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Solar Air-Heated Humidification-Dehumidification Desalination Unit

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Abstract: A solar powered desalination unit which working on a humidification –dehumidification technique (HDH) is one of the most important techniques used in brackish and seawater desalination especially in remote and rural areas. In the present study, a test-rig was designed and constructed for conducting a set of experiments on a solar assisted desalination unit working on a HDH principle under the prevailing conditions of Tajoura-Libya. Experiments were carried out on specified days in March, 2019 at the laboratories of Center for Solar Energy Research and Studies (CSERS) at Tajoura. The effect of different design parameters and operating conditions on the performance of the unit and its productivity is closely investigated and interpreted. Results show that the productivity of the HDH unit decreases by increasing the process air mass flow rate. A significant improvement in the productivity of the unit is noticed when the feed water mass flow rate to the humidifier is increased. Furthermore, initial water temperature inside the tank has a remarked effect on the productivity of the unit. In order to obtain a reasonable amount of fresh water, the temperature of the water inside the tank should be increased. Increasing the cooling water mass flow rate to the dehumidifier leads to a corresponding decrease in the surface temperature of the cooling coil and hence the productivity of the unit is improved. The Productivity of the unit is varying from its lower value of (0.903 kg/m2.day) to a higher value of (6.47 kg/m2.day). These values are obtained for one meter square of solar air heater area. Gained Output Ratio (GOR) values range from a minimum of (0.082) to a maximum of (0.572). It is reasonable when compared to ones in literature for the water-heated HDH units.

وحدة تحلية تعمل بالطاقة الشمسية على مبدأ ترطيب وإزالة الرطوبة من الهواء

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ملخص: تعتبر وحدة التحلية التي تعمل بالطاقة الشمسية على مبدأ ترطيب وإزالة الرطوبة من الهواء، واحدة من أهم التقنيات المستخدمة في تحلية المياه: الماء العسر ومياه البحر، خاصة في المناطق البعيدة والنائية. في هذه الدراسة تم تصميم وتصنيع وتركيب وحدة التحلية بغرض إجراء مجموعة من التجارب على هذه الوحدة تحت الظروف المحلية السائدة بمدينة تاجوراء -ليبيا. تم إجراء هذه التجارب في أيام محددة من شهر مارس 2019م، في معامل مركز بحوث ودراسات الطاقة الشمسية بتاجوراء. تم التحقق من تاثير العوامل التصميمية المختلفة والظروف التشغيلية على الأداء الحراري وعلى انتاجية هذه الوحدة. أظهرت النتائج أن إنتاجية الوحدة تنخفض مع زيادة معدل سريان الكتلة الهواء المار عبر الوحدة. تم ملاحظة وجود تحسن مهم في إنتاجية الوحدة عندما يتم زيادة معدل سريان الكتلة لمياه التغذية للمرطب. بالأضافة الى ذلك، فإن درجة حرارة المياه الإبتدائية داخل خزان المياه لها تأثير ملحوظ على إنتاجية الوحدة: لأجل الحصول على كميات معقولة من المياه المحلاة، يستوجب زيادة درجة الحرارة الأبتدائية للمياه داخل الخزان. زيادة معدل سريلن الكتلة لمياه التبريد الخاصة بالمكثف يؤدي الى انخفاض مناظر في درجة حرارة سطح ملف التبريد، وبهذا تتحسن إنتاجية الوحدة. مقدار الأنتاجية للوحدة يتغير من أقل قيمه له وهي($0.903\ kg/m^2.day$) ، الى أكبر قيمة له وهي ($6.47\ kg/m^2.day$)، هذه القيم محسوبة لكل متر مربع من مساحة مسخن الهواء الشمسي. قيم نسبة الكسب الخارج، (GOR)، تتغير من أقل قيمة لها وهي(0.082)، الى أعلى قيمة وهي (0.572) ، هذه القيم تعتبر معقولة عند مقارنتها بالقيم المذكورة لنفس الوحدات – المسخنة بالمياه، حسب الدراسات السابقة.

Keywords: ***Solar, desalination, humidification, dehumidification, productivity.***

1. INTRODUCTION

In recent years, solar thermal desalination systems have received a lot of attention because they are environmentally friendly and can be operated with low temperature sources such as solar energy, lost heat and geothermal energy. Conventional desalination processes consume a large amount of energy derived from oil and natural gas as heat and electricity, while emitting harmful CO2 gas. They have many negative environmental impacts involves climate change, depletion of the ozone layer and pollution, in addition to its contribution to the increase in the demand for electricity and the consequent economic problems resulting in increasing the cost of supplying this power. Therefore, solar-powered desalination systems have the potential to reduce many of these problems [1]. Solar thermal desalination has emerged as a promising renewable energy-powered technology for producing fresh water. Combining the principle of humidification-dehumidification with solar desalination results in an increase in the overall efficiency of the desalination plant, and therefore appears to be a promising method for water desalination with solar energy [2,3]. The solar powered humidification-dehumidification desalination process is a simple, economical and efficient method for small capacity of fresh water production. It has no parts which require extensive maintenance work like membranes or high temperature steam lines. There is also no bottle-neck in applying HDH for tough and varied water qualities. In view of above merits, HDH systems are convenient for application in arid and remote areas and limited applications. Moreover, no need for skilled or qualified people to operate and maintain such systems [3]. The aim of this study is to investigate the effect of different design parameters and operating conditions on the thermal performance and the productivity of a solar assisted HDH desalination unit under the prevailing conditions of Tajoura-Libya. Different configurations of the solar water desalination systems based on the humidification-dehumidification technique have been proposed in the literature, such as; (i) with/without air heating, (ii) with/without water heating, (iii) closed/open water and air cycles, (iv) forced/natural air circulation. The system used in this study is based on the principle of open air-closed water cycles and forced air circulation.

