SOLAR DESALINATION BY HUMIDIFICATION-DEHUMIDIFICATION PROCESS USING AIR AS THE WORKING FLUID.

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R7 – Aplicacoes de baixa Temperatura

Abstract

Libya is a country with about 90% of its land occupied by desert. It faces a significant problem with the water shortage which may increases slowly but surely each year. The quality of the available water is questioned due to the high salt content and therefore the water used for domestic proposes should be subject to some type of treatment. Solar desalination process seems to be a good solution, due to the fact that Libya has high solar intensity and this process uses cost free energy and causes practically no ecological damage to the environment. Solar desalination processes use collected solar energy for direct heating and evaporating of salty water to gain distilled water. In this study a Humidification-dehumidification of salty water distillation system is designed, constructed and tested in the solar energy laboratory of Alzwyia University, Sabratha Engineering College, Sabratha Libya. The obtained results are presented in a graphical form showing the affect of various design, geometrical and operational parameters on the system performance.

Keywords: Solar collector; Humidification–dehumidification; Desalination; and experimental work

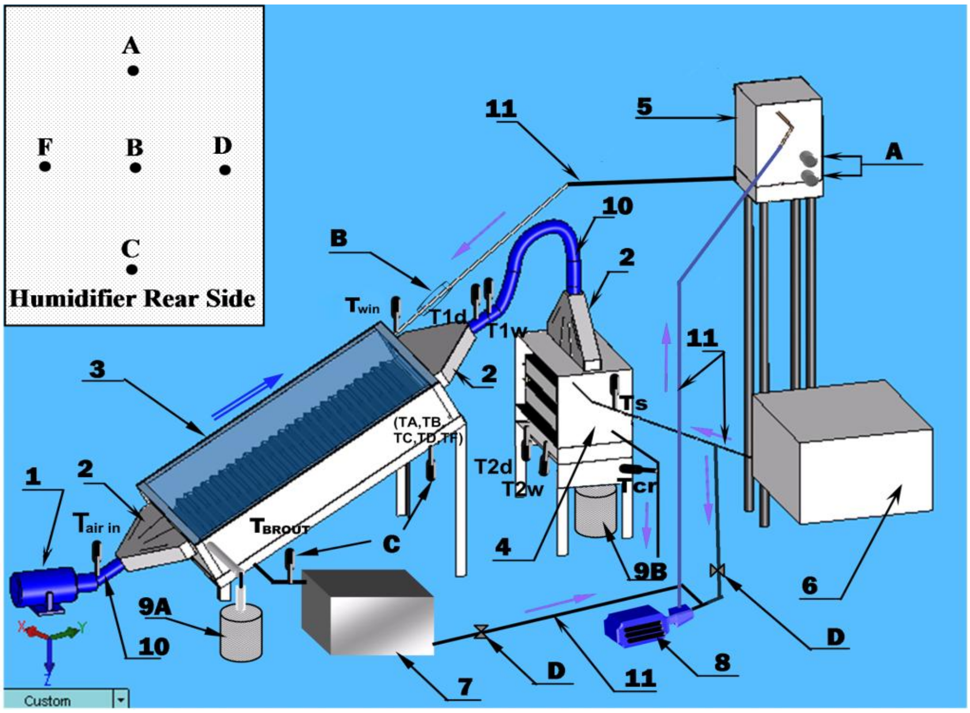
1. Introduction

Potable water shortage is expected to be one of the major worldwide challenges of the near future. The areas with severest water lack are the warm, arid countries located in northern Africa and southern Asia with latitudes of 15-35º N. Libya is an arid region. It contains one of the largest deserts in the world and needs fresh water badly while anguish high intensity of solar energy.

The Shortage of water occurring at places with a hot climate might make the application of the solar energy for water desalination more practical. Solar desalination exhibits considerable economic advantages over other salt-water desalination processes because of cost-free energy, reduced operating cost and simple structure. The use of solar energy to fulfill the task of seawater evaporation and to obtain potable water is a subject of many investigations done during the last years. The solar desalination process offers the advantage of doing practically no ecological damage and creating minimum energy cost. The most promising development in solar desalination was the use of the humidification-dehumidification (HD) process. Solar desalination with humidification-dehumidification processes has proven to be an efficient means of production of fresh water in remote and sunny regions (Lourdes Garcia Rodriquez, 2003). The HD process is based on the fact that air can be mixed with important quantities of vapor. The amount of vapor carried by air increases with the temperature; in fact, 1 kg of dry air can carry 0.5 kg of vapor and about 670 kcal when its temperature increases from 30°C to 80°C (G.Nebbia, 1968). In this process air is heated and humidified by the hot water received from a solar collector, and then it is humidified in a large surface condenser using the saline feed. Most of the latent heat of condensation is used for preheating the feed. The successful feature of the process lies in its ability to utilize the latent heat of condensation by preheating the feed saline water, such units produce desalinated water at rates higher than those usually obtained from single basin solar stills under similar solar radiation. One of the advantages of this technique is the production of hot water in considerable amounts that can be used for domestic applications, this fact has been mentioned by Al-Hallaj et.al (1998) water quantities produced can reach more than 200 L/day in an open cycle.

