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Design &Development of humidification chamber with the help of solar circular collector for close water open air system (CWOA) humidification dehumidification process

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Abstract — *When the humidification-dehumidification (HD) process is used to produce fresh water, design of humidification chamber play important role with solar circular collector air heater and dehumidifier. A GI humidification chamber is developed without any insulation cover. The water is pumped by submersible pumps to the humidifier grass bed and then fall back on the bottom in small drops and hot air supplied by blower into the humidifier through four pipes from solar air heater. To study the effect of mass flow rate of air on evaporation rate, various experiments are conducts by varying mass flow rate of air by regulating speed of blower. It is observe that the evaporation rate is varying with different mass flow rate of Air. Also water temperature is influence on the vapor content difference and the humidification efficiency. In spite of the efficiency of the humidifier is obtained up to 90%.*

Keywords-*Humidification, Dehumidification, Circular solar collector, air heater , humidifier*

1. Introduction

Many devices are utilized for air humidification includingbubble columns spray towers,packed bed towers and wetted-wall towers [6]. The principle of operation for all of these devices is similar. When water is brought into contact with air which is not saturated with water vapor, water diffuses into air and increase the humidity of the air. The driving force for this diffusion process is the concentration difference between thewater vapor in air and the water-air interface . This concentration difference depends onthe partial pressure of water vapor in the air and the vapor pressure at the gas-liquid interface . Any of the above listed devices can be used as a humidifier in the HDHsystem.Spray tower used by Kreith [1]which is cylindrical vessel in construction where water is sprayed at the top of the vessel and air stream passing upward. In spray tower design, the diameter-to-length ratio is a very important parameter.Design of spray towers required the contact surface area of the water dropletsas well asknowledge of heat and mass transfer coefficients. The spray nozzles have High capacity but low efficiency, result of the low water hold-up due to the loose packing flow because small pressure drop on the gas side moderate pressure drop on the water side.Process 2-3 in a psychometric chart (Fig. 2) as show thatspecific humidity increases with small drop in temperature .The single Bubble column exactly opposite in principle to the spray towerstudied by El-Agouz and Abugderah [3].Air bubbles are ejected from several orifices located at the bottom of the vessel which is filled with water.. Many parameters such as bubble velocity bubble diameter,water and air temperatures , gas hold-up (the ratio of air bubbles-to-water volume), as well as the heat and mass transfer coefficients. It is also depend on geometrical factors such as thenumber of orifices orifice diameter, water head height and column diameter effect the performance.Wetted-wall towers was used by Muller-Holst et al. [4] where pipes are arranged in vertical position and water is loaded on the top of the tower. A well distributed flow of water around the inner perimeter of the tube , wets the inner surface of the tube in down direction of its length. Air flowing either co- currently or counter currently when a thin film of water is formed running downward inside a vertical pipe. Experiment was done byJ. Orfi [5]to increase saturation point of incoming hot air. Evaporator has a rectangular cross section of wood and horizontal in position. Five parallel plates made with wood and layer with textile (cotton) are fixed in the evaporator.Tubes are arrange on the vertical plates and the fiber glass is applied for insulation .The airand feed water are counter current. The vertical plates are wetted by capillarity action and finally the water is sprinkle by means of tubes with small holes set in them.The horizontal surface of the evaporator is covered by the hot water which provide better heat and mass exchange. Ben-Amara et al. [9] experimented the spray tower humidifier bykeeping the inlet water temperature and absolute humidity constant and varying the ratio of water-to-dry air mass flow rate . The water spray temperature (60°C)was less than the inlet air temperature (80°C) . They found that increasing the amount of water sprayed increased the absolute outlet humidity. In spite of, further increase in the water quantity resulted in air cooling and this led to condensation some of the water vapor content in the air. This means a decrease in the absolute humidity, although the outlet air is always saturated. Therefore, for air heated HDH cycles there is an optimum value of the mass flow ratio which gives maximum air humidity.Devices that contain packing material are known as packed bed towers and special types that are used to cool water are called cooling towers.. Packed bed towers have been used by many researchers as a humidifier device in HDH desalination systems because of the higher effectiveness. Different packing materials have been used as well (Table 6). The factors influencing the choice of a packing are its heat and mass transfer performance, the quality of water, pressure drop, cost and durability. Over the last 30 years, there has been a gradual change in the types of fill used in packed bed towers as indicated by Wallis &Aull [13]. The most dramatic change has been the introduction of film fills that provide significantly higher thermal performance through the increase of water-to-air contact area and a reduction in pressure drop. However, in HDH desalination application, due to high fouling potential, these benefits are forfeited and the older splash-type fill packing is used. [17]. To evaluate the performance of an air humidifier, an efficiency or effectiveness should be used. The maximum humidity difference in this definition assumes that the outlet air is saturated at the exit air temperature. This definition is basically used for evaporative coolers [18] where unsaturated air passes through a packing material wetted with water that is sprayed at the top of the packing. The sprayed water is circulated and at steady state condition its temperature reaches the wet-bulb temperature of the inlet air. In this case the air temperature decreases and it approaches the wet-bulb temperature. This humidifier efficiency cannot be used if the inlet air is saturated because there will be no humidity increase.Analysis of the conventional HDH includes design of the humidifier, these systems assumes steady state operation and negligible losses to the surroundings. Also, it is assumed that the air stream leaving the humidifierare saturated.