2. EXPERIMENTAL WORK

2.1. Description of the test-rig

An experimental set-up was designed and constructed at different private mechanical workshops at Al-khoms-Libya. It was assembled and started up at CSERS laboratories located at Tajoura-Libya as shown in Figure 1. The main components of the experimental set-up are as follows;

- Double-pass flat plate solar air heater
- Humidifier
- Water storage tank
- Dehumidifier
- Water circulating pump and Air blower
- Measurement system

Figure 2 shows the location of the measuring and testing points at the system.

Figure (1). General view of the test-rig.

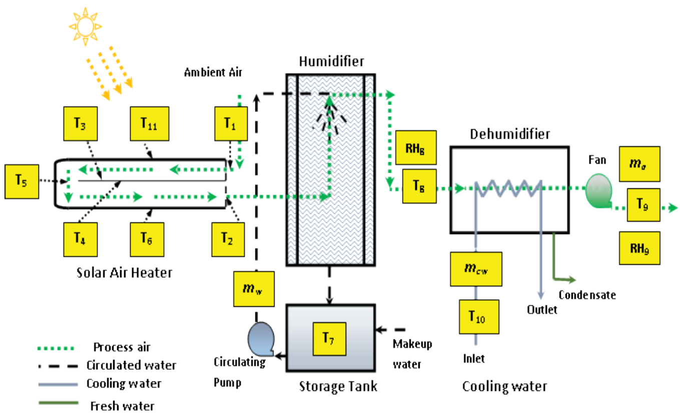

Figure (2). The location of the measuring and testing points at the system.

2.2. Experimental Procedure

A set of experiments were planned and conducted. The main parameters studied are; (Process air mass flow rate, circulated water mass flow rate, cooling water mass flow rate, water temperature). Two settings were proposed for the studied parameters. Table 1 shows a summary of the setting values for the main parameters. Moreover, six experiments were planned and conducted based on the experimental work plan shown in Table 2 below.

Table (1). Setting values for the main parameters.

Symbol	Setting value No.1	Setting value No.2
	0.07	0.11
	0.075	0.25
	0.013	0.036
T_w (°C)	30	45

Table (2). Experimental work plan.

Exp. No.	Exp. Code	Exp. Date
Exp.# (1)	hd (1,1,1,1)	05.03.2019
Exp.# (2)	hd (2,1,1,1)	06.03.2019
Exp.# (3)	hd (1,2,1,1)	07.03.2019
Exp.# (4)	hd (1,1,2,1)	08.03.2019
Exp.# (5)	hd (1,1,1,2)	09.03.2019
Exp.# (6)	hd (2,2,2,2)	10.03.2019

It should be noted that the experimental code, hd (x,x,x,x) , is related to the setting values of the four parameters studied , (m_a,m_w,m_{cw}&T_w), respectively. For example, experiment code, hd (1,1,1,1), means that the four parameters; process air mass flow rate, circulating water mass flow rate, cooling water mass flow rate and water temperature, are experimented at setting values no.1, respectively as shown in Table 2. The experimental code, hd (2,2,2,2), is proposed for the same parameters at their setting values no.2. whereas, a mix of experiments were carried out at both setting values no.1 and 2, namely, Exp. No.2, Exp.No.3, Exp. No.4 and Exp. No. 5.

Prior to experimentation, the whole setup piping system, fittings, connections, tubes...etc, should be checked against leakage. In addition, special attention should be taken into account for electric wiring, connections, grounding, and all safety measures to avoid undesirable electricity source accidents. The experiments were started by switching on the power to the electric heaters at the water storage tank. When the water storage tank temperature reached its proposed value; (setting value no.1 or setting value no.2), the circulating water pump and air blower are switched on and adjusted according to their setting values for the experiment chosen. In addition, cooling water tap is opened and adjusted according to the mass flow rate proposed. Data acquisition system is also put in operation and configured to start data recording process. The product of fresh water is collected in a measuring bottle. The measurements were taken every

10 minutes interval by data logger, starting from 9.00 O'Clock at morning until 17.00 O'Clock evening under the prevailing conditions of Tajoura-Libya. In order to record the experimental data, an experimental data recording sheet is designed and used. Finally, the recorded data was analyzed and interpreted by the help of Excel Sheets and graphical curves.

