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Performance of Humidifier & Dehumidifier for close water and open air system (CWOA) with circular solar collector of Humidification-Dehumidification process

ANILKUMAR MOTIRAM PATEL[1],

[1]*Assistant Professor Department of Mechanical Engineering, Faculty of Tech.and Engg. The M S University of Baroda*
anilpatel0265@gmail.com

Abstract — Humidifiers and dehumidifier are heat and mass exchanger devices. It is used to transfer energy by both heat and mass simultaneously between two fluid streams at different temperatures and concentrations. Mass transferred will occur through the fluid streams when they come in thermal contact or direct contact They can exchange energy alternatively and intermittently where two fluid streams are flow through the same flow passages. The direct contact heat and mass exchange may be liquid-vapor type or gas-liquid type. Heat and mass transfer are also depending on the flow configuration. The air heated ,closed air cycle where the water in the humidifier cannot be cooled to a much lower temperature .result as air is not saturated The closed-water and open-air (CWOA) cycle which is air heated ,the wet bulb temperature is much lower and hence the water in the humidifier can be cooled to a much lower temperature. Also in dehumidifier humidifier air cool which result in condensation and fresh water production achieve .Thus, one might expect that the humidifier and dehumidifier effectiveness will influence the cycle performance, unlike in the closed air cycle. From the literature survey have been found that no attempts done to improve the cycle performance by modifying the humidifier as well as dehumidifier. Hence, the objective of this paper is to study of the thermodynamic behavior of humidifier to propose novel method for high-performance

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Keywords- *Humidification, Solar Radiation, Circular Solar Collector, Dehumidification, Air Heater, Dehumidifier, Exchangers, thermal balancing, humidifiers.*

1. Introduction

The simplest form of the HDH process divide in to three part (1) solar energy is used to heat an air /or water by heater, which work with;(2) an evaporator or a humidifier and (3) a condenser or the dehumidifier . The HDH process are two types one is an open air cycle with close water where the water is re circulated, and another type is open-water cycle with closed air where air is circulated in a closed loop between the humidifier and the dehumidifier. The air in these systems may be circulated by mechanical blowers. Also, these HDH systems are sub classified based on the type of heating used as water or air heating systems. The air heater at a higher temperature it can be observed that it is easier to raise the temperature of saturated air than at a lower temperature which can be seen from the properties of moist air So by a smaller heat input a given top temperature can be attained easily Also, the heat recovered ratio is high in the humidifier since the water stream is cooling he air stream (and humidifying it) in the humidifier. This cycle can be worked in two ways, closed air or closed water. We describe the open air cycle below.

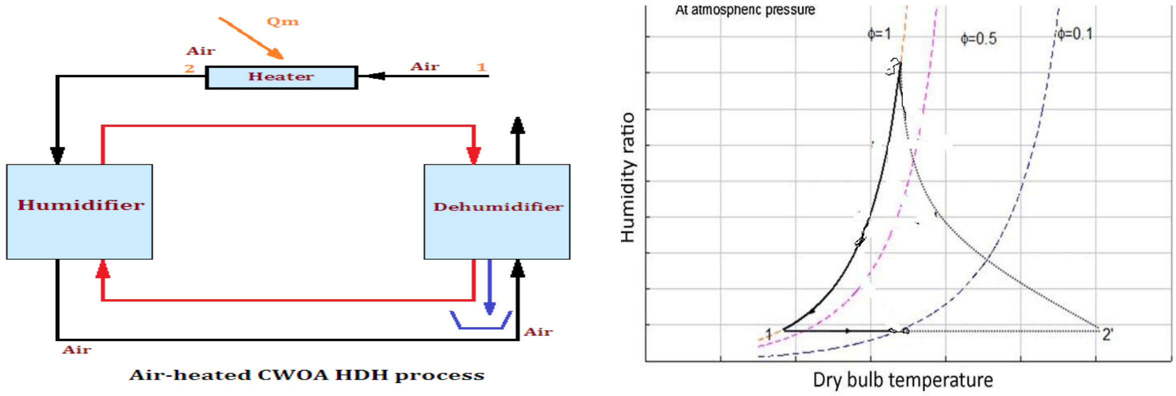

Figure 1 air-heated CWOA HDH process on psychometric chart

The air after getting heated in the solar collector (line 1–2) Air humidified in the evaporator (line 2–3) it is dehumidified in the condenser. Many such regions are found in the developing world in regions of high incidence of solar radiation available for 300 day in a year. For small-capacity water desalting for remote regions, lack of skilled personnel or erection and maintenance facilities. Several advantages of this technique can be presented which include flexibility in capacity, moderate installation and operating costs, simplicity, and possibility of using low-grade thermal energy (solar, geothermal, recovered energy or cogeneration).

2 Thermodynamic behavior of humidification dehumidification process on psychometric chart

Heating, humidifying and dehumidification process of air shown in H-X diagram which is also known as psychometric behavior on psychometric chart

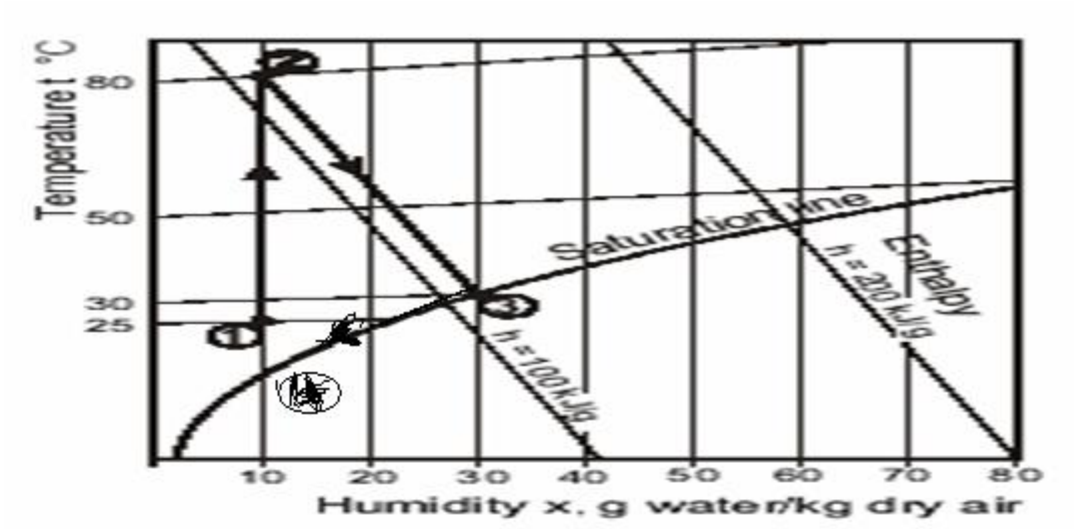

Figure 2 Heating, humidifying and dehumidification process of air on H-X diagram

An airstream with 25ºC and 10g of water per kg of dry air having initial humidity and initial temperature as shown in the chart at position (1), now it can be heated up to 80ºC which is gain position (2) and after injection of water adiabatically to increase its humidity up to 30g/kg of air and get humidified .Humidification process result in lower the temperature of air. 1 kg of dry air can carry 0.5 kg of vapor and about 670 kcal the vapor carrying capability of air increases with temperature when its temperature increases a certain quantity of vapor is extracted by air when flowing air is in contact with salt water which provide cooling. The humid air bringing with contact to a cooled surface and condensation of part of the vapor in the air takes place. On the other hand distilled water may be recovered