2. Experimental setup and procedure

The experimental setup for the desalination unit is shown in Fig. 1. It consists of four major parts: solar evaporator (Humidifier), condenser, water and air system, and data acquisition system.



A Electric heaters
B Water flow meter
C Digital thermometers
D Control valves

1 Air blower
2 Triangle ends
3 Humidifier
4 Condenser
5 Elevated water tank
6 Water source tank
7 Recovery water tank
8 Water pump
9A Collecting vessel
9B Collecting vessel
10 plastic hosepipe
11 PPR pipes

Figure 1. Schematic diagram of the experimental test apparatus.

All parts of the experimental apparatus have been assembled in the College of Engineering, Zawia University in Sabratah city located at the Libyan western coastal, about 60km west of the capital Tripoli. The symbols shown in the figure are as follows:

$T_{air\ in}$: Temperature of air entering the humidifier
T_{win} : Temperature of water entering the humidifier
T_{BRout} : Brine temperature
T_{cr} : Temperature of water leaving the condenser
T_S : Temperature of water source
T_{1d} : Dry air temperature leaving the humidifier and entering the condenser
T_{1w} : Wet air temperature leaving the humidifier and entering the condenser
T_{2d} : Dry air temperature leaving the condenser
T_{2w} : Wet air temperature leaving the condenser

(TA,TB,TC,TD,TF) : Temperature of humidifier inside base plate in 5 positions (step shape plate)

2.1 Humidifier

Figure 2, is the main part of the system. It heats up the water that enters the humidifier via a PPR pipe (11) mounted in the top of the humidifier. Its base was built in step shape shown in Fig 2, dimensions for the upper face 5 cm and the front face 3 cm this design to ensure the slow motion of water downwards in the humidifier, resulting in higher evaporation. The base temperature (the step shape plate) was measured in 5 locations using digital thermometers. All sides of the humidifier were insulated with 5 cm of glass wool the upper side of the solar humidifier (3) was covered with 10 mm regular glass.

The humidifier is coupled with two triangle shaped ends (2) in the bottom and the top of the collector these triangle shaped ends are constructed with fins in the inside as shown in Fig 3.5 there purpose is to direct the airflow through a plastic hosepipe (10) distributing the airflow evenly inside the humidifier.

This is essentially an extraction process; water source (brackish water) enters the top of the humidifier and drips down slowly, in continues process by a ½ inch diameter pipe. As the droplets come out through 5 irrigation nozzles distributed equally along the pipe. As the small drops of brackish water fall downward, warm dry air flows upward ejected a blower in the opposite direction to the brackish water stream.

2.2 Condenser

In this part (4) which is connected directly to the humidifier using a plastic hosepipe (10), the second process occurs in the system which is condensing the water (Vapor) in the airflow that leaves the humidifier, the condenser, as shown in Fig 4, consists of two radiators installed over each other with a triangle frame fixed on top of the condenser, distributing the airflow inside the condenser. At the bottom of the condenser is a conical plate, used to collect the water that condenses on the radiators and drops from them into a small water vessel (9B) which gathers the produced water (desalinated water).

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2.3 Water and Air System

The water system consists of three water tanks, two collecting vessels, and a small pump. The source water tank is the biggest one (6) with volume of $2m^{3.}$ It stores the brackish water. This tank is connected to a water pump (½ hp) (8) that pumps water to the elevated tank (5) with a volume of $0.1m^3$ which is located 2.5m above system level. This water tank is connected to the humidifier by PPR pipe (11). Elevated water tank provides the pressure for the water entering the humidifier, at the same time it acts as a water heater, with two electric heaters fixed to the elevated water tank, and equipped with a thermocouple to measure the temperature which is ranging from 40C° - 80C°. a water flow meter (B) is connected between the elevated water tank and the humidifier to guarantee a fixed water flow rate to the humidifier. The third tank is the recovery tank, 50 L, collects the warm brine water from the humidifier and joined to the pipe that connect the water source tank to the pump, water in the system is controlled by valves (D), so when the recovery tank is full the water can be raised by the pump to the elevated tank, which can increase the temperature of the water entering the humidifier. The air system works with a small air blower (1). It blows the air directly into the solar humidifier and moves the vaporized water upward in the humidifier direct to the condenser.