3. RESULTS AND DISCUSSION

3.1. Site Weather Conditions

The measured weather data during the period of experimentation in specified days in March 2019 at Tajoura-Libya were considered. These data were measured and recorded every ten minutes by the site weather station located at Center of Solar Energy Research and Studies, CSERS, Tajoura-Libya. Figure 3 shows the measured meteorological data for the specified experimental dates, namely solar radiation, ambient air temperature, humidity and wind speed.

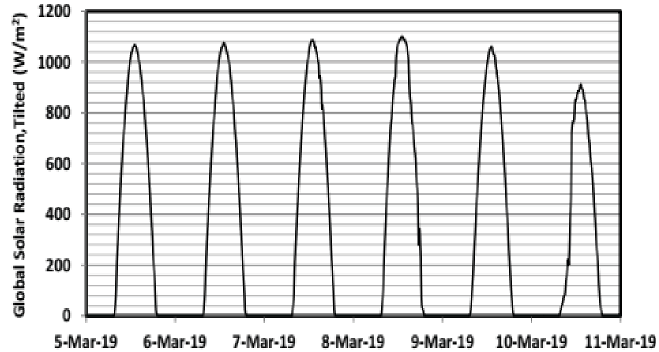

Figure 3-a. Measured meteorological data for Tajoura-Libya; Solar radiation.

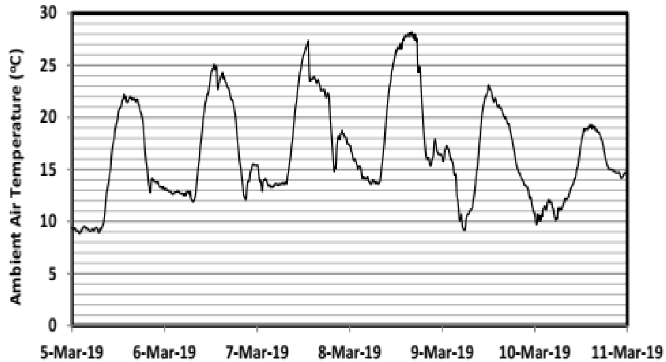

Figure (3-b). Measured meteorological data for Tajoura-Libya; Ambient Air Temperature.

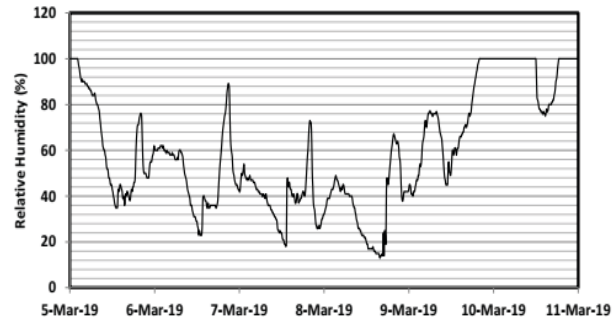

Figure (3-c). Measured meteorological data for Tajoura-Libya; Humidity Ratio.

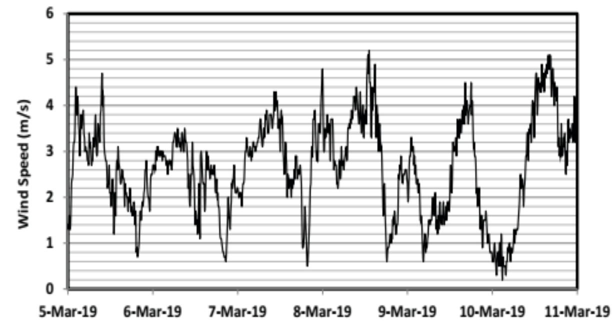

Figure (3-d). Measured meteorological data for Tajoura-Libya; Wind Speed.

3.2. The effect of process air mass flow rate

Figure 4 illustrates the effect of the process air mass flow rate on the productivity of the unit from 9.00 AM to 17.00 PM at 05th and 06th of March 2019. Two different flow rates were experimentally investigated, [m_a = 0.07 kg/s) and m_a = 0.11 kg/s]. The value of the daily accumulated productivity is changing from 1.5 (kg/m^2.day) to about 0.905 (kg/m^2. day) corresponding to air mass flow rates of [m_a = 0.07 kg/s and m_a = 0.11 kg/s], respectively. In general, the productivity of the unit decreases by increasing the process air mass flow rate. This is attributed to the fact that increasing air mass flow rates results in decreasing the temperature of the air leave the solar air heater and, hence, the moisture content of the air leaving the humidifier. Moreover, the humidifier effectiveness is also negatively affected. In other words, the dry-bulb temperature of the air leaving the humidifier decreases and gets closer to the wet-bulb temperature of the air at the inlet of the humidifier. As a result, the moisture content is decreased as well and the water temperature in the storage tank and the rate of vaporization in the humidifier are also decreased. Furthermore, at a constant cooling water mass flow rate and temperature, increasing air mass flow rate increases the absolute humidity of the air leaving the dehumidifier. For these reasons, the productivity of the unit is decreased. However, according to the theoretical study results [3], at a range of air mass flow rates of, [m_a = 0.005 kg/s to m_a = 0.05 kg/s], increasing inlet air mass flow rate, increases the productivity of the unit to a certain maximum value corresponding to air mass flow rate of [m_a = 0.015 kg/s] and then it decreases as inlet air mass flowrates become higher. This agrees with this study results since process air mass flow rates considered are higher than [m_a = 0.015 kg/s], namely, [m_a = 0.07 kg/s and m_a = 0.11 kg/s].