3 Principles of the HD Process

The HD process is based on the fact that the vapor carrying capability of air increases progressively with temperature. For example 1 kg of dry air can carry 0.5 kg of vapor when its temperature increases from 30 to 80°C.The HD unit is the distillation under atmospheric conditions by an air loop saturated with water vapor, and has three main sections: the humidifier, dehumidifier and heat source. In the humidifier, air and water, where one or both of them have been heated by an external heat source, are in contact and a certain amount of vapor, extracted by air. Hot and humid air leaves the humidifier and enters the dehumidifier. In this section, water vapor is distilled by bringing the humid air in contact with a cooled surface which causes the condensation of the vapor in the air and production of fresh water. The HD unit with a closed air cycle and water heating. Latent heat of condensation is used for preheating The HD process can be used in a closed or open air cycle. In an open air cycle, the amount of fresh air feed to the unit increases water productivity while the closed air cycle has the higher thermal efficiency. The next section is the heat source for providing the heat required for increasing air temperature and surface evaporation in the humidifier. In order to provide it air or water or both of them can be heated. Water heating techniques are more available and cheaper than air heating. Water heating system also leads to corrosion and decrease its efficiency .The HD process will be used in ambient pressure and there is no necessity for high temperature in the evaporation process. That is why a low-grade heat source such as solar energy or waste heat from other processes can be used. Solar energy is available in areas that need drinking water and as energy source is very.

Figure3 **Practical model of humidifier & dehumidifier for (CWOA) using circular solar collector of humidification-dehumidification process**

4 Mass balances in 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 , for which mass balance is given by,

$$\omega_3 m = \omega_2 m + m_v$$
$$m_v = m(\omega_3 - \omega_2)$$

Where specific humidity ω

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

And relative humidity ø

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

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

5 Energy and mass balances Dehumidifier

Energy and mass balances are applied to a segment of height Δy as shown in Fig.

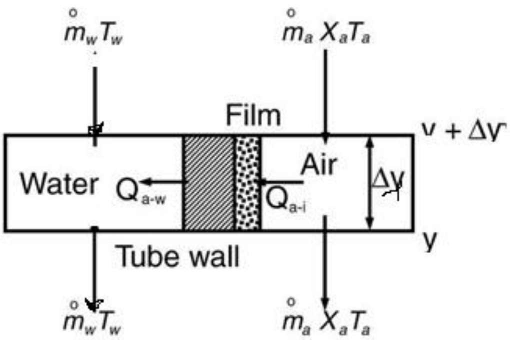

Figure4 . An element of the dehumidifier

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

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

The logarithmic mean $LMTDc = \frac{(Tac - Tcwo)(Tac - Tcwi)}{\ln\left(\frac{(Tao - Tcwo)}{(Tac - Tcwi)}\right)}$

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

$$Md = Ma(Wo - Wc)$$

Dehumidifier effectiveness η

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

Figure 5 humidifier & dehumidifier

6 Data collection

The temperatures of the water and air (dry and wet bulb) at different locations in the system were measured by using the PT100 RTD, connected to 8 channel digital temperature indicator recording device. One PT100 RTD, having a minimum scale division of 1°C was used to measure the ambient temperature. Wet-bulb temperature of the air was measured by using a specially prepared RTD. The accuracy of the millimeter is ±0.1%. The process air velocity and wind speed were measured by using a digital battery-powered mini thermo anemometer .The accuracy of the anemometer is ±2%. The mass flow rate of the process air was calculated by using the air velocity. An analog thermo hygrometer was used to measure the relative humidity of the ambient air. Response time of the hygrometer is one minute and its accuracy is ±2%

7 Result and discussion

The experimental setup was run from 21 Jan 2016 to 25 may 2016 during 8:00 am to 6:00 pm and from that excellent data collected for the result and discussion. The experiments are conducts by varying mass flow rate of air

Humidifier Performance

Table 1:24/4/2016 **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
1	8	35	25	10	44	33	32	1	93
2	9	43	29	14	37	37	35	2	87
3	10	50	32	18	34	40	38	2	84
4	11	52	35	17	31	44	41	3	83
5	12	53	35	18	29	46	43	3	82
6	1	54	36	18	29	47	43	4	78
7	2	55	35	20	27	48	44	4	79
8	3	51	34	17	31	47	44	3	83
9	4	49	33	16	34	46	43	3	84
10	5	47	32	15	37	45	43	2	85
11	6	43	30	13	40	41	39	2	87