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2. Humidification process on psychometric chart

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 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.

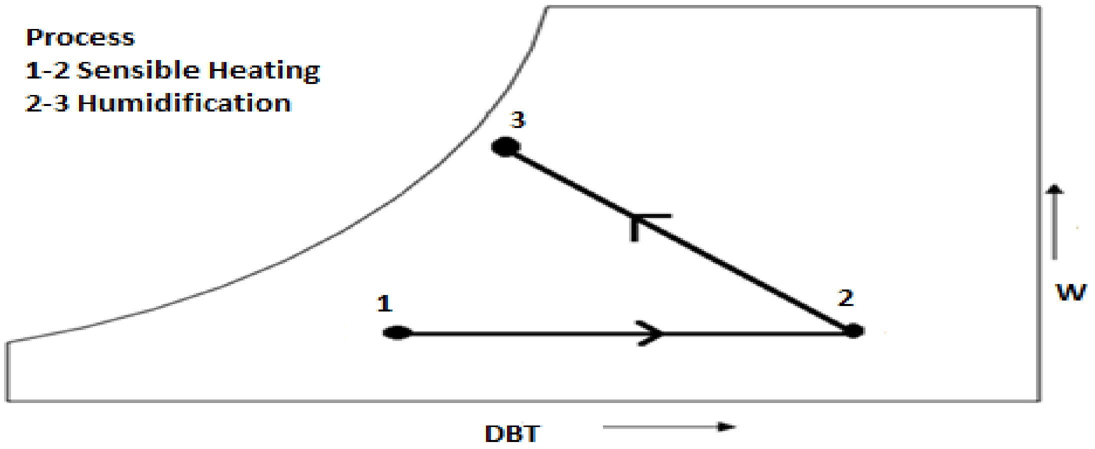

Fig.1 Humidification process on psychometric chart

3 Humidifier design

Humidification chamber is constructed from the galvanized iron sheet having thickness 2.5mm.It is sheared on hydraulic press in dimension such as 914 mm×305 mm, 610 mm ×305mm, 914 mm×610 mm .Humihification chamber fabricated by Arc welding process.Manualy four hole is done for air heater pipes where hot air enter in to the humidifier . Two ball valve provide for water in and out on chamber. Provison for submersible pump connection and water level indicator are installed .Mesh tray with grass pad arranged on top of the chamber. The sprinkling pipes are PVC pipes of 10mm diameter, in where pinholes are made at equal distances which result into small water drops .sprinkle pipe are placed on grass pad which connected to submersible pumpthrough flexible plastic pipes to circulates the water. All the corners and joints are seal by m-seal and white silicon sealant to make the system leak proof. A window with nut, bolt and asbestos gasket is provided for the maintenance.