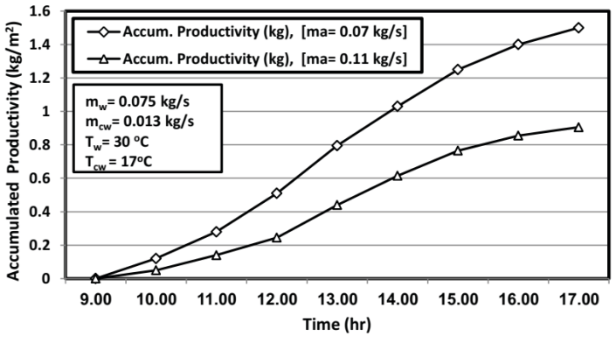

Figure (4). The effect of process air mass flow rate on the productivity of the unit on daily basis.

Figures 5 and Figure 6 show a variation of temperatures at different measuring points in the desalination unit at air mass flow rates of [m_a = 0.07 kg/s] and [m_a = 0.11 kg/s], respectively. In general, it can be noticed that as solar radiation intensity increases, the temperatures at different measuring locations are increased to their maximum values around mid of the day, between 12.00 and 15.00 PM. The maximum temperature reached a value of 70 °C, recorded at the bottom surface of the absorber plate of the solar air heater. There are some fluctuations in the readings at Figure 5. This is attributed to the effect of clouds that partially hinders solar radiation from time to time at the day of experiment.

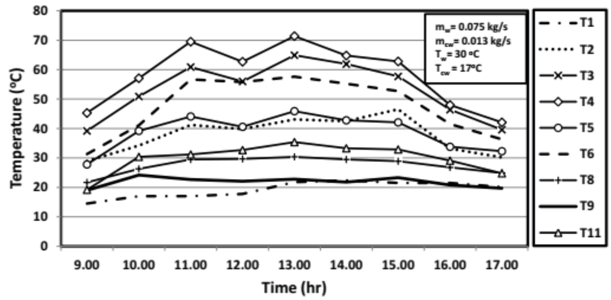

Figure (5). Variation of temperatures at different measuring points in the unit, [m_a = 0.07 kg/s], (05 March 2019).

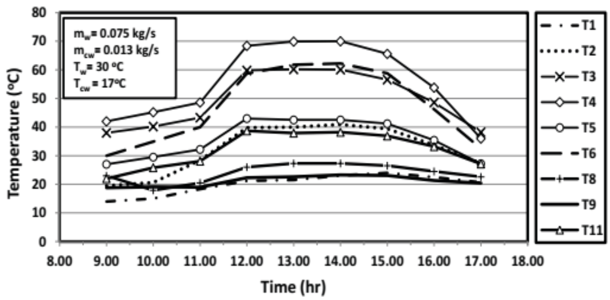

Figure (6). Variation of temperatures at different measuring points in the unit, [m_a = 0.11 kg/s], (06 March 2019).

3.2. The effect of humidifier feed water mass flow rate

The effect of the humidifier feed water mass flow rate on the unit productivity is shown in Figure 7. Experiments were carried out from 9.00 AM to 17.00 PM at 5th and 7th of March 2019. Two different flow rates were experimentally investigated, [mw = 0.075 kg/s and mw = 0.25 kg/s]. The value of the daily accumulated productivity is changing from 1.5 (kg/m2.day) to 1.93 (kg/m2.day) corresponding to water mass flow rates of [mw = 0.075 kg/s and mw = 0.25 kg/s], respectively. In general, the productivity of the unit increases by increasing the feed water mass flow rate. Since air is brought into contact with the water in the humidifier, the water temperature drops and wet-bulb temperature of the air leaving the humidifier at saturation state increases. For this reason, at a constant air mass flow rate, when the water mass flow rate increases, the wet-bulb temperature of the air leaving the humidifier increases and approaches to the temperature of the water at the inlet of the humidifier. As a result, the moisture content of the air leaving the humidifier increases and a significant improvement on the unit productivity is noticed.

Figures 8 and Figure 9 show a variation of temperatures at different measuring points in the desalination unit at feed water mass flow rates of [m_a = 0.075 kg/s] and [m_a = 0.25 kg/s], respectively. In general, it can be noticed that as solar radiation intensity increases, the temperatures at different measuring locations are increased to their maximum values around mid of the day, between 12.00 and 15.00 PM. The maximum temperature reached a value of 73 °C, recorded at the bottom surface of the absorber plate of the solar air heater. There are some fluctuations in the readings at both Figures. This is attributed to the effect of clouds that partially hinders solar radiation from time to time at the day of experiment.