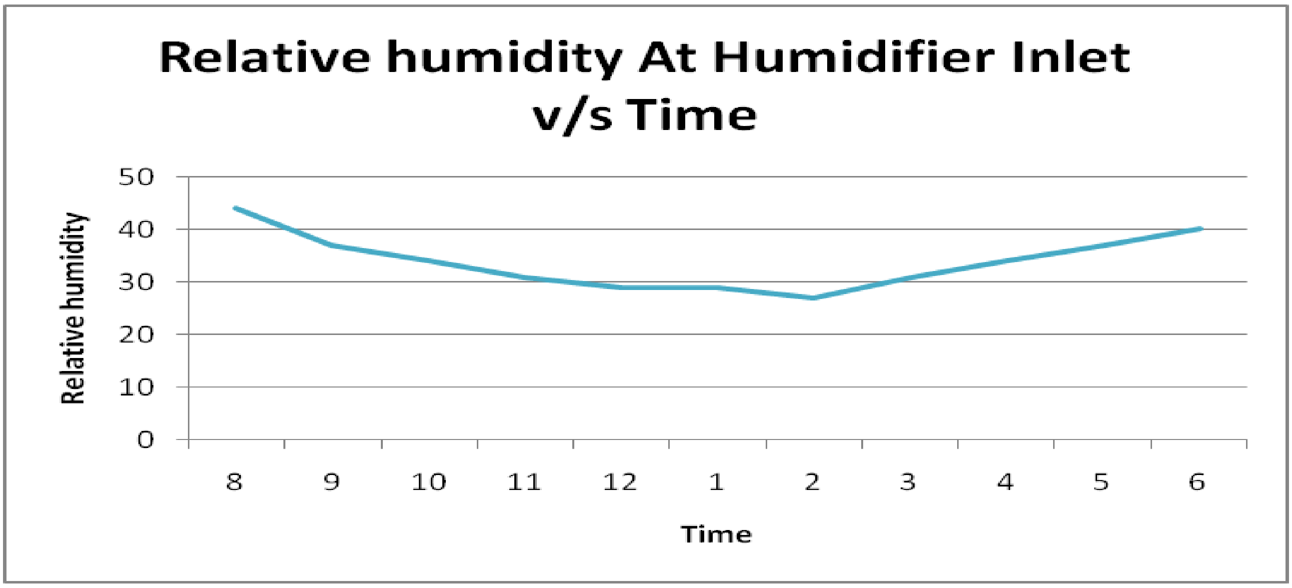

Figure 6 24/04/2016 Volume flow rate =0.033 m3/s

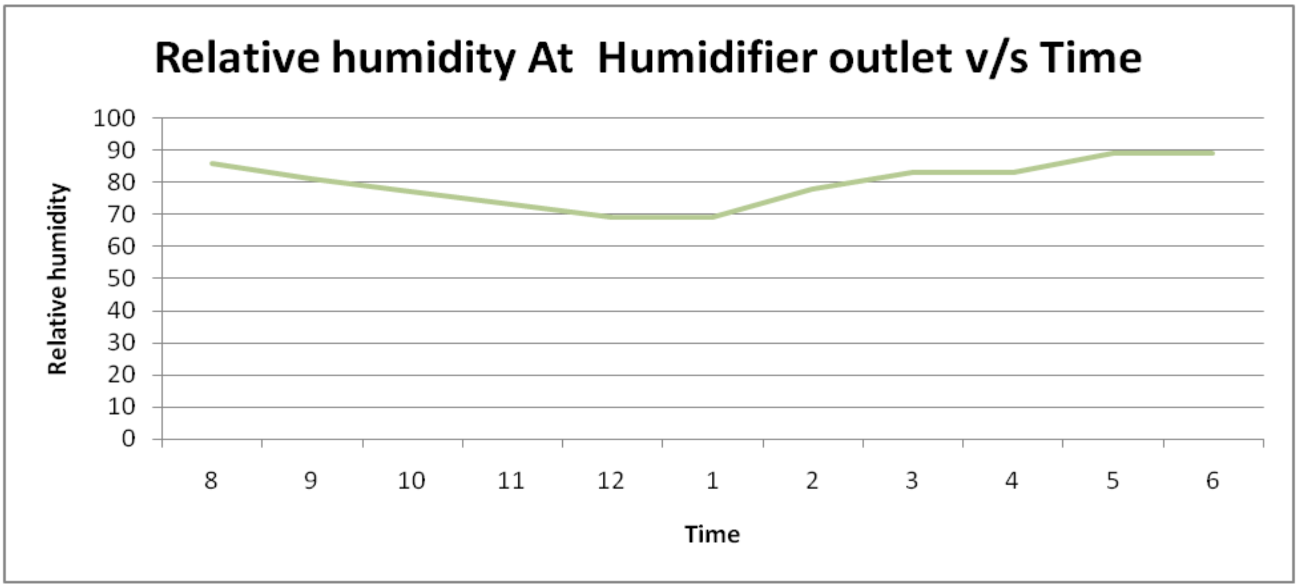

Figure 7 24/04/2016 Volume flow rate =0.033 m3/s

Table 2:25/4/2016 **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
1	8	34	21	13	31	33	32	1	93
2	9	43	26	17	26	37	35	2	88
3	10	48	29	19	26	40	37	3	83
4	11	49	30	19	26	44	41	3	83
5	12	52	33	19	25	46	42	4	78
6	1	53	33	20	24	47	41	6	70
7	2	54	34	20	24	50	45	5	75
8	3	53	33	20	24	49	46	3	84
9	4	50	31	19	26	47	44	3	86
10	5	47	29	18	27	46	44	2	89
11	6	44	26	18	28	44	43	1	94