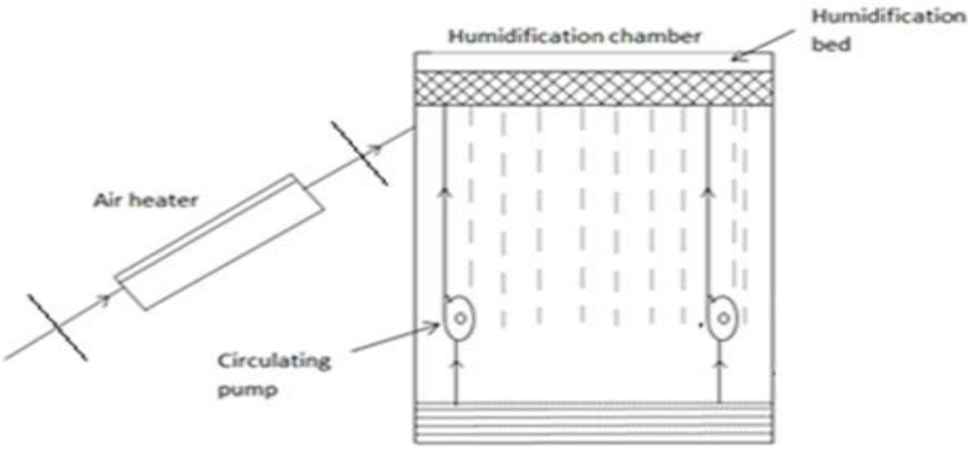

Fig.2 Schematics of solar assisted humidifier

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 result in increase relative humidity of air and get specific humidity ω_3 .

Which mass balance is given by,

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

Where specific humidity

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

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.

5Heat balance in humidifier

The following assumptions have been considered:

- The process is operating under adiabatic conditions.
- The water distribution over the packed bed is uniform
- The liquid and gas flows are steady state
- Heat and mass transfer coefficients are constant along the column
- A very thin layer of saturated air exists between the liquid and the gas streams

The heated air at outlet of solar collectors has to beentered inthe humidifying chamberOn the assumption that there is a balanced heat and mass transfer process between airflow and sprayed water flow, the water enthalpy reduction will be result in to the enthalpy increase of air. Therefore the exchange of heat will be governed by the heat balance equation:

$$m_L \dot{\Delta h}_L = cp_w \, m_w (t_{wi-} t_{wf})$$
$$\Delta \dot{h}_L = \frac{m_w}{m_L} cp_w (t_{wi-} t_{wf})$$

where m_L is air flow rate, kg/h; m_w _flow rate of water, kg/h;
$t_{wi\,-}$ Initial Water temperature, t_{wf} - Finalwater temperature
cpW specific heat of water, kJ/kg"K, Δh_L- enthalpy change of air flow, kJ/kg.

Assuming the same outlet temperature of air and water, the above equation must be solved by try and error, using the h-x-diagram in order to get ,Δh_L and water outlet temperature t_{wf}. The influence of the mass flow ratio water to air m_w/m_L on the efficiency of the humidification.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
ωout is outlet humidity ratio;ωin is inlet humidity ratio; and ωout,sat is outlet humidity ratio at saturation
.

Fig 3 Experimental model of humidification chamber with the help of solar circular collector for close water open air system (CWOA) humidification dehumidification process

6. Results and discussion

The experimental setup was run from 21 Jan 2016 to 2 may 2016 during 8:00 am to 5:00 pm and from that excellent data collected for the result and discussion. The experiments are conducts by varying mass flow rate of air,

Table 1: Effect of mass flow rate of air on water evaporation rate.

Date	Mass flow rate of air kg/hr	Water evaporates (kg/hr) during working hours									Total
		9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	(kg/day
25/4/16	300	0.53	1.38	1.76	1.96	2.10	2.56	2.44	2.17	0.17	15.06
21/4/16	240	0.42	1.10	1.41	1.57	1.68	2.05	1.95	1.74	0.40	12.31
22/4/16	200	0.31	0.69	1.00	1.09	1.29	1.52	1.56	1.45	0.24	9.15
24/4/16	100	0.30	0.61	0.74	0.87	0.93	1.03	1.02	1.00	0.37	6.87