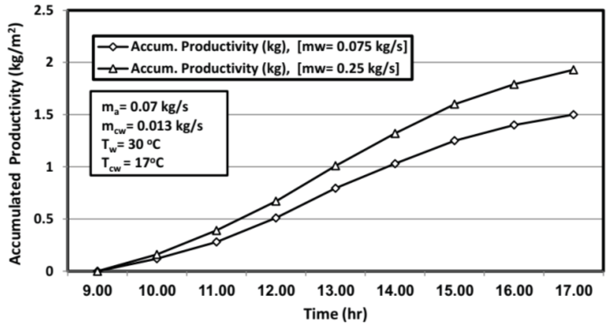

Figure (7). The effect of humidifier feed water mass flow rate on the productivity of the unit, on daily basis.

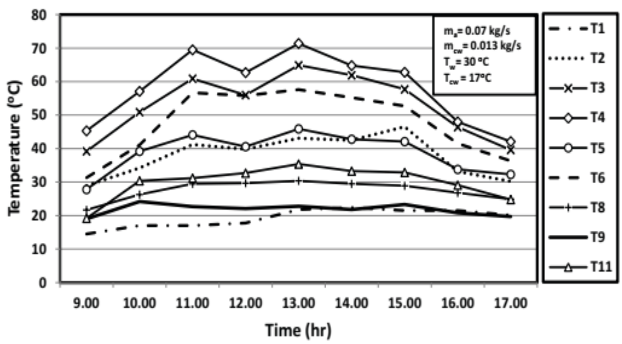

Figure (8). Variation of temperatures at different measuring points in the

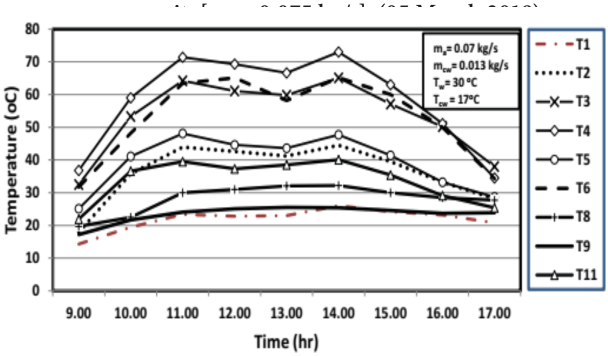

Figure (9). Variation of temperatures at different measuring points in the unit, [m_w = 0.25 kg/s], (07 March 2019).

3.3. The effect of dehumidifier cooling water mass flow rate

The effect of the dehumidifier cooling water mass flow rate on the system productivity is shown in Figure 10. Experiments were carried out from 9.00 AM to 17.00 PM at 5th and 8th of March 2019. Two different flow rates were experimentally investigated, [mcw = 0.013 kg/s and mcw = 0.036 kg/s]. The value of the daily accumulated productivity is changing from 1.5 (kg/m2.day) to 1.79 (kg/m2.day) corresponding to cooling water mass flow rates of [mcw = 0.013 kg/s and mcw = 0.036 kg/s], respectively. It can be deduced that the productivity of the unit increases by increasing the cooling water mass flow rate. By increasing the cooling water mass flow rate at a constant cooling water temperature, a significant drop in the surface temperature of the cooling coil can be achieved which results in an increase of the rate of the condensation of the water vapor on the cooling coil surface and ,thus, the unit gives higher yield. During preliminary testing and start up period (18-02-2019 to 28-02-2019), it is interesting to note that when changing the

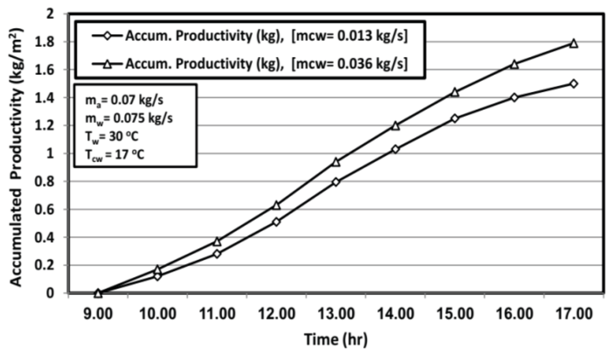

Figure (10). The effect of dehumidifier cooling water mass flow rate on the productivity of the unit, on Daily Basis.

Cooling water entrance connection from the lower part of the dehumidifier to the upper part, a remarkable decrease in the condensation rate of the fresh water was noticed. At the upper part of the dehumidifier, a dropwise condensation layer was noticed. In the other hand, at the lower part of the dehumidifier only filmwise condensation layer was the case. This is attributed to the fact that at a constant cooling water flow rate, the temperature of the cooling water inside the dehumidifier gets higher as cooling water passes through the dehumidifier tubes from top to bottom, results in decreasing of the condensation rate in general. In addition, at higher air flow rates, the velocity and momentum of the forced humid air that passes across the dehumidifier may be another reason that retards droplets of condensate water from falling down. However, when cooling water entrance is located at the lower part of the dehumidifier, the situation is completely different and the condensation rate got higher and reasonable values.