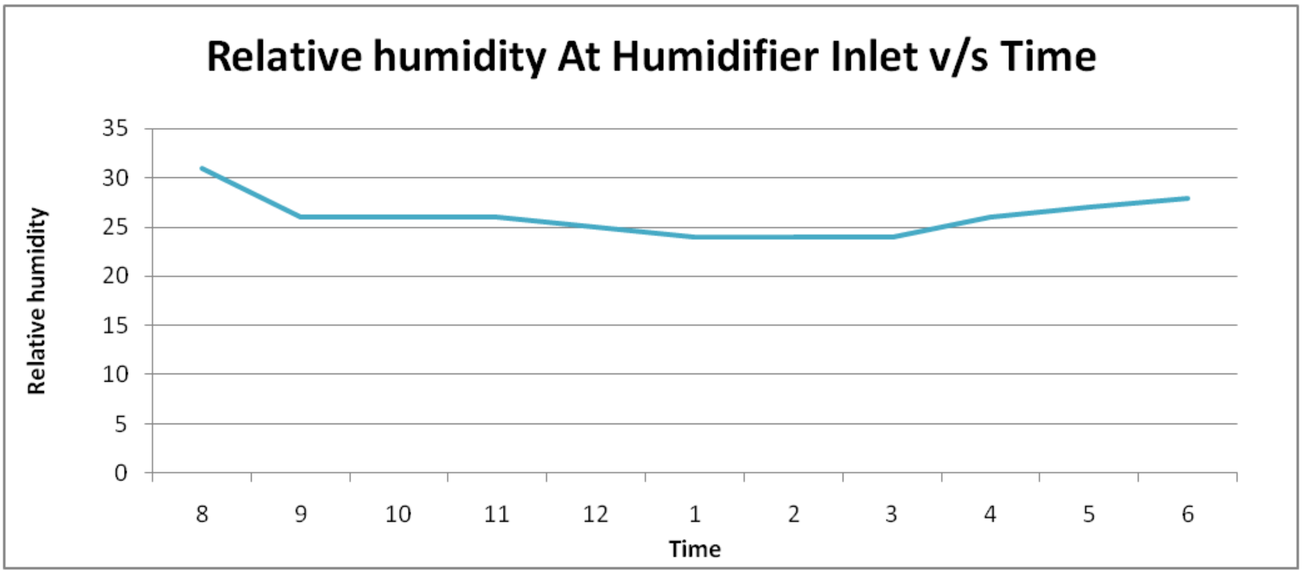

Figure 8: 25/04/2016 Volume flow rate =0.029 m3/s

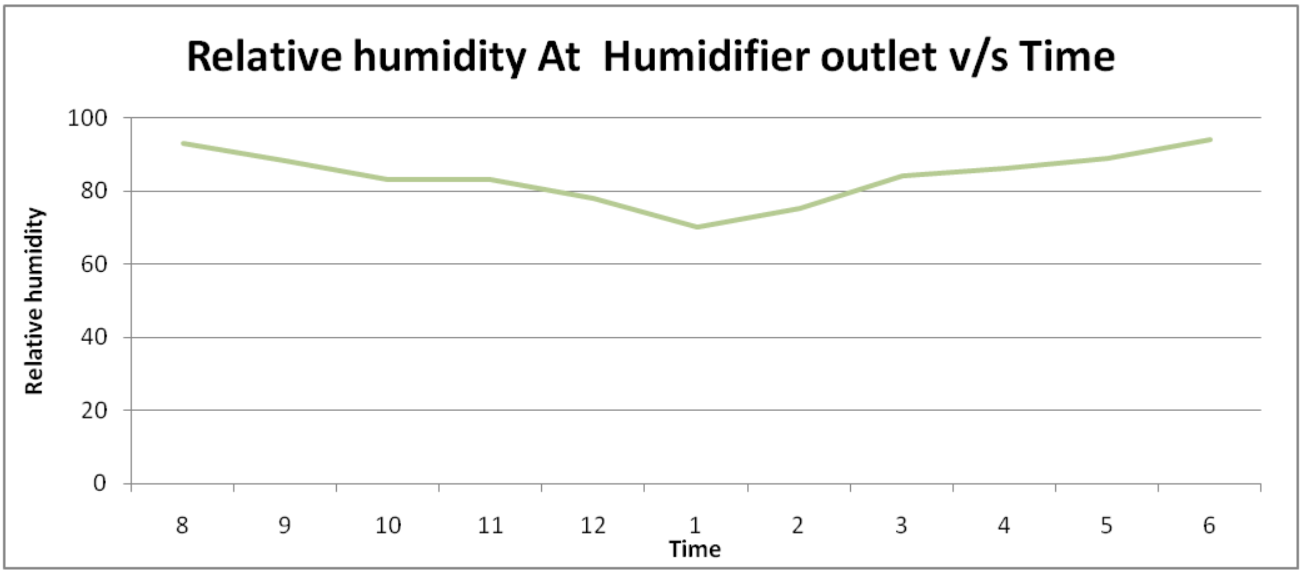

Figure 9: 25/04/2016 Volume flow rate =0.029 m3/s

Table 3: 26/4/2016 **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
1	8	37	26	11	40	34	33	1	93
2	9	44	30	14	37	36	35	1	93
3	10	50	34	16	34	40	37	3	82
4	11	51	36	15	34	41	37	4	78
5	12	53	37	16	33	44	38	6	69
6	1	55	37	18	32	46	41	5	73
7	2	54	35	19	26	47	43	4	79
8	3	52	34	18	32	47	44	3	84
9	4	51	34	17	33	46	44	2	89
10	5	50	33	17	33	45	43	2	89
11	6	43	30	13	35	40	39	1	94

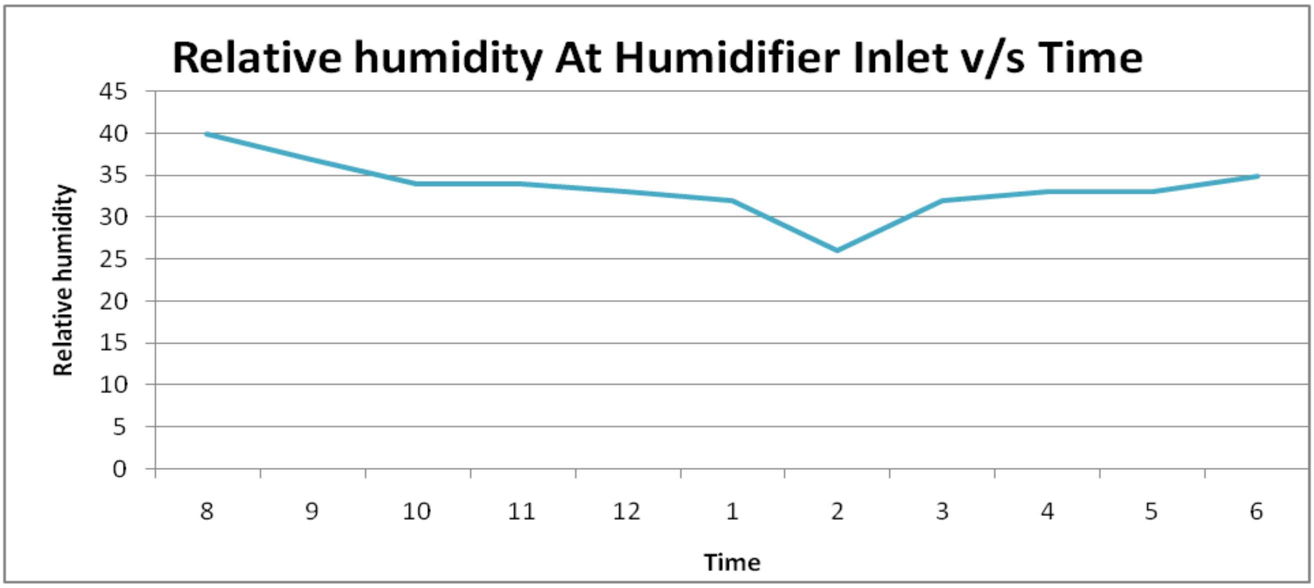

Figure 10: 26/04/2016 Volume flow rate =0.026 m3/s

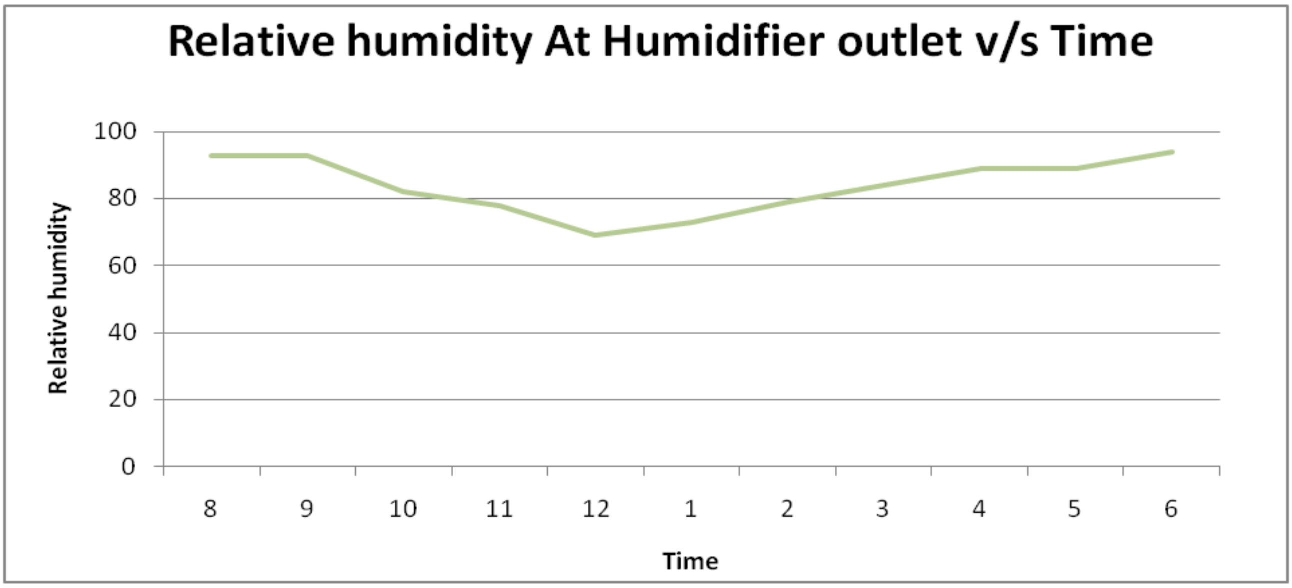

Figure 11: 26/04/2016 Volume flow rate =0.026 m3/s

Table 4 : 27/4/2016 **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
1	8	40	30	10	40	33	31	2	86
2	9	44	31	13	40	35	32	3	81
3	10	50	34	16	34	40	36	4	77
4	11	52	36	16	34	44	39	5	73
5	12	54	37	17	33	46	41	5	69
6	1	55	38	17	33	47	41	6	69
7	2	55	39	16	37	47	43	4	78
8	3	53	38	15	37	47	44	3	83
9	4	52	37	15	37	46	43	3	83
10	5	51	36	15	37	44	42	2	89
11	6	43	31	12	40	43	41	2	89

