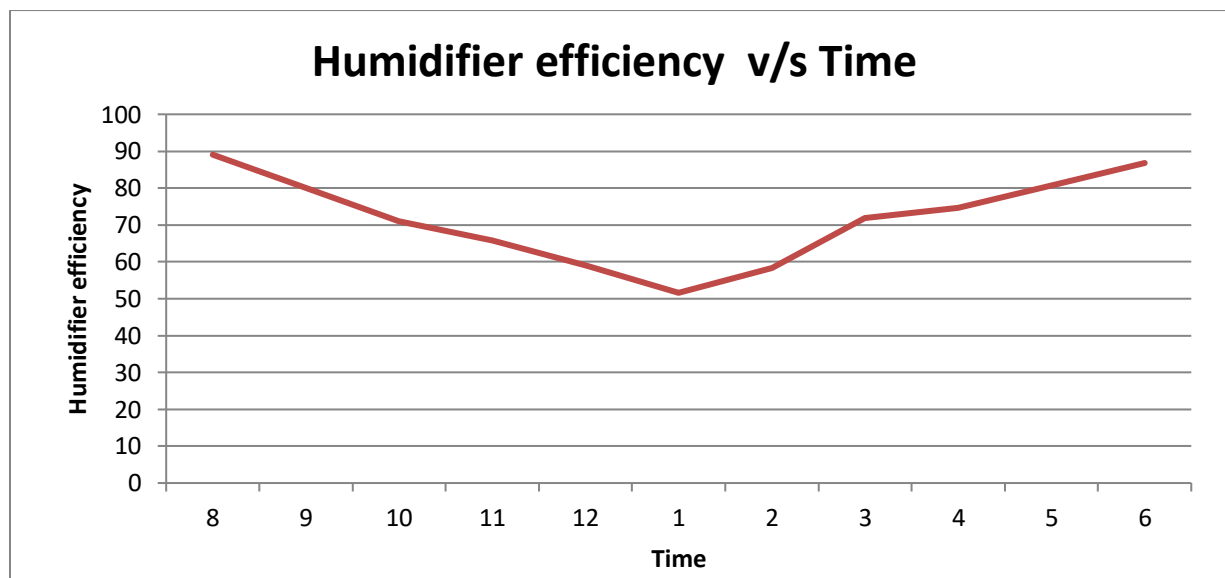


Figure 17: 7/5/2016 Volume flow rate =0.029 m³/s

Table 7:8/5/2016 Volume flow rate =0.026 m³/s

Sr.no	Time	Dry Bulb temperature At Humidifier Inlet	Wet Bulb temperature At Humidifier Inlet	DBT-WBT	Relative humidity	Dry Bulb temperature At Humidifier out let	Wet Bulb temperature At Humidifier outlet	DBT-WBT	Relative humidity	Efficiency
1	8	36	26	10	40	33	32	1	91	82.54629
2	9	41	31	10	39	35	34	1	87	71.24823
3	10	46	35	11	37	39	36	3	84	64.89921
4	11	54	36	18	32	41	37	4	81	49.49004
5	12	56	38	18	30	43	38	5	76	46.91533
6	1	57	40	17	28	45	41	4	74	46.10748
7	2	59	39	20	30	47	43	4	78	51.08983
8	3	57	38	19	32	46	44	2	79	52.17751
9	4	53	36	17	33	45	43	2	83	65.34212
10	5	48	35	13	38	44	42	2	85	70.84078
11	6	45	33	12	39	39	38	1	92	82.31765