2.4. Data Acquisition System

The temperature values $T_{air\ in}$, T_{win}, T_{BRout}, T_{cr}, T_S, T_{1d}, T_{1w}, T_{2d}, T_{2w}, are temperatures for different points of the system, while (TA,TB,TC,TD,TF) are the temperatures of the humidifier inside the base plate in 5 positions (step shaped plate). Water flow was measured using a water flow meter as mentioned before, its measuring range is from 0.4 – 4 Lpm. The water produced is measured by using graduate lab vessel of 2000 ml volume with an accuracy of ±10 ml. The results of the (T.D.S) for the water that was used in the experiment was 2259 mg/L measured at Temp = 27.8 C° , from Table 1 (Michael Smith et al, 2000), this type of water is classified as Brackish water. This type of water is common the Libyan coast.

Table 1. Type of water classified according to TDS value

Type of water	TDS value (mg/l)
Sweet water	0-1000
Brackish water	1000-5000
Moderately saline water	5000-10000
Severely saline water	10000-30000
Seawater	More than 30000

2.5. Experimental Procedure

The experimental runs are carried out considering the following procedure:
The humidifier is assembled and joined with the condenser. The surface temperatures of the base plate, inlet water temperature are measured ensure that the heat sources are at uniform reading. The supplied electrical power heater is adjusted at the required value of the water temperature. The air mass flow rate and water flow rate are adjusted at a required value through a moving plate fixed on the blower and a gate valve on the entrance of the water pipe. The temperatures, humidity, water productivity, are recorded every 1 hour during the whole test.

3. Results and discussion

3.1 Case 1

The humidifier was tested by passing water through the humidifier without recovery, open water cycle. The temperature of water entering the humidifier is the water source temperature without heating. In this case the blower and the condenser were not used and the only variable is the water flow rate $\dot{m}_{win}$. Four different values for water flow rate were used during this case, $\dot{m}_{win} = 0.19, 0.38, 0.57, 0.76\ Lpm$. Each value of the mentioned water flow rates was tested on a different day. The obtained results for each day are presented in a set of graphical forms. In case 1 the humidifier acts like a solar still, the only difference is that water inside the humidifier is running over the step plate or (base plate) while in solar stills water is motionless (still) in a basin. The generated water drops from the vaporization process flow on the inside face of the glass cover to the lateral collecting channels.

Figures (2A, 2B) and Figures (3C , 3D) present the accumulated hour productivity recorded for four different values of mass flow rate. In this case the only tested value is the mass flow rate. It can be concluded from the figure that the accumulated productivity is inversely proportional to the mas flow rate. On 31/7/2008 with value of $\dot{m}_{win} = 0.19\ Lpm$ gave the highest hour productivity and accumulative productivity. The efficiency of the system for this type of flow rate can be improved if a good technique was found to guarantee the distribution of brackish water over the step shape plate to cover the whole area of the plate with water. At $\dot{m}_{win} = 0.19\ Lpm$ the highest temperature of humidifier (base plate) and the outlet water temperature of humidifier (brine) are recorded for case1.