Figures 11 and Figure 12 show a variation of temperatures at different measuring points in the desalination unit at cooling water mass flow rates of [m_{cw} = 0.013 kg/s] and [m_{cw} = 0.036 kg/s], respectively. In general, it can be noticed that as solar radiation intensity increases, the temperatures at different measuring locations are increased to their maximum values around mid of the day, between 12.00 and 15.00 PM. The maximum temperature reached a value of 75.6 °C, recorded at the bottom surface of the absorber plate of the solar air heater. There are some fluctuations in the readings at Figure 11. This is attributed to the effect of clouds that partially hinders solar radiation from time to time at the day of experiment.

3.4. The effect of initial water temperature in the storage tank

The effect of the initial water temperature in the storage tank on the unit productivity is illustrated in Figure 13. Experiments were carried out at 5th and 9th of March 2019, from 9.00 AM to 17.00 PM. Two different water temperatures were considered and experimentally investigated, [Tw = 30 oC and Tw = 45 oC]. The value of the daily accumulated productivity is changing from 1.5 (kg/m2.day) to 2.28 (kg/m2.day) corresponding to initial water temperatures of [Tw = 30 oC and Tw = 45 oC], respectively. In general, the productivity of the unit increases by increasing the initial water temperatures. Initial water temperatures in the storage tank have a considerable influence on the unit productivity. This is attributed to the fact that any increase in the initial water temperature in the storage tank leads to a corresponding increase in the feed water temperature to the humidifier. As a result, the moisture content of air leaving the humidifier increases and the quantity of the fresh water produced as well.

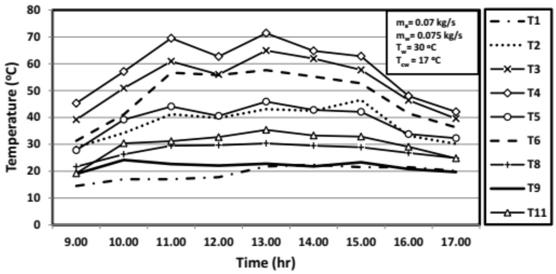

Figure (11). Variation of temperatures at different measuring points in the unit, [m_{cw} = 0.013 kg/s], (05 March 2019).

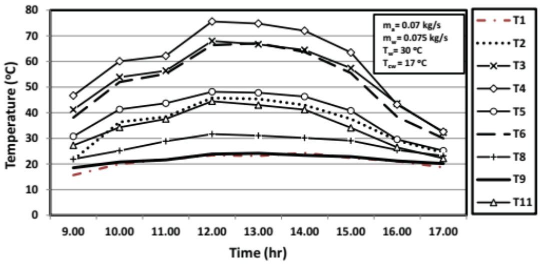

Figure 12. Variation of temperatures at different measuring points in the unit, [m_{cw} = 0.036 kg/s], (08 March 2019).

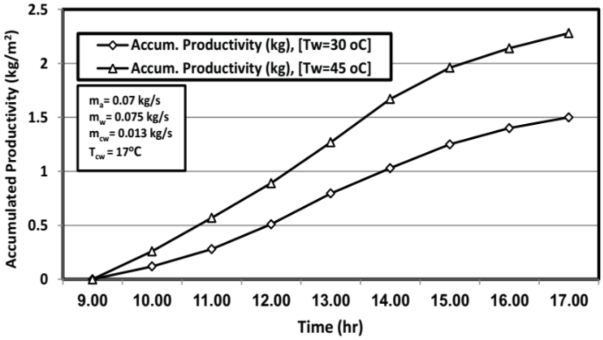

Figure (13). The effect of initial water temperature inside the water tank on the productivity of the unit, on daily basis.

Figures 14 and 15 show a variation of temperatures at different measuring points in the desalination unit at initial water temperatures of [T_w = 30 °C and T_w = 45 °C], respectively. In general, it can be noticed that as solar radiation intensity increases, the temperatures at different measuring locations are increased to their maximum values around mid of the day, between 12.00 and 15.00 PM. The maximum temperature reached a value of 82 °C, recorded at the bottom surface of the absorber plate of the solar air heater. There are some fluctuations in the readings at Figure 14. This is attributed to the effect of clouds that partially hinders solar radiation from time to time at the day of experiment.