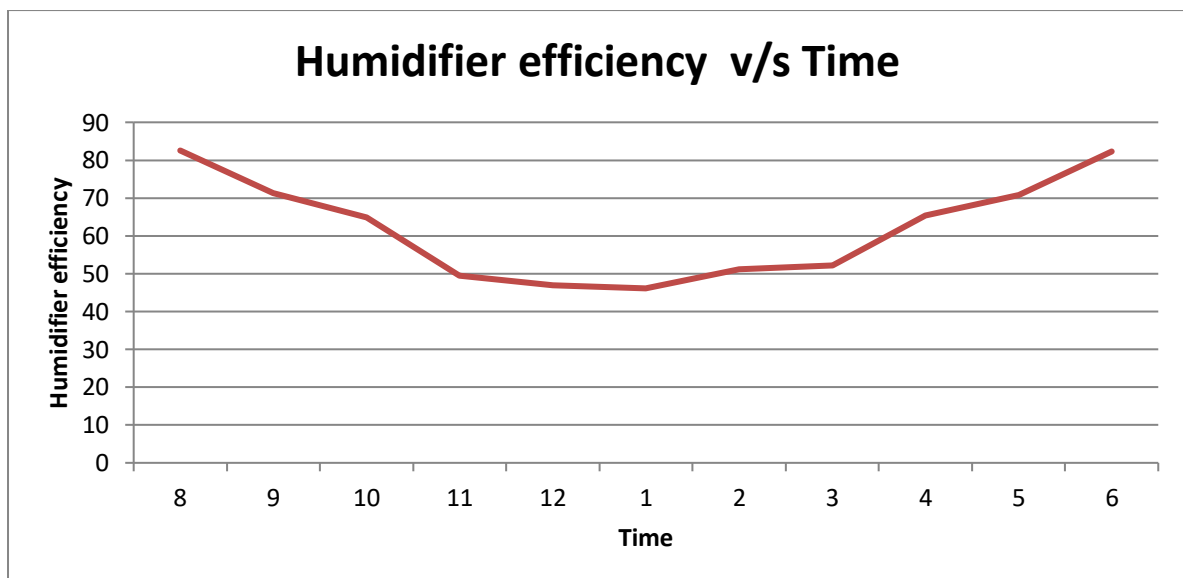


Figure 18: 8/5/2016 Volume flow rate =0.026 m³/s

Table 8:9/5/2016 Volume flow rate =0.0202 m³/s

Sr.no	Time	Dry Bulb temperature At Humidifier Inlet	Wet Bulb temperature At Humidifier Inlet	DBT-WBT	Relative humidity	Dry Bulb temperature At Humidifier out let	Wet Bulb temperature At Humidifier outlet	DBT-WBT	Relative humidity	efficiency
1	8	40	30	10	39	34	32	2	89	75.57566
2	9	46	33	13	36	36	33	3	83	55.66988
3	10	53	36	17	34	41	37	4	79	48.93399
4	11	55	38	17	32	45	40	5	75	46.07173
5	12	57	39	18	30	47	42	5	72	43.7058
6	1	61	41	20	26	48	42	6	71	42.05842
7	2	59	40	19	28	46	42	4	74	43.65285
8	3	56	38	18	33	45	42	3	78	47.88312
9	4	50	37	13	34	44	41	3	81	60.41245
10	5	48	36	12	38	42	40	2	84	66.36952
11	6	45	33	12	40	41	39	2	87	73.53931