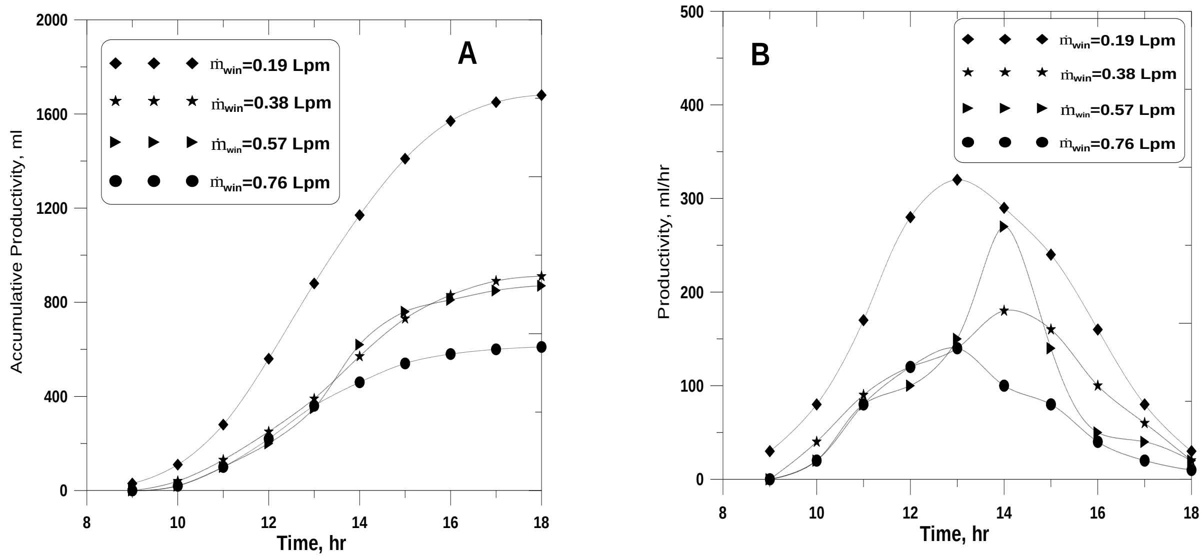


Figure 2. Accumulative and hour productivities recorded during four different values of $\dot{m}_{win}$

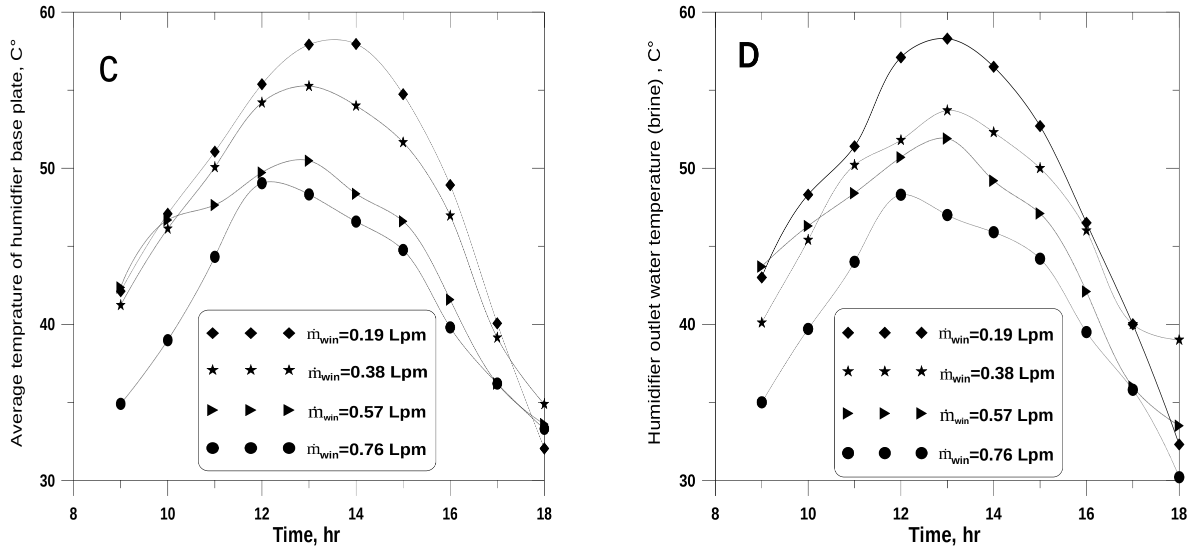
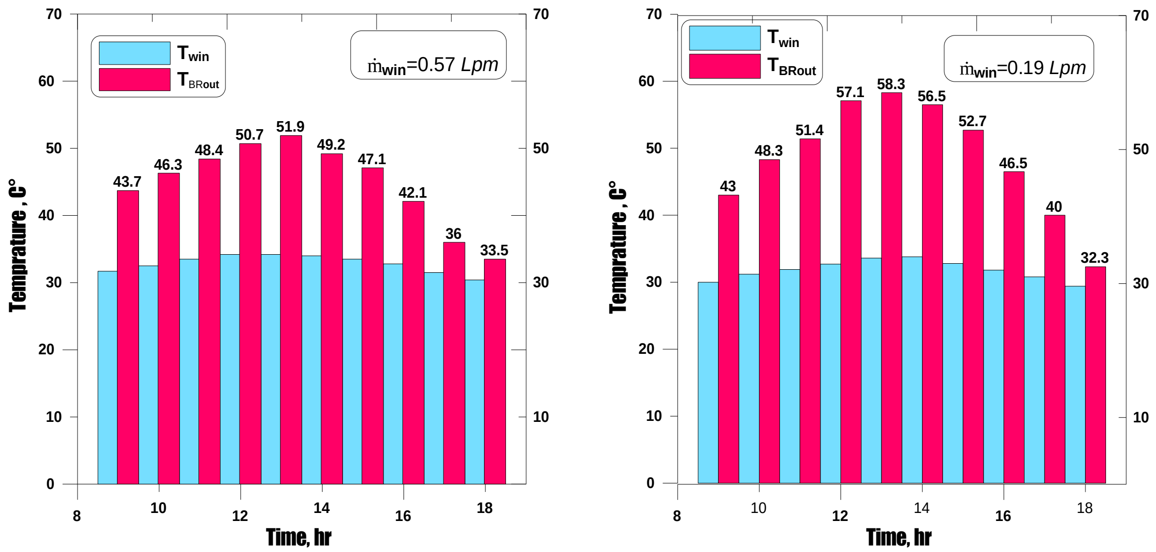