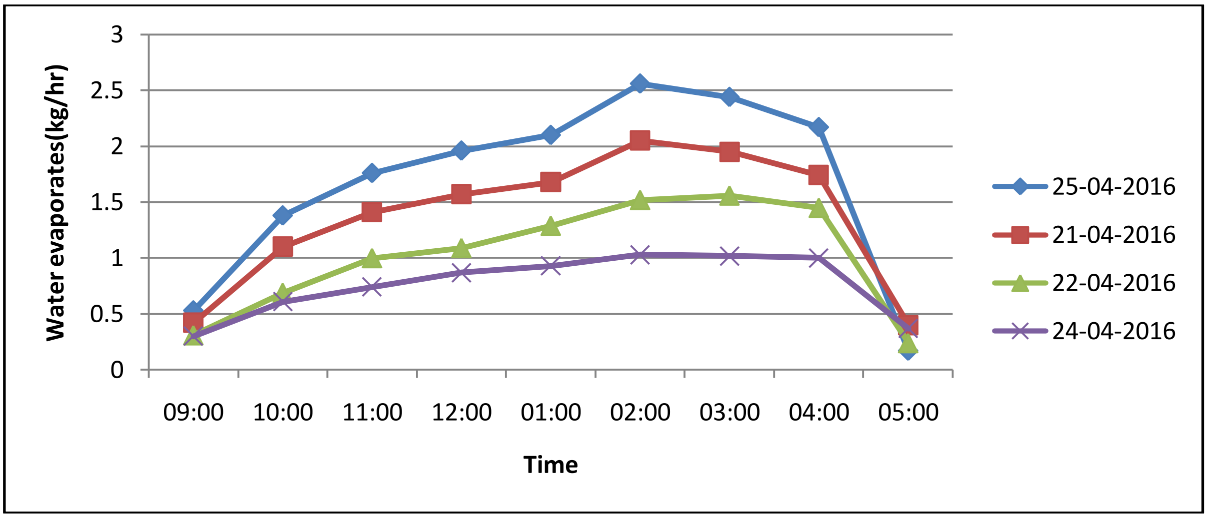

Fig 4:Effect of mass flow rate of circulating water on evaporation rate.

It is notice that evaporation rate of water is increase with increase in mass flow rate of air. Figure 1 is the graph of evaporation rate v/s working hours for different mass flow rate of air. In addition, it is seen that evaporation rate achieve during working hours 1:00 pm to 3:30 pm is higher compare to other working hours.

At mass flow rate 300 kg/hr of air, evaporation rate achieve is highest up to 15.06 kg/day. Table 1 shows the evaporation rate for different working hours at different mass flow rate of air.

Table 2:Air Mass flow Rate 300Kg/hr

Sr.No.	Time	Air outlet temp (DBT) (°c)	air outlet temp.(WBT) (°c)	Water temp (°c)	Air inlet temp.DBT (°c)	Air inlet temp.(WBT)(°c)
1	7:00	27	26	29	30	29
2	8:00	28	27	31	38	37
3	9:00	29	28	34	42	41
4	10:00	35	34	37	46	45
5	11:00	52	39	48	50	48
6	12:00	51	42	47	53	51
7	1:00	50	43	50	55	54
8	2:00	45	40	44	56	55
9	3:00	41	39	41	55	54
10	4:00	38	36	39	53	52
11	5:00	36	25	28	50	49