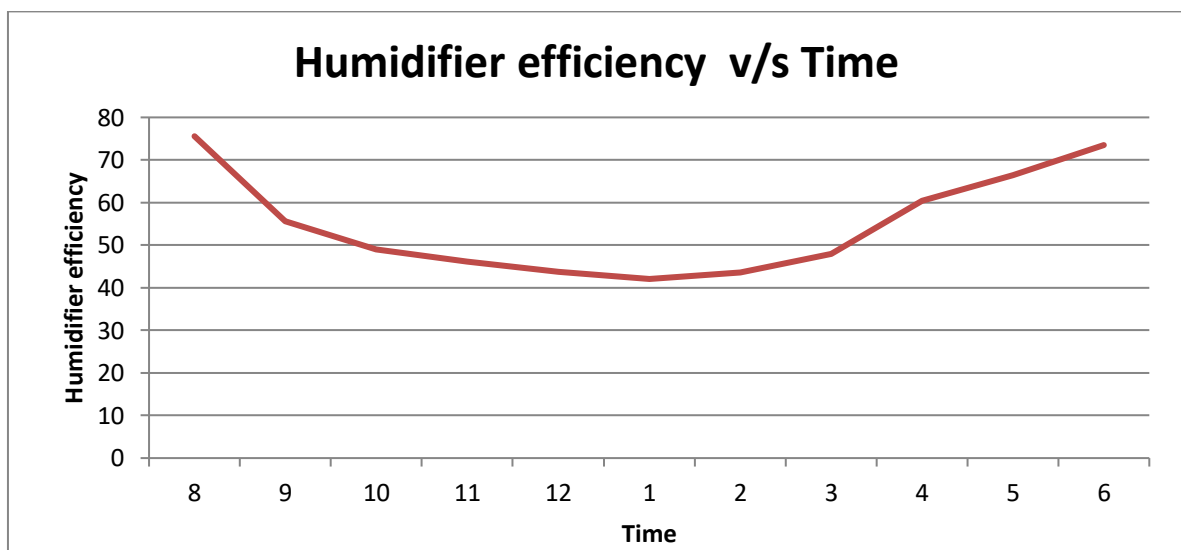


Figure 19 9/5/2016 Volume flow rate =0.0202 m³/s

Table 9:6/5/2016 Volume flow rate =0.033 m3/s

Time	Dry Bulb temperature At dehumidifier inlet(°C)	Wet Bulb temperature At dehumidifier inlet(°C)	Dry Bulb temperature At dehumidifier outlet(°C)	Wet Bulb temperature At dehumidifier outlet(°C)	Air inlet temperature (°C)	Efficiency of Dehumidifier	Quantity of water (ml)	Solar radiation W/m2
8	36	31	30	33	29	85.7142857	0	325
9	38	34	34	35	33	80	0	531
10	40	37	36	39	35	80	6	711
11	45	40	38	41	36	77.7777778	16	824
12	46	42	43	42	42	75	28	844
1	47	43	44	43	43	75	46	835
2	47	42	43	42	42	80	33	658
3	46	41	42	42	41	80	20	585.2
4	46	40	41	41	40	83.3333333	14	457
5	45	40	40	41	39	83.3333333	9	365.58
6	43	38	37	40	36	85.7142857	5	256.2