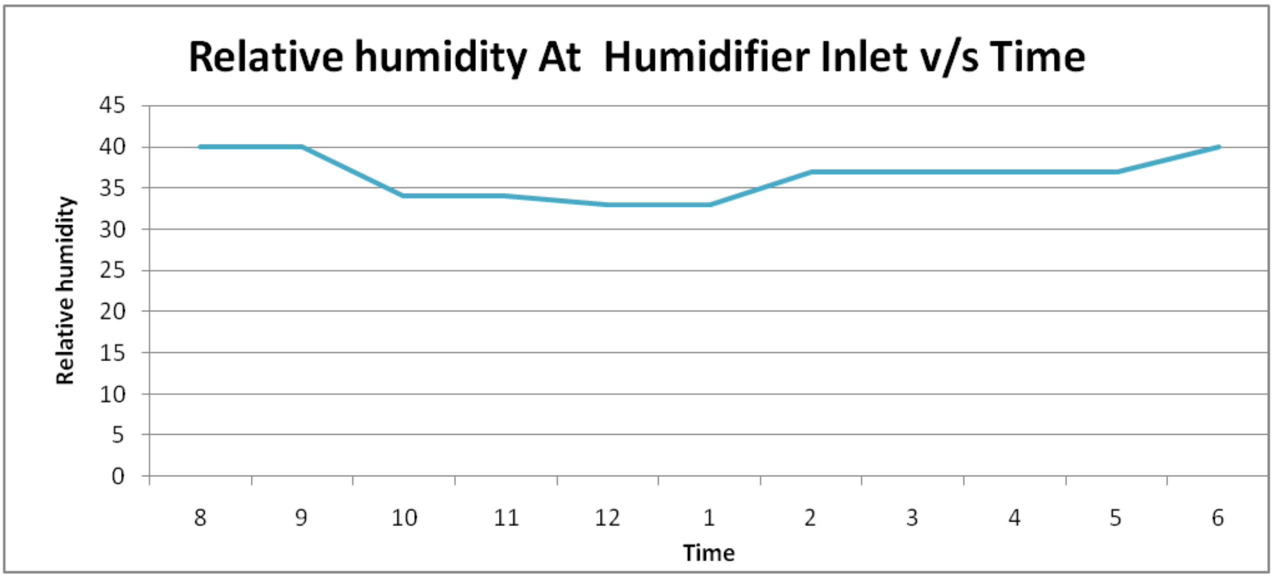

Figure 12 27/04/2016 Volume flow rate =0.0202 m3/s

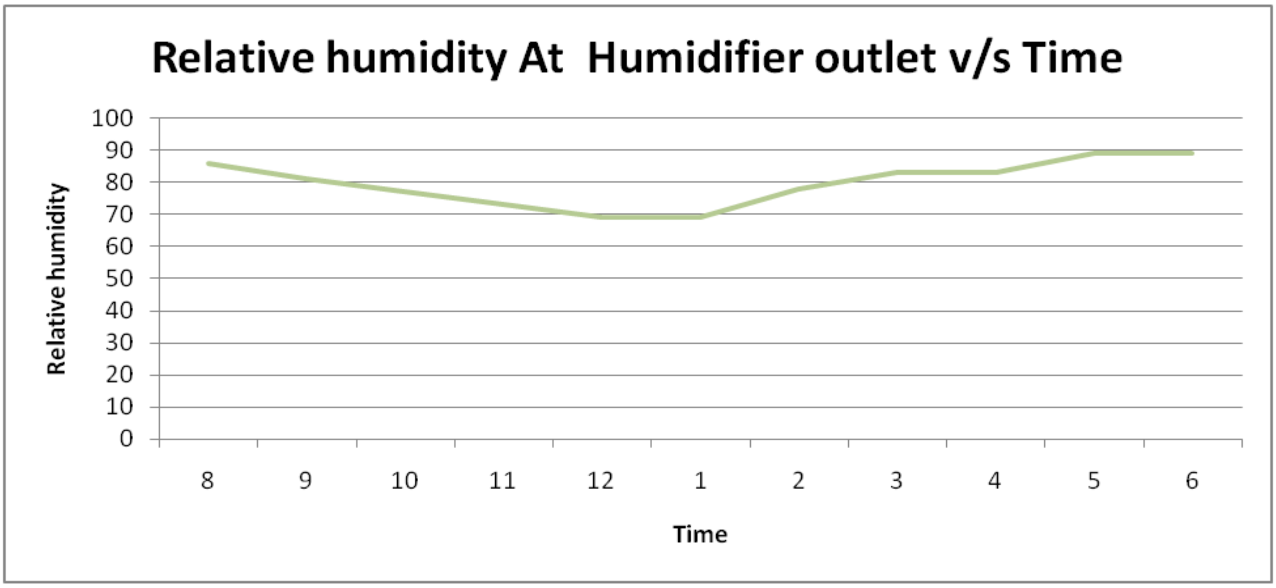

Figure 13 27/04/2016 Volume flow rate =0.0202 m3/s

Dehumidifier Performance

Table 5:24/4/2016 **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)
8	35	24	34	33	31	0.25	0
9	37	29	36	35	34	0.333333333	0
10	41	31	39	39	36	0.4	5
11	44	35	40	41	37	0.571428571	12
12	46	37	41	42	38	0.625	28
1	48	39	43	43	42	0.833333333	41
2	50	41	43	42	41	0.777777778	31
3	49	39	44	42	42	0.714285714	20
4	48	39	43	41	40	0.625	13
5	47	38	43	41	39	0.5	9
6	46	37	42	40	37	0.444444444	6