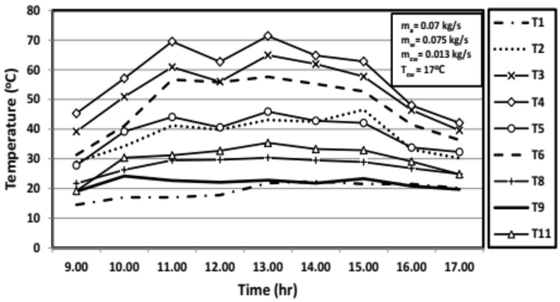

Figure (14). Variation of temperatures at different measuring points in the unit, [T_w = 30 °C], (05 March 2019)**.**

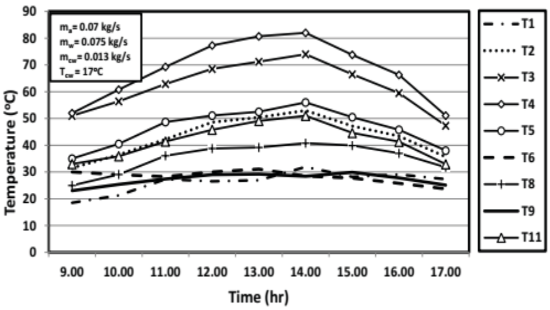

Figure (15). Variation of temperatures at different measuring points in the unit, [T_w = 45 °C], (09 March 2019).

3.5. The combined effect of all parameters

Referring to Table 1 and Table 2 that illustrate the setting values of the main experimental parameters, namely, process air mass flow rate, feed water mass flow rate to the humidifier, cooling water mass flow rate to the dehumidifier and initial water temperature inside the storage tank, there are two experiments; hd (1,1,1,1) and hd (2,2,2,2) represent the minimum setting values and the maximum setting values for the experimental parameters studied, respectively.

Figure 16 shows the effect of the combined parameters on the productivity of the unit. Experiments were carried out at 5th and 10th of March 2019, from 9.00 AM to 17.00 PM. Two different settings were considered and experimentally investigated, hd (1,1,1,1) with values of [ma = 0.07 kg/s, mw= 0.075 kg/s, mcw = 0.013 kg/s, Tw = 30 oC] and hd (2,2,2,2) with values of [ma = 0.11 kg/s, mw= 0.25 kg/s, mcw = 0.036 kg/s, Tw = 45 oC]. The value of the daily accumulated productivity is changing from 1.5 (kg/m2.day) to 6.47 (kg/m2.day). Corresponding to experiments, hd (1,1,1,1) and hd (2,2,2,2), respectively. Consequently, a remarkable increase in the productivity of the unit is noticed when compared to other results. This is attributed to the combined effect of all mentioned parameters studied above.

Figures 17 and Figure 18 show a variation of temperatures at different measuring points in the desalination unit at both settings hd (1,1,1,1) and hd (2,2,2,2). In general, it can be noticed that as solar radiation intensity increases, the temperatures at different measuring locations are increased to their maximum values around mid of the day, between 12.00 and 15.00 PM. The maximum temperature reached a value of 76.4 oC, recorded at the bottom surface of the absorber plate of the solar air heater. There are some fluctuations in the readings at Figure 17. This is attributed to the effect of clouds that partially hinders solar radiation from time to time at the day of experiment.

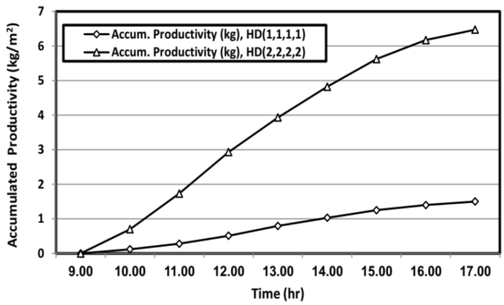

Figure (16). The effect of the combined parameters on the productivity of the unit, on Daily Basis.

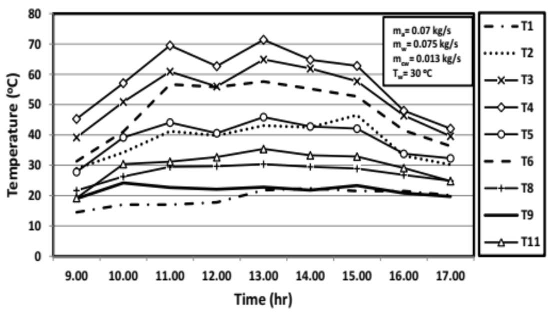

Figure (17). Variation of temperatures at different measuring points in the unit, [HD(1,1,1,1)], (05 March 2019).

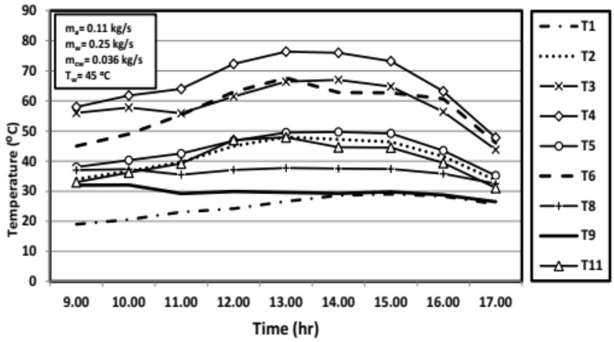

Figure (18). Variation of temperatures at different measuring points in the unit, [HD(2,2,2,2)], (10 March 2019).

