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Experimental study of the performance of tubular solar still in Najaf city

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Abstract
A tubular solar still (TSS) was designed, fabricated and tested in Najaf city, Iraq conditions. The trough was made of polycarbonate material black color of a rectangular shape (0.0972 m^2 Area) its painted black to increase its absorptivity. The tube cover made of Pyrex glass (0.6 m) length, (0.24 m) outer diameter and (0.01 m) thickness. Number of experiments was conducted to observe the behavioral variation inside the still. The experimental study studied the effect of solar radiation, basin depth and direction of TSS on the productivity of solar still and temperature distribution inside the still for Najaf city condition for period (February to August) in 2015. The result show the maximum productivity in north-south direction and the productivity increase with decreasing the depth of water in basin.

Keywords: Tubular solar still; Productivity; Direction of TSS.

1. Introduction

Water is a basic necessity for human along with food and air, the importance of supplying fresh water can be hardly overstressed. Many people have been suffering from the shortage of safe drinking water, particularly in arid regions and remote areas. If these regions were rich in solar energy, solar distillation would be an effective solution for the scarcity of water resources. Human kind depends on rivers, lakes and underground water reservoirs for fresh water requirements in domestic life, agriculture, and industry. However, use of water from such sources is not always possible or desirable on account of the presence of large amount of salts, impurities and harmful organisms. The impact of many diseases afflicting human kind can be drastically reduced if fresh water is provided for drinking.

According to the United Nations (2006), about 1.1 billion people cannot have easy access to safe drinking water [1]. Further, the rapid industrial growth and population explosion all over the world has resulted in a large escalation of demand for fresh water. This invariably leads to acute fresh water shortages since the natural sources of water can meet the demand to a very limited extent. Added to this is the problem of pollution of the rivers and lakes by the industrial wastes and the large amount of sewage disposals. Thus, there is scarcity of fresh water even in cities, towns and villages located near lakes and rivers. Dangerous pollutants left on open ground also find their way into the underground reservoirs along with rainwater.

Islam and Fukuhara [2] presented in the his study semi steady heat and mass transfer model of a Tubular Solar Still taking account of humid air properties inside the still. In order to validate the suggested model, an indoor output experiment on a Tubular Solar Still (TSS) was conducted in a thermostatic room at the University of Fukui, Japan. They developed the experimental technique to measure the evaporation flux