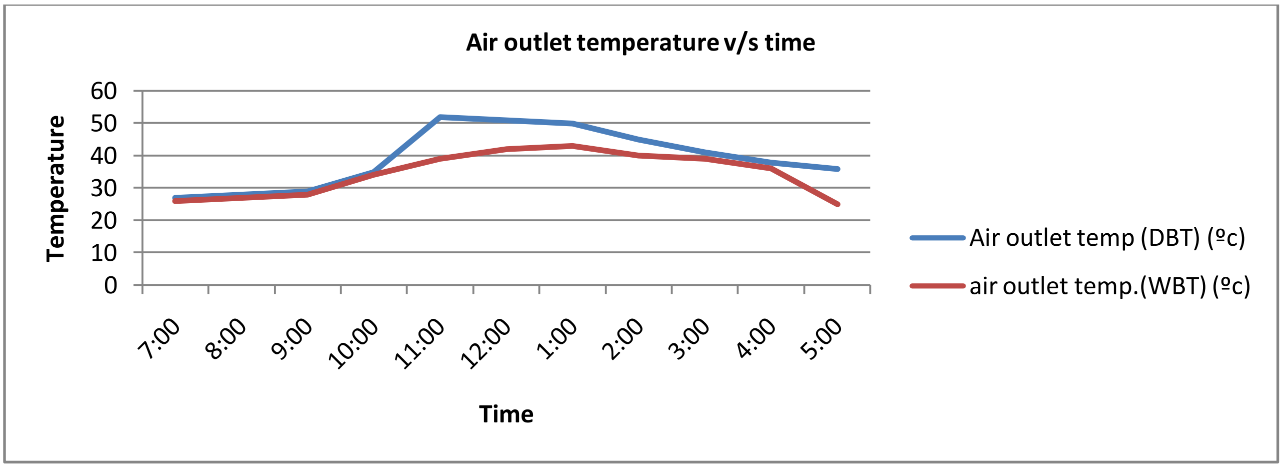

Fig 5:Air Mass flow Rate 300Kg/hr

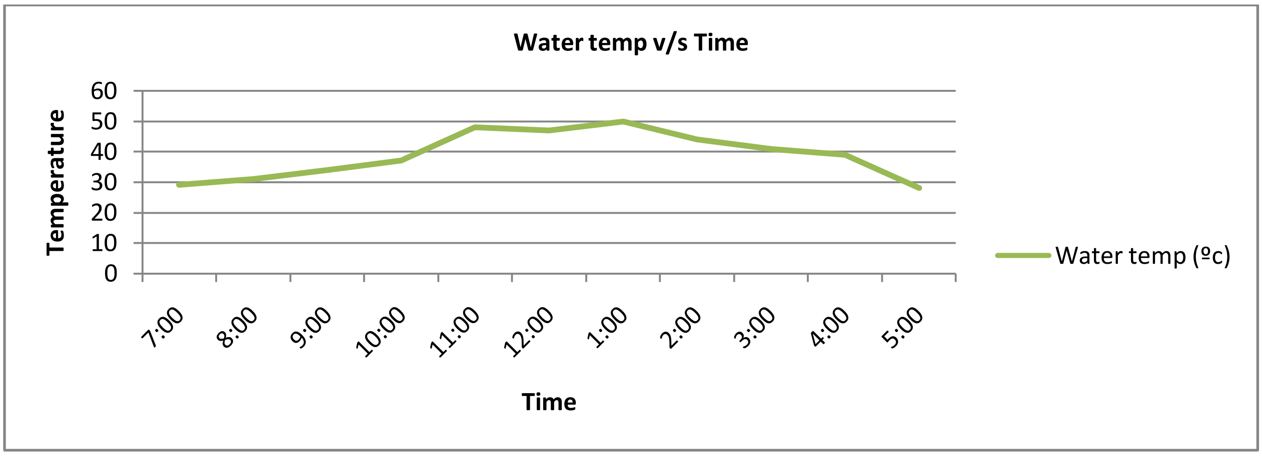

Fig 6:Air Mass flow Rate 300Kg/hr

Table 3:Air Mass flow Rate 240Kg/hr

Sr. No	Time	Air Outlet Temp.(DBT)(ºC)	Air Outlet Temp.(WBT)(ºC)	Water Temp.(ºC)	Air inlet Temp.(DBT)(ºC)	Air inlet Temp.(WBT)(ºC)
1	7.00	28	26	27	29	28
2	8:00	29	27	29	37	35
3	9:00	34	31	34	43	42
4	10:00	49	44	39	51	50
5	11:00	50	46	42	55	53
6	12:00	51	47	43	56	55
7	1:00	50	45	42	58	57
8	2:00	42	39	39	59	57
9	3:00	39	35	36	56	55
10	4:00	38	34	25	52	50
11	5:00	35	31	24	49	48