Figure 3. Average temperature of humidifier (base plate), (C) Outlet water temperature of humidifier (brine) (D) recorded for four different values of $\dot{m}_{win}$.

One of the advantages of this technique is the production of hot water in considerable amounts that can be used for domestic applications water quantities produced can reach more than 200 L/day in an open cycle, a simple computation for the date 19/7/2008 where $\dot{m}_{win} = 0.57\ Lpm$ the warm water accumulated is: $m_{produced(warmwater)} = 0.57\ Lpm \times 60\ \text{min}/\ hour \times 7\ hours = 239.4\ L$. Taking in consideration the mass of water vaporized and other losses in the system, the final result could be 200 L with an average temperature of brine water in this day is 47.42 C°, as a verification Fig 4.8 shows a comparison between the inlet water temperature T_{win} and the outlet water temperature T_{BRout} on date of 31/7/2008.



31/7/2008 19/7/2008

Figure 4. Comparison between the inlet water temperature T_{win} and the outlet water temperature T_{BRout}

3.2 Case 2

In this case the flow rate of the air was changed to study its effect on the productivity, the air flow rate was increased to $\dot{m}_{air} = \dot{m}_{medium}$ coming from the blower, while the value of $\dot{m}_{win}$ was chosen to be $\dot{m}_{win} = 0.38\ Lpm$, electric heaters were used and the target temperature for the entering water T_{Win} was to be $Twin = 40\ C^{\circ}$ for case 2. Figures (5A,5B) shows a comparison between accumulated productivity and a comparison between hour productivity for different air flow rate at $Twin = 40\ C^{\circ}$ and $\dot{m}_{win} = 0.38\ Lpm$ during two recorded experimental working days From figure (5A) it can be clear that the effect of air flow rate is significant, increasing the air flow rate caused the productivity of the system to fall down sharply, a study made by Younis et al, (1993) indicates the same. At the same temperature for entering water $Twin = 40\ C^{\circ}$ and the same water flow rate $\dot{m}_{win} = 0.1gpm$ the productivity for the air flow rate at $\dot{m}_{air} = \dot{m}_{\min}$ is 1720 ml, while the productivity for $\dot{m}_{air} = \dot{m}_{medium}$ is 630 ml.