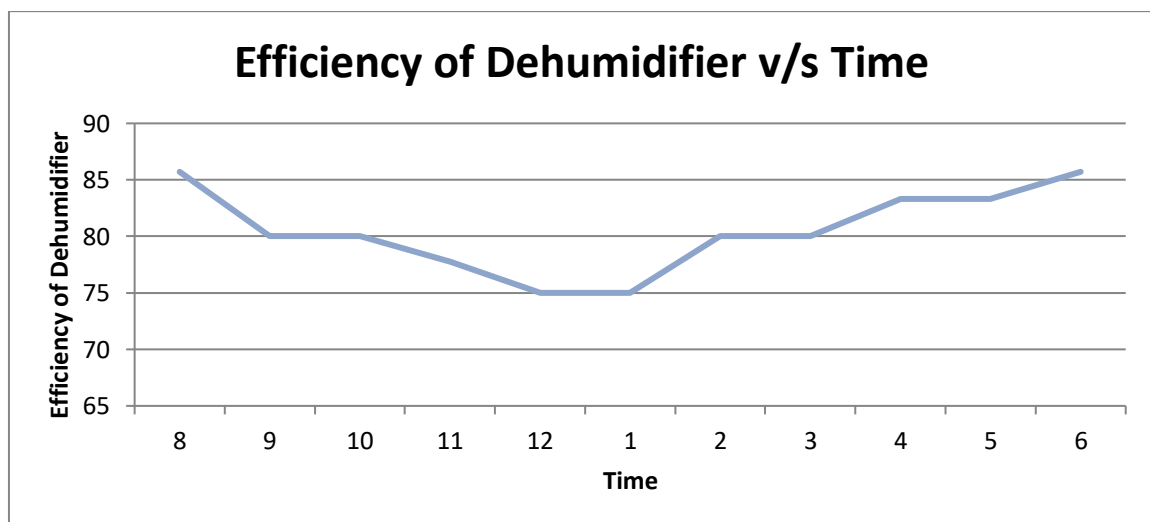


Figure 20 6/5/2016 Volume flow rate =0.033 m3/s

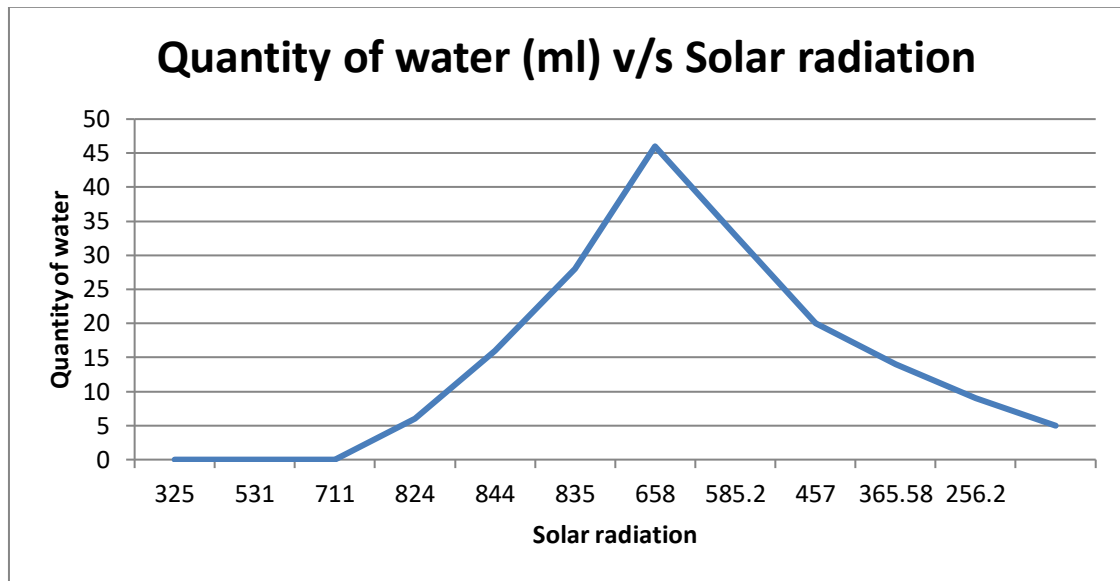


Figure 21 6/5/2016 Volume flow rate =0.033 m³/s

Table 10:7/5/2016 Volume flow rate =0.029 m³/s

Time	Dry Bulb temperature At dehumidifier inlet(°C)	Wet Bulb temperature At dehumidifier inlet(°C)	Dry Bulb temperature At dehumidifier outlet(°C)	Wet Bulb temperature At dehumidifier outlet(°C)	Air inlet temperature (°C)	Efficiency of Dehumidifier	Quantity of water(ml)	Solar radiation W/m²
8	34	33	28	33	27	85.7142857	0	232.36
9	38	36	33	34	32	83.3333333	0	340.5
10	41	38	37	38	36	80	6	479.38
11	44	41	40	42	39	80	9	647.78
12	46	42	43	42	42	75	25	743.32
1	46	41	44	44	43	66.6666667	43	766.1
2	50	44	44	42	42	75	32	730.35
3	49	44	43	42	41	75	19	657.29
4	46	43	41	41	40	83.3333333	14	526.78
5	45	42	40	38	39	83.3333333	8	389.41
6	43	41	37	36	36	85.7142857	5	325.28