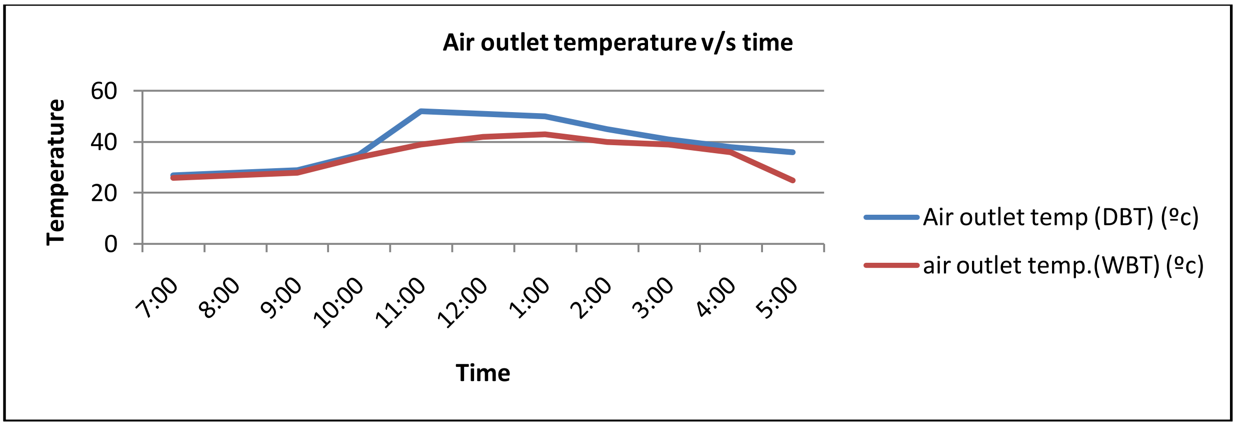

Fig 7:Air Mass flow Rate 240Kg/hr

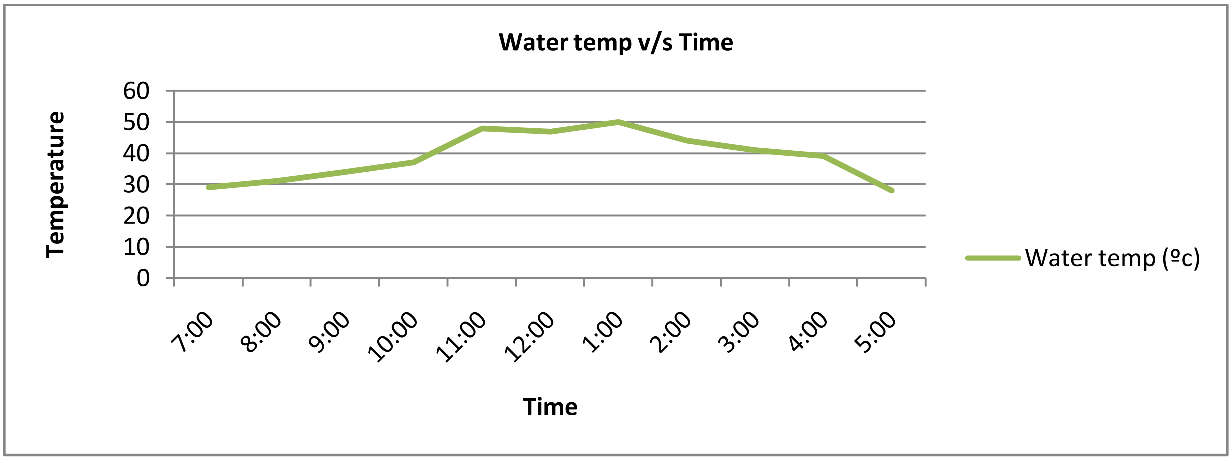

Fig 8Air Mass flow Rate 240Kg/hr

Table 4:Air Mass flow Rate 200 Kg/hr

Sr. No	Time	Air Outlet Temp.(DBT)(ºC)	Air Outlet Temp.(WBT)(ºC)	Water Temp.(ºC)	AIR inlet DBT (ºC)	Air inlet Temp.(WBT)(ºC)
1	7.00	26	25	27	30	28
2	8:00	28	26	29	39	37
3	9:00	33	30	34	47	46
4	10:00	48	44	39	51	50
5	11:00	52	48	42	56	54
6	12:00	53	47	43	58	56
7	1:00	48	46	41	59	57
8	2:00	41	37	39	57	55
9	3:00	38	35	36	56	54
10	4:00	37	30	25	54	52
11	5:00	34	29	24	49	47