3.6 Comparison of Results

A comparison of the experimental results for this study is illustrated in Table 3.

Table 3. Comparison of the experimental results for the present study.

Exp. No.	Exp. Date	Accumulated Productivity (kg/m^2.day)	GOR
Exp.# (1)	05.03.2019	1.5	0.121
Exp.# (2)	06.03.2019	0.905	0.082
Exp.# (3)	07.03.2019	1.93	0.142
Exp.# (4)	08.03.2019	1.79	0.128
Exp.# (5)	09.03.2019	2.28	0.162
Exp.# (6)	10.03.2019	6.47	0.572

It can be deduced that the highest productivity value is (6.47 kg/m2.day) corresponding to Experiment No. 6, Code hd (2,2,2,2), which studies the combined effect of all parameters on the unit productivity at their maximum values. However, the lowest productivity value is recorded for Experiment No. 2, code hd (2,1,1,1), where the effect of process air mass flow rate is investigated. It is 0.905 (kg/m2.day). In order to improve the productivity, minimum value of air mass flow rate should be considered (ma = 0.07 kg/s) in Experiment No.6 instead of the maximum value of (ma = 0.11 kg/s) since increasing air mass flow rate will negatively affect the unit yield. In addition, the effect of initial water temperature in the storage tank is more efficient than that of the feed water mass flow rate to the humidifier and cooling water mass flow rate to the dehumidifier respectively. It is worth to say that studying the effect of cooling water temperature is also very important, but due to some technical problems, the team couldn't manage that.

3.7 Gained Output Ratio (GOR)

The Gained Output Ratio (GOR), or sometimes known as the performance ratio, is defined as the amount of product produced for a given heat input according to the following equation:

$$GOR = \frac{m_p h_{fg}}{Q_{in}} \quad (1)$$

where, m_p is mass flow rate of the fresh water produced, h_{fg} , is the heat of vaporization evaluated at the inlet water temperature and Qin, is the heat input to the unit.

According to literature, a solar still has a GOR of about 0.5, air-heated HDH cycles have a GOR that ranges from 1.7 to 3, whereas the water-heated cycles have a GOR that ranges between 0.3 and 4.5. GOR values for conventional desalination systems such as RO (GOR = 35 - 45), MSF (GOR of about 8), and MED (GOR up to 12) [6]. In this study, GOR values for different experiments on March 2019, are evaluated and tabulated in Table 3. As expected, the maximum gain output ration, GOR, value is 0.572, attained from Exp. No.6 that represents the highest value of productivity, whereas, the lowest value of GOR is 0.082, the one related to Exp. No. 2 which represents the lowest productivity of the unit. These values are below the values mentioned in reference [6] for air heated HDH cycles but it reasonable when compared with the ones for water-heated cycles. This is attributed to the relatively low values of solar radiation intensity, ambient air temperatures and humidity ratio for cold season situation (winter season), when compared to hot season in summer where the HDH unit is expected to reach its maximum GOR values.

4. CONCLUSIONS

In this paper, an experimental study for a solar assisted desalination unit based on humidification – dehumidification principle was carried out at CSERS located at Tajour-Libya on the first ten days of March, 2019. The influence of different parameters and operating conditions were investigated under the prevailing weather conditions of Tajoura-Libya. The productivity of HDH unit decreases by increasing the process air mass flow rate. However, increasing feed water mass flow rate to the humidifier, initial water temperature inside the water tank and cooling water mass flow rate to the dehumidifier lead to a corresponding increase in the productivity of unit in general. The Productivity of the unit per one meter square of solar air heater area is changing from its lower value of (0.903 kg/m^2.day) to a higher value of (6.47 kg/m^2.day). Finally, Gained Output Ratio, (GOR) values were ranging from a minimum of (0.082) to a maximum of (0.572). There is a good agreement with others in literature.

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7. NOMENCLATURE

Parameter	Description	units
T_1	Temperature of the process air at the inlet of the solar air heater	ºC
T_2	Temperature of the process air at the outlet of the solar air heater	ºC
T_3	Temperature of the upper surface of the absorber plate	ºC
T_4	Temperature of the lower surface of the absorber plate	ºC
T_5	Temperature at the end of the first pass of the process air	ºC
T_6	Temperature of the base plate	ºC
T_7	Temperature of the water inside the water storage tank	ºC
T_8	Temperature of process air at the outlet of the humidifier	ºC
T_9	Temperature of process air at the outlet of the dehumidifier	ºC
T_{10}	Temperature of cooling water at the inlet of the dehumidifier	ºC
T_{11}	Temperature of the glass surface at the top of the solar air heater	ºC
T_w	Initial water temperature inside the water tank	ºC
m_a	Mass flow rate of the process air	kg/s
m_w	Mass flow rate of the circulating water to the humidifier	kg/s
m_{cw}	Mass flow rate of the cooling water to the dehumidifier	kg/s
RH_8	Relative humidity of the process air at the outlet of the humidifier	%
RH_9	Relative humidity of the process air at the outlet of the dehumidifier	%