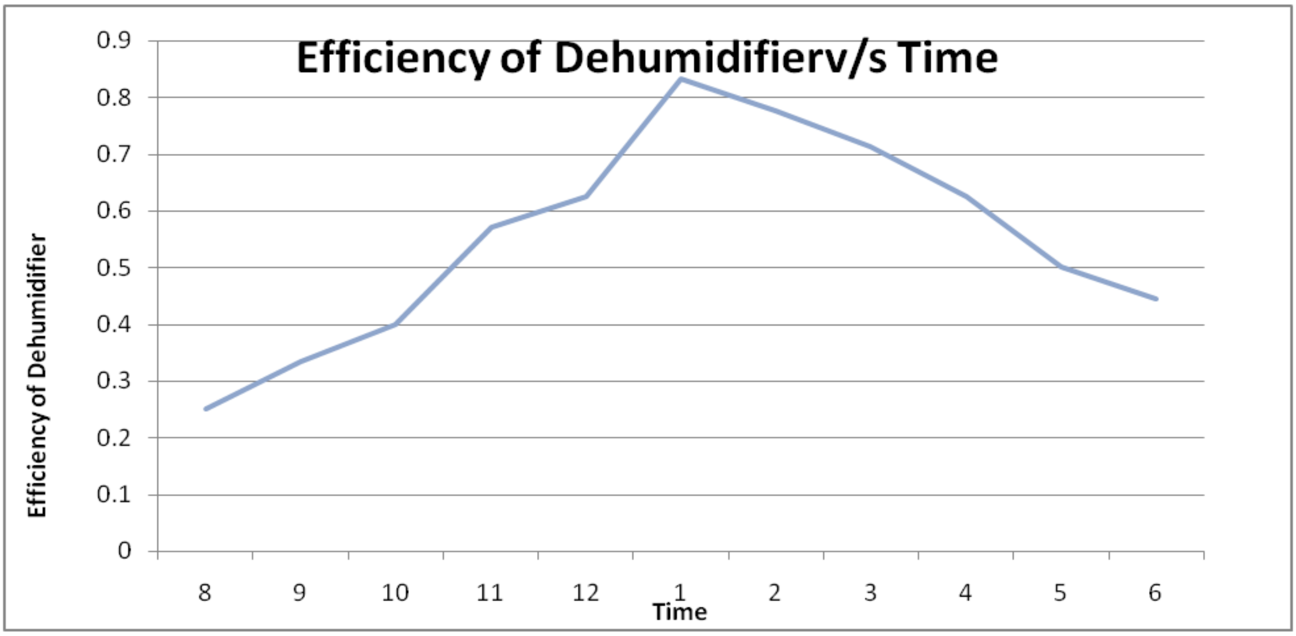

Figure14:24/4/2016 **Volume flow rate =0.033 m3/s**

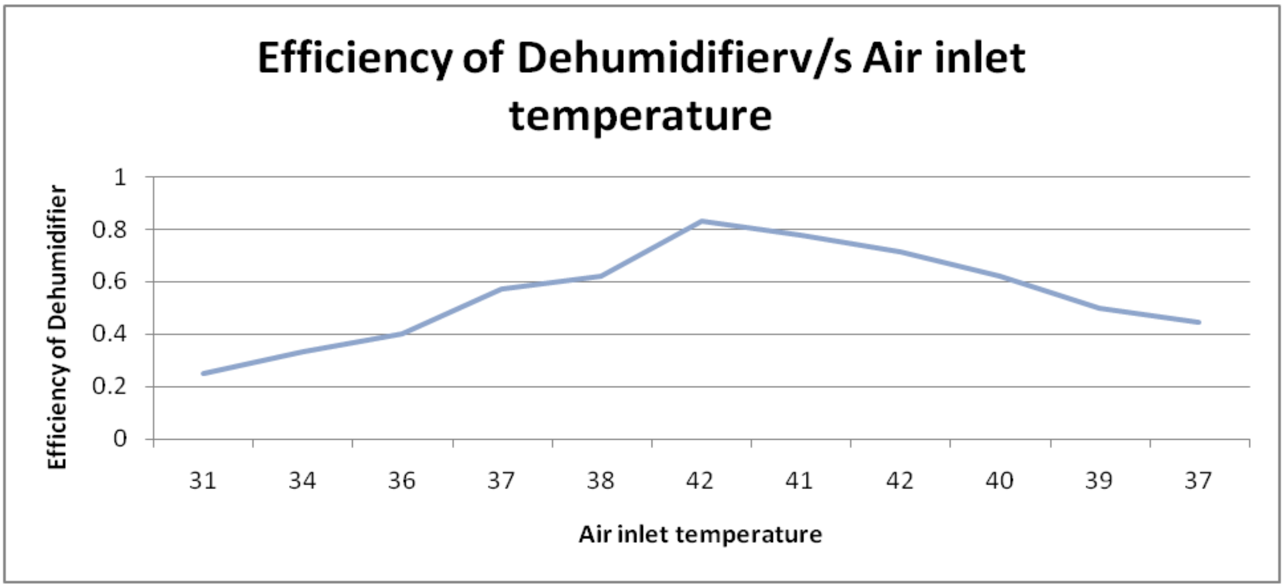

Figure15:24/4/2016 **Volume flow rate =0.033 m3/s**

Table 6:25/4/2016 **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)
8	35	25	34	33	29	0.166667	0
9	38	27	36	34	34	0.5	0
10	43	32	40	38	37	0.5	7
11	47	35	43	42	40	0.571429	11
12	49	37	43	42	41	0.75	29
1	50	39	43	44	42	0.875	40
2	46	39	43	42	42	0.75	31
3	45	38	42	42	40	0.6	21
4	44	38	41	41	39	0.6	11
5	42	37	40	38	37	0.4	6
6	40	35	38	36	34	0.333333	4