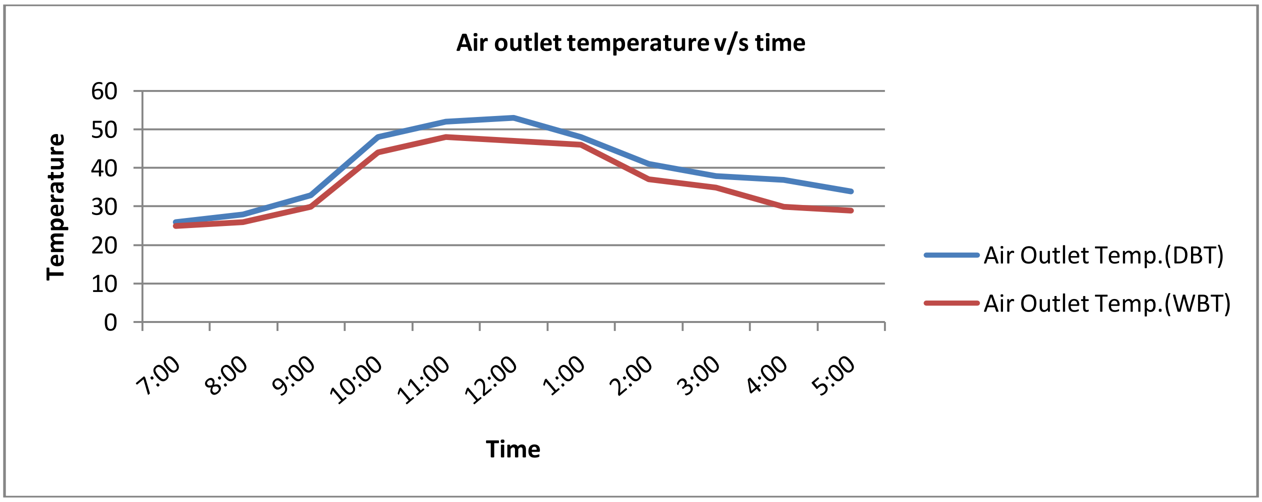

Fig 9Air Mass flow Rate 200 Kg/hr

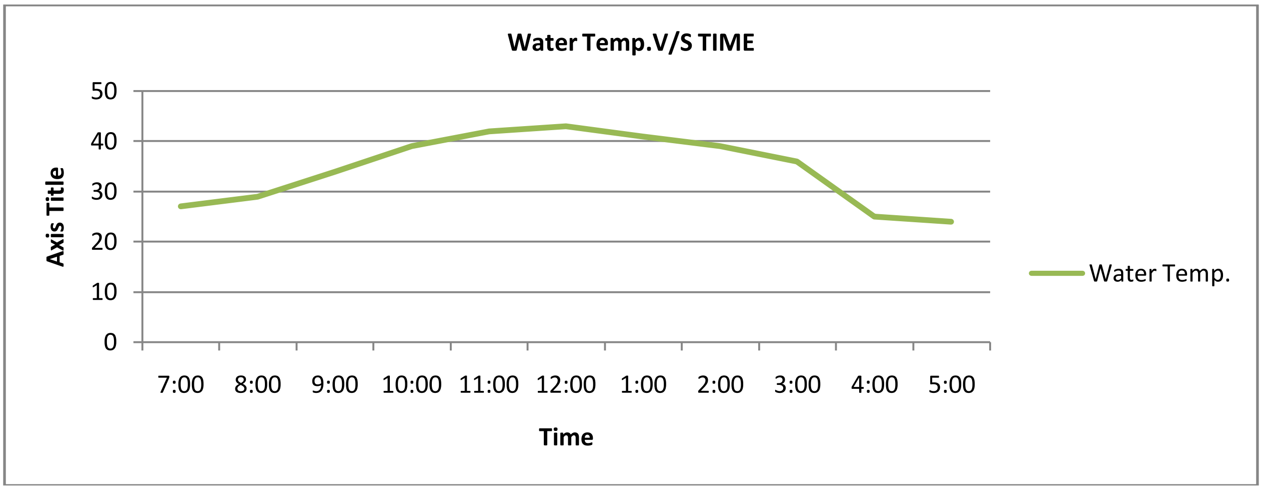

Fig 10:Air Mass flow Rate 200 Kg/hr

Table 5:Air Mass flow Rate 100 Kg/hr.

Sr.No.	Time	Air Outlet Temp (DBT) (ºC)	Air Outlet Temp.(WBT) (ºC)	Water temp (ºC)	AIR inlet Temp.DBT (ºC)	Air inlet Temp.(WBT(ºC)
1	7.00	26	26	29	30	29
2	8:00	28	27	30	38	37
3	9:00	29	28	33	42	41
4	10:00	36	34	36	45	45
5	11:00	45	39	47	49	48
6	12:00	49	42	48	52	51
7	1:00	50	43	50	55	53
8	2:00	45	40	45	56	55
9	3:00	41	38	41	54	53
10	4:00	37	32	38	52	51
11	5:00	36	25	28	50	49