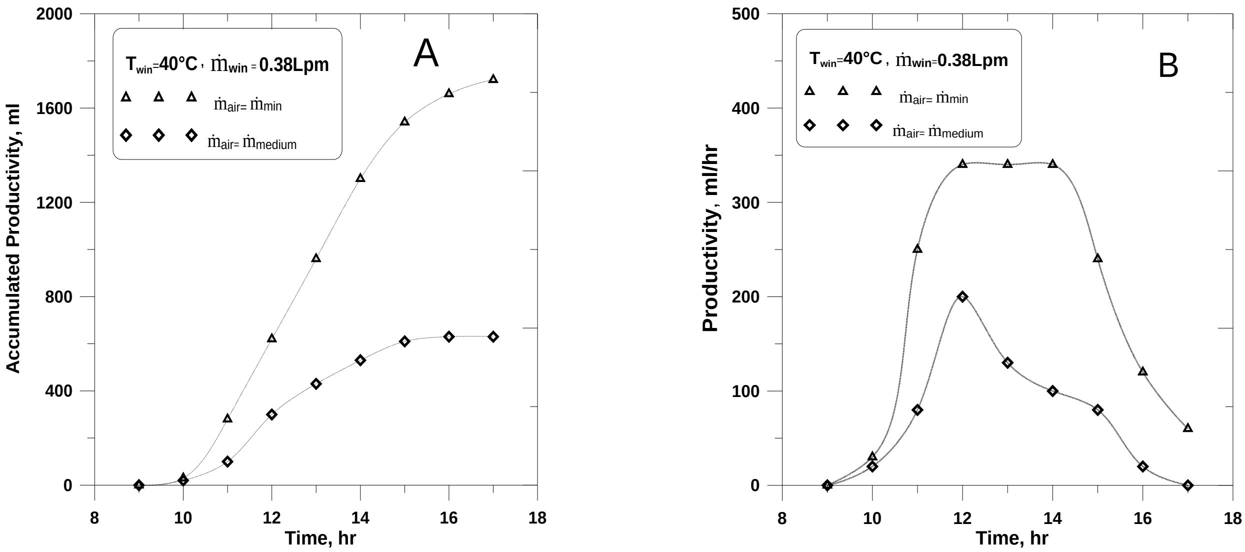


Figure 5. Accumulated productivity (A), Hour productivity (B) compared during two recorded experimental working days.

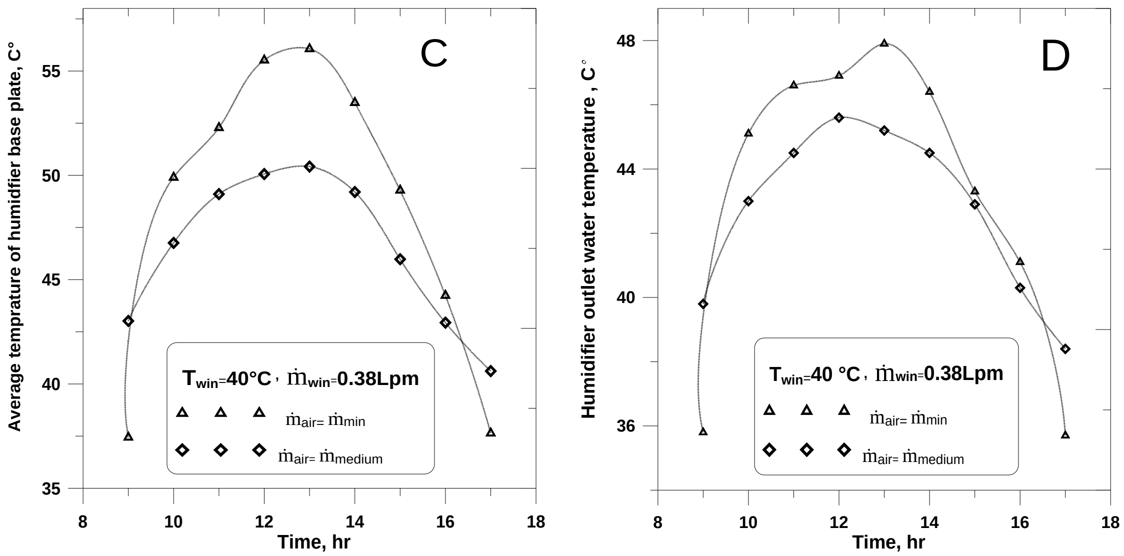


Figure 6. Average temperature of humidifier (base plate) (C) , Outlet water temperature of humidifier (brine) (D) compared during two recorded experimental working days at case 2

Figure (5B) illustrates that hour productivity has been affected by the change in air flow rate, in addition Figures (6C,6D) show a decrease in the temperature of the humidifier base plate and brine, this fact clarify that the air flow rate must be selected which offer the best results, even the air blower used in this study lowest rate value might be higher than the optimum rate value.

4. Conclusions

The authors have reached the following conclusions:

- The wall height for the humidifier should must not exceed 15 cm to allow an early morning hours sun radiation.

- The outlet water flow leaving the humidifier to the source tank should be controlled automatically.
- The materials used should be of light weigt to avoid shifting moving problems.
- The distribution of inlet water evenly in the humidifier above the step shape plate presented
- The plate must be supported from underneath and should be made of at least 3mm thickness to avoid deflection in the plate which direct the water flow in one direction, which may result in some dry areas inside the humidifier, decreasing in this way system efficiency.
- The use of non corrosive materials is recommended.
- Slowing down the speed of water entering the humidifier is significant to increase the temperature of water passing on the step shape plate and the use of barriers to ensure slowing down water speed.
- Avoid sites with strong wind factors.
- System efficiency is inversely proportional to the water flow rate.

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