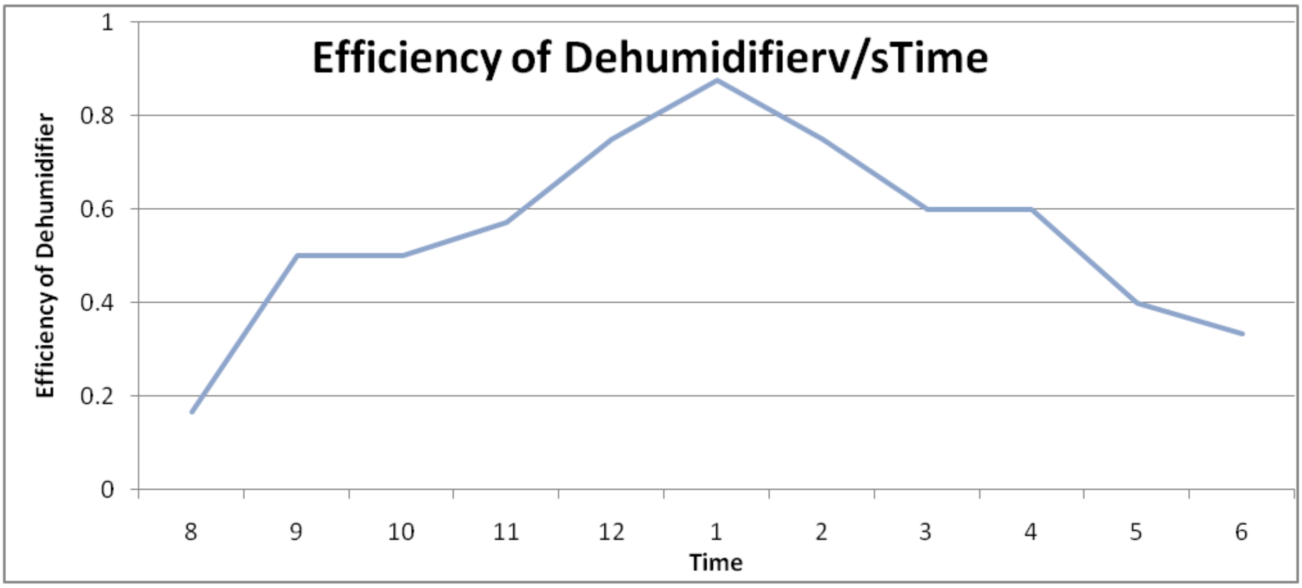

Figure16:25/4/2016 **Volume flow rate =0.029 m3/s**

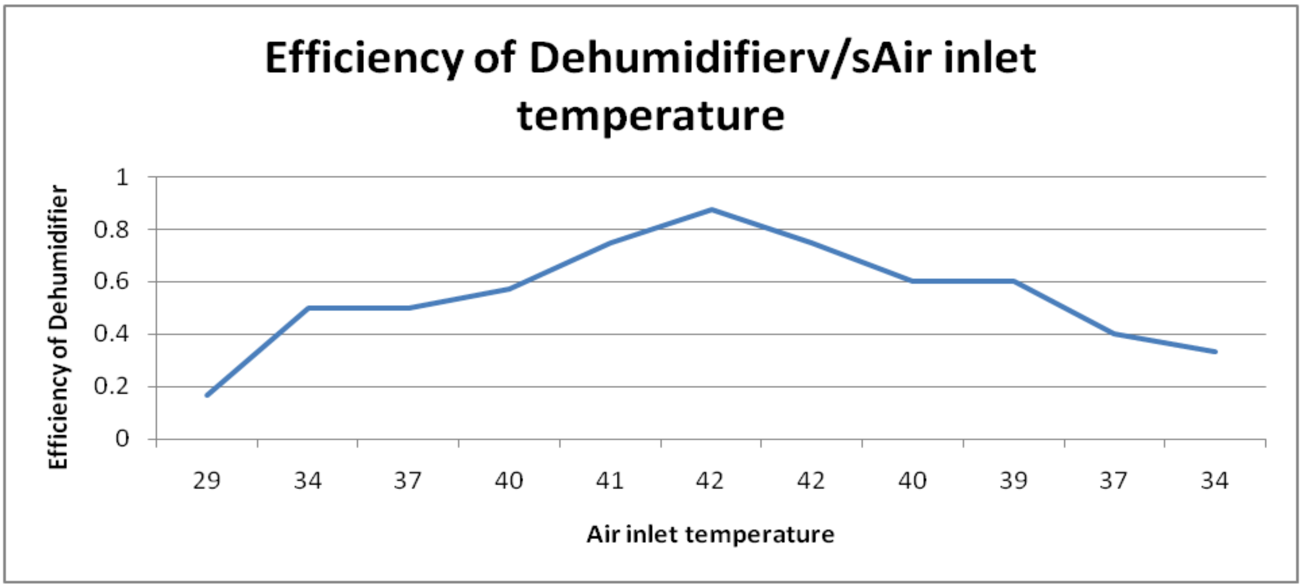

Figure 17:25/4/2016 **Volume flow rate =0.029 m3/s**

Table 7: 26/4/2016 **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)
8	35	25	33	32	29	0.3333333	0
9	37	28	35	34	32	0.4	0
10	41	32	39	38	37	0.5	8
11	43	34	40	39	38	0.6	16
12	45	36	41	40	39	0.6666667	28
1	47	38	42	41	41	0.8333333	38
2	48	39	43	42	41	0.7142857	32
3	47	38	43	41	41	0.6666667	23
4	45	38	41	40	38	0.5714286	18
5	43	37	40	39	37	0.5	11
6	41	36	38	37	34	0.4285714	4