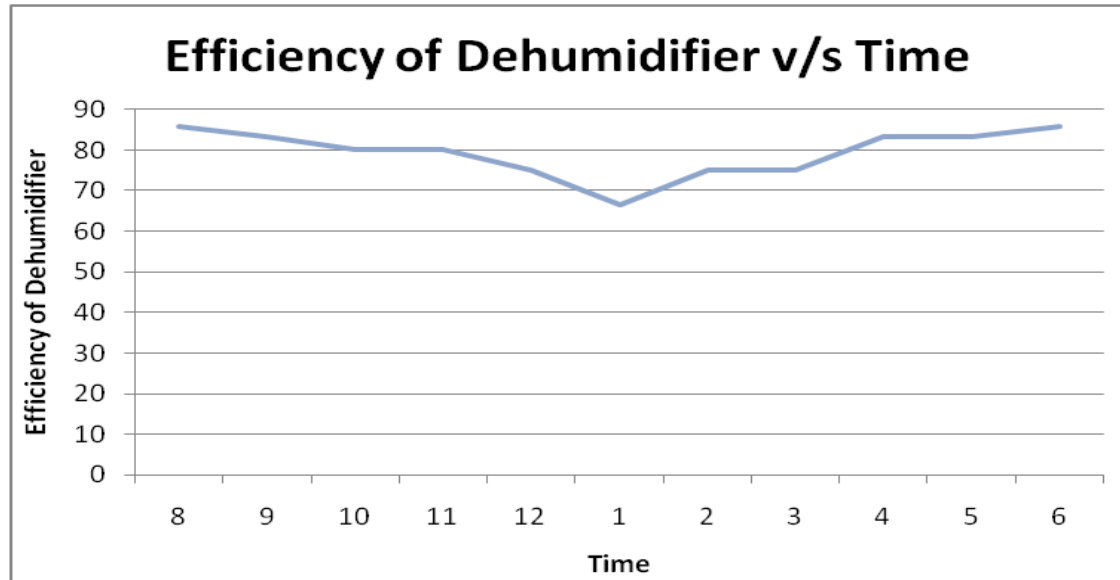


Figure 22: 7/5/2016 Volume flow rate =0.029 m3/s

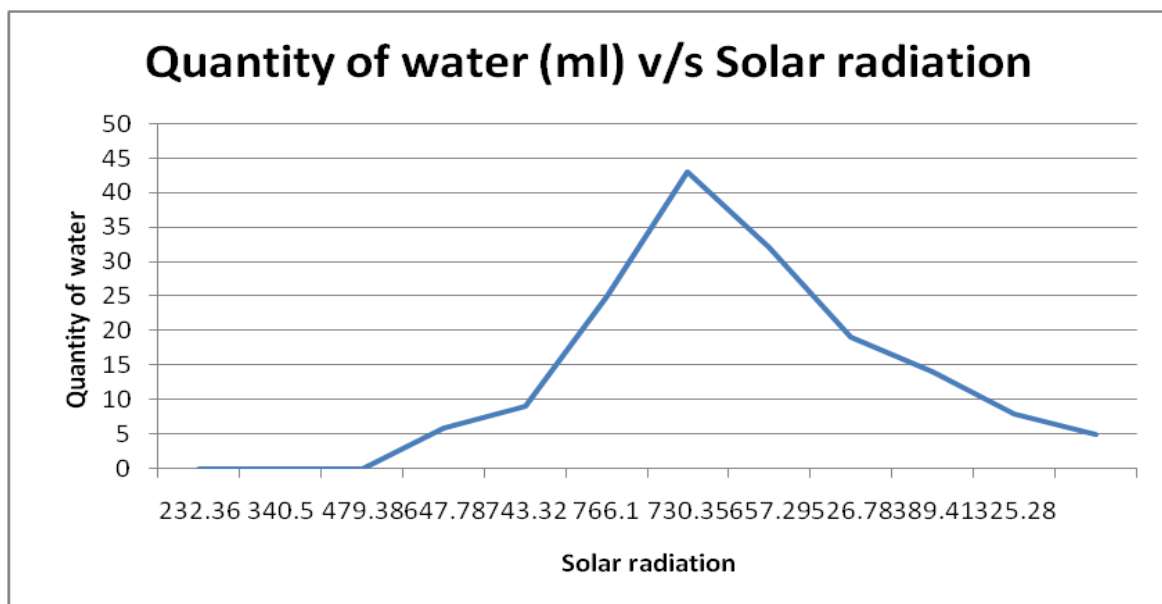


Figure 23: 7/5/2016 Volume flow rate =0.029 m3/s

Table 11:8/5/2016 Volume flow rate =0.026 m3/s

Time	Dry Bulb temperature At dehumidifier inlet(°C)	Wet Bulb temperature At dehumidifier inlet(°C)	Dry Bulb temperature At dehumidifier outlet(°C)	Wet Bulb temperature At dehumidifier outlet(°C)	Air inlet temperature (°C)	Efficiency of Dehumidifier	Quantity of water (ml)	Solar, radiation W/m2
8	37	32	32	32	31	83.3333333	0	215.51
9	38	34	34	34	33	80	0	362.28
10	40	36	37	38	36	75	8	522.36
11	42	37	39	39	38	75	15	779.07
12	43	38	41	40	40	66.6666667	27	851.16
1	45	41	42	41	40	60	35	889.65
2	47	43	44	42	42	60	27	860.9
3	46	44	43	41	42	75	18	731.78
4	45	43	41	40	40	80	9	561.21
5	44	42	40	39	39	80	7	395.211
6	43	38	38	37	37	83.3333333	2	299.19