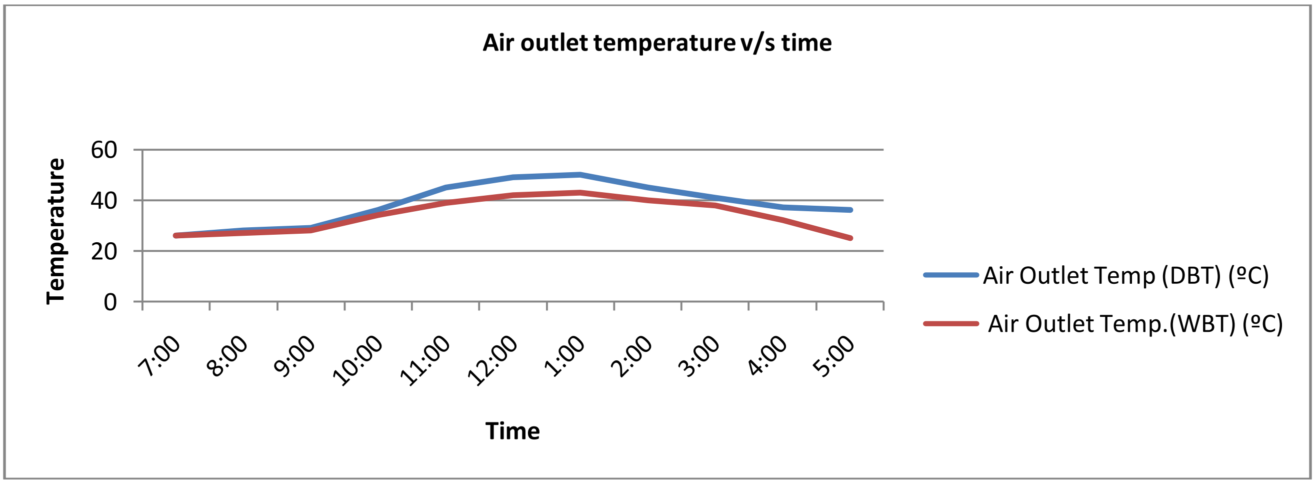

Fig 11:Air Mass flow Rate 100 Kg/hr

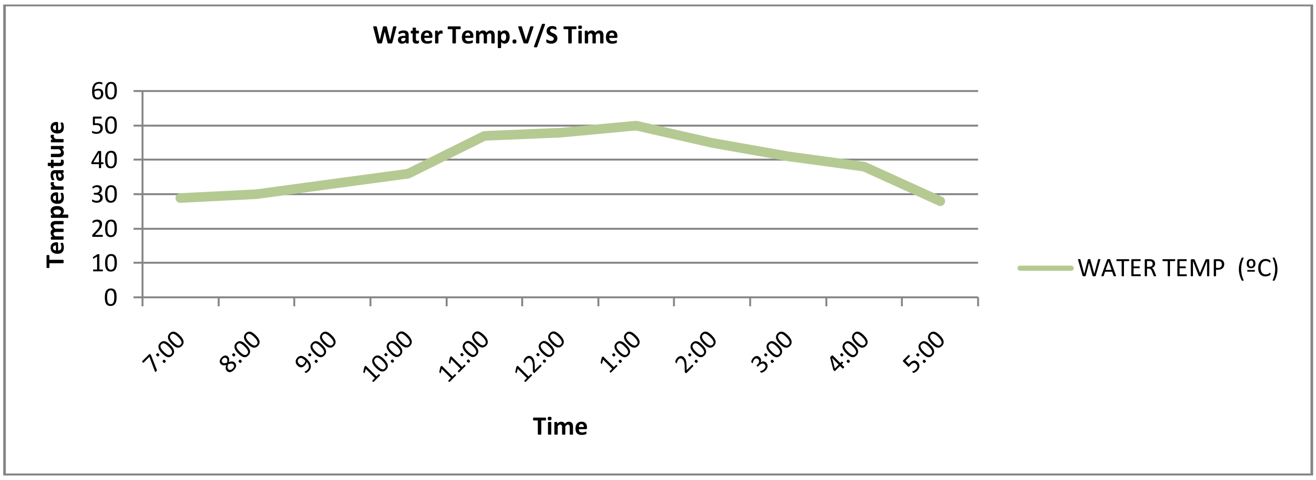

Fig 12:Air Mass flow Rate 100 Kg/hr

Air outlet temperature v/s time

In the graph, time taken on the X axis and air outlet temperature of the humidifier on Y axis. There are variation in DBT and WBT which indicate that air humidified in humidifier and maintains the same difference between them. It is observed that the humidity increases drastically and found to be maximum in11.00 to 3.00 pm. We can conclude that during the starting of the day time it is seen during 8:00 to 10:00 a parabolic trend of outlet air temperature, this nature then goes on to attain its increasing position and reaches its maximum temperature at 11:00. This then decreases gradually till evening.The maximum difference between DBT and WBT is seen during 12:00 to 2:00 temperature because of the reason that at this point the maximum heat exchange takes place

Water temperature v/s time

This graph is plotted for the water temperature v/s time , this reason can be attributed to the mere fact that water, when comes in contact with hot air in humidifier, takes some heat from the hot air and in turn gives some of the moisture and coldness to the air, this is very much similar to a heat exchanger process. This is the most influential reason for the increasing water temperature .The water temperature reaches its peak point not at 12:00, but at 1:00. This confirms that it is similar to that of a heat exchanger. This also gives us an practical idea of the air temperature may not be at its peak, the heat exchanger process between water and air can yet be at its best position.

Conclusion

Important interesting inference, which was found out that the heat exchange ,always highest during 1.00 pm because water temperature at that time higher inside the humidifier. The effect of the air mass flow rate on the efficiency of the humidifier can be seen.The efficiency of humidifier η dependent on the air velocity and the length of the humidification chamber which have been find out and take into account .

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