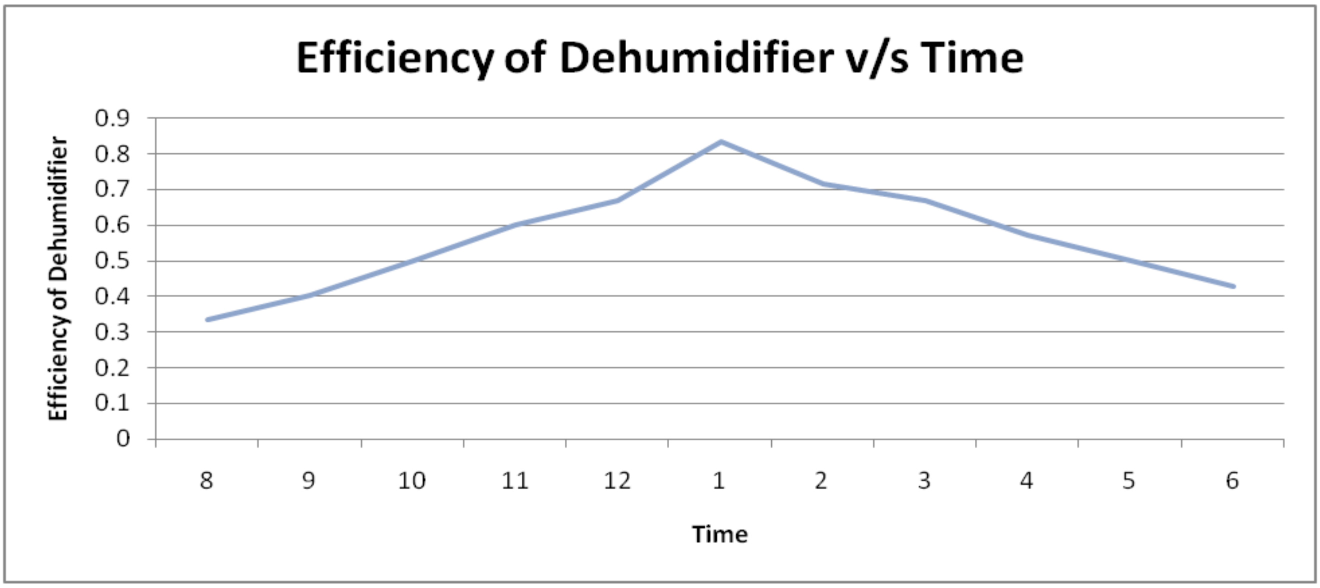

Figure18: 26/4/2016 **Volume flow rate =0.026 m3/s**

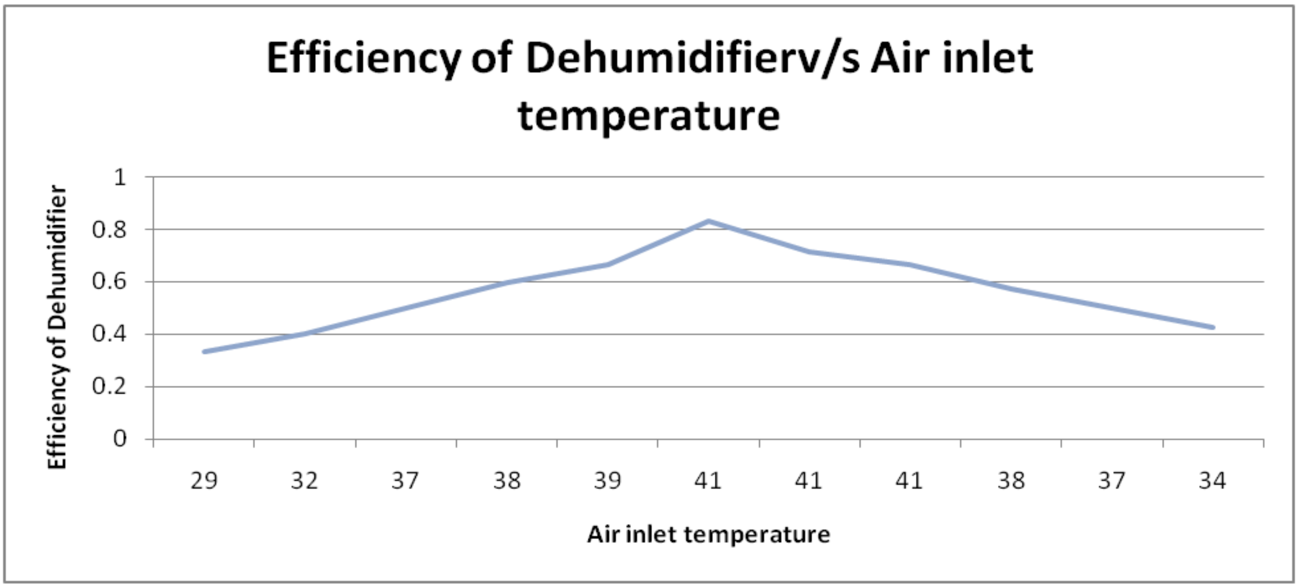

Figure19: 26/4/2016 **Volume flow rate =0.026 m3/s**

Table 8: 27/4/2016 **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)
8	31	26	30	30	28	0.333333333	0
9	38	30	36	34	33	0.4	0
10	41	33	39	39	37	0.5	7
11	45	37	42	43	40	0.6	11
12	46	38	44	43	43	0.666666667	25
1	47	39	44	43	43	0.75	31
2	48	38	44	44	42	0.666666667	21
3	48	37	45	44	43	0.6	14
4	47	37	44	43	41	0.5	11
5	45	36	43	42	40	0.4	5
6	42	35	41	39	39	0.333333333	2

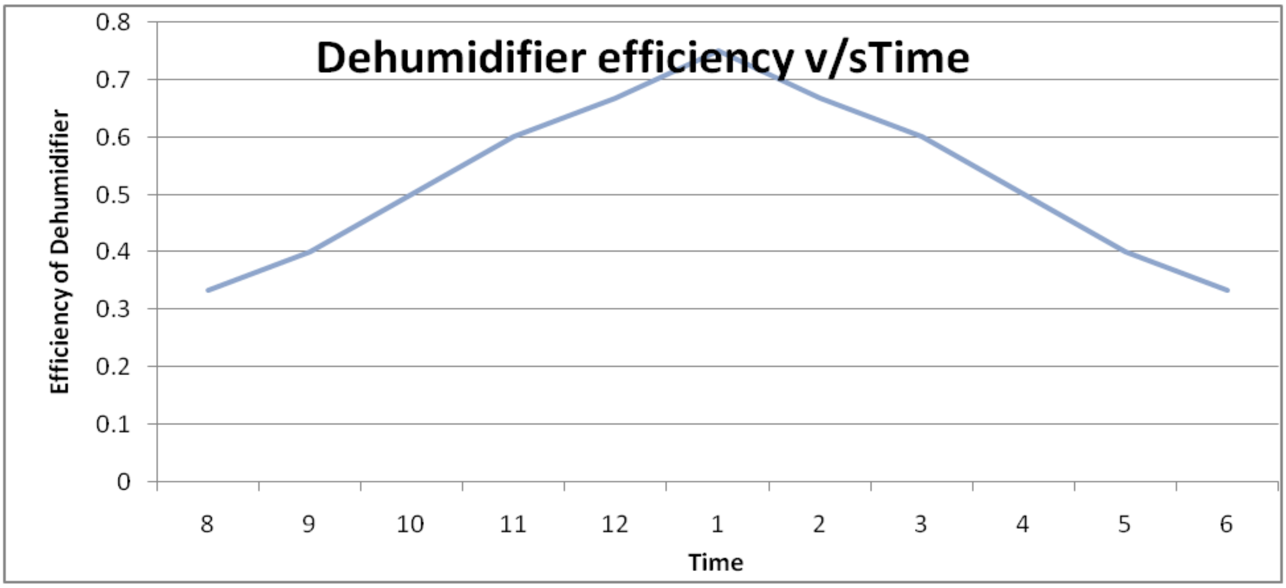

Figure20: 27/4/2016 **Volume flow rate =0.0202 m3/s**

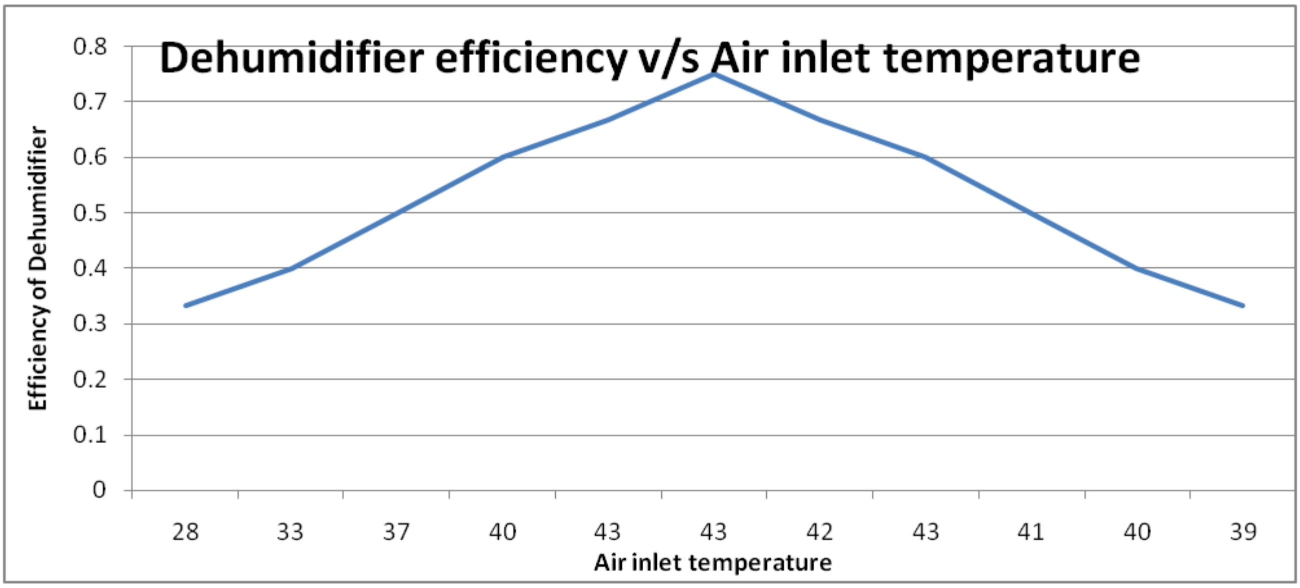

Figure 21: 27/4/2016 **Volume flow rate =0.0202 m3/s**

6 Conclusion

Graphs between Relative humidity At Humidifier Inlet to Time indicate that in the morning relative humidity is near 40 % then decrease up to 12 o'clock and afterward it is increase in the evening . Another graphs for Relative humidity At Humidifier outlet to Time shows that, humidity in the morning is near 90% and small change in it to noon then increase up to narrow with 93%.

Efficiency of dehumidifier increase from 8.00 to 12.00 noon and achieve maximum value then reduced to evening at 6.00pm.,in other graphs air inlet temperature increase efficiency of dehumidifier moderately increase at 1.00pm then decline in value The ambient condition also influence on the performance of humidifier and dehumidifier.

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