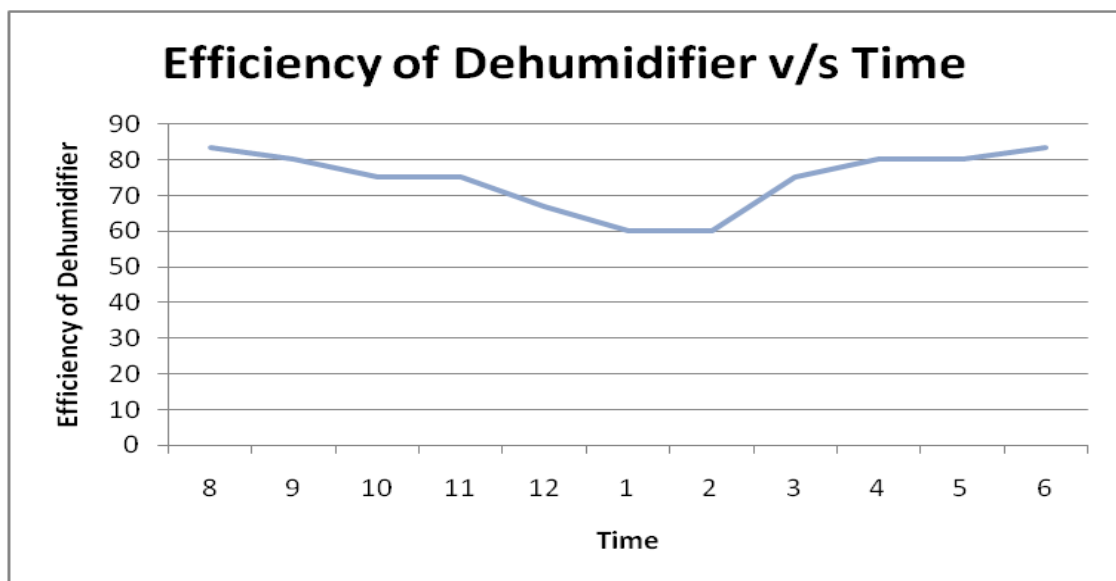


Figure 24 8/5/2016 Volume flow rate =0.026 m3/s

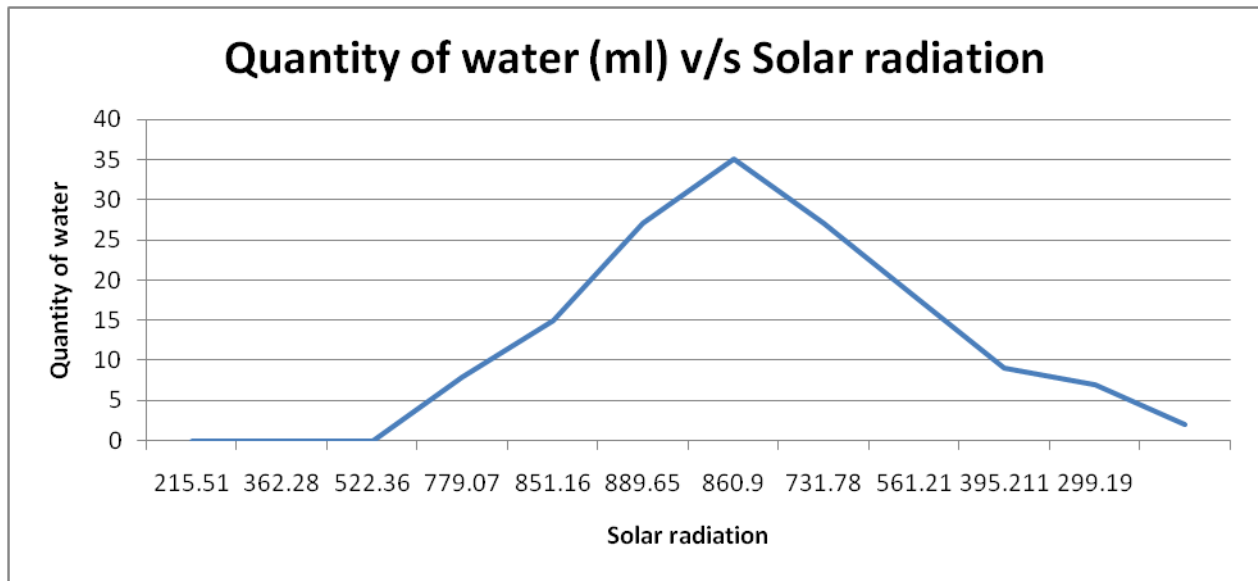


Figure 25: 8/5/2016 Volume flow rate =0.026 m³/s

Table 12:9/5/2016 Volume flow rate =0.0202 m³/s

Time	Dry Bulb temperature At dehumidifier inlet(°C)-	Wet Bulb temperature At dehumidifier inlet(°C)	Dry Bulb temperature At dehumidifier outlet(°C)/	Wet Bulb temperature At dehumidifier outlet(°C)	Air inlet temperature (°C)	Efficiency of Dehumidifier	Quantity of water (ml)	Solar, radiation W/m2
8	34	32	31	30	30	75	0	297.51
9	36	33	33	34	32	75	0	516.47
10	41	37	39	39	38	66.66667	7	703.86
11	45	40	42	43	40	60	11	833.82
12	47	42	44	43	42	60	20	877.62
1	47	42	44	43	42	60	31	844.2
2	46	42	44	44	43	66.66667	18	721
3	45	42	43	44	42	66.66667	11	599.4
4	44	41	42	43	41	66.66667	8	355.08
5	43	40	40	42	39	75	5	296
6	41	39	38	39	37	75	1	212

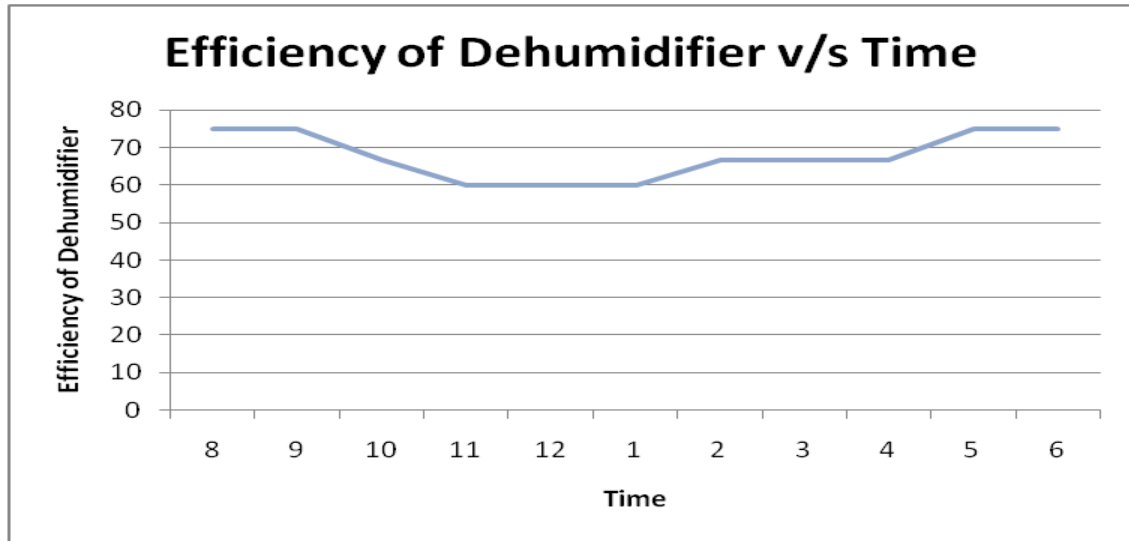


Figure 26 9/5/2016 Volume flow rate =0.0202 m³/s

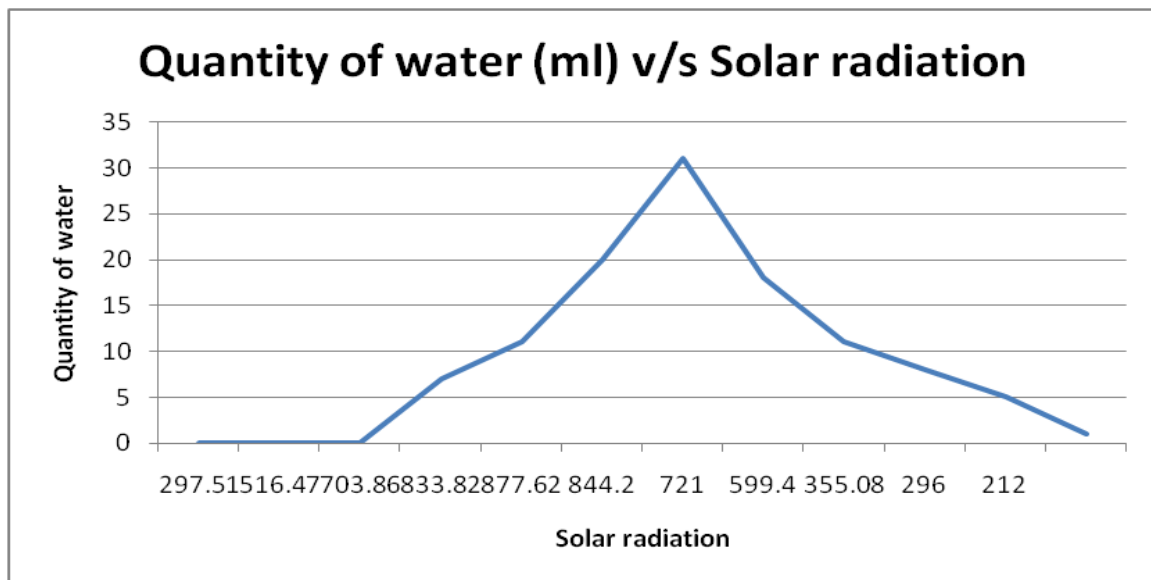


Figure 27 9/5/2016 Volume flow rate =0.0202 m³/s

8 Conclusion

For solar circular collector air heater, air inlet temperature increase and reach maximum temperature at noon then alleviate in the evening. Solar radiation v/s time graph shows that radiation higher at noon and its lower value at morning and evening. solar collector air heater efficiency higher at starting and end time of experiment, due to ambient condition its value lower at 10.00 am to 3.00pm.

Humidifier efficiency v/s time graph indicate that efficiency 8.00am to 12.00 noon diminish then it aggravate and reach maximum value in the evening.

Dehumidifier efficiency v/s time graph represent how efficiency change with time, also increase with air mass flow rate. Another graph of quantity of water v/s solar radiation, in the morning quantity of water is zero and then increase up to 1.00pm and reaches lower value in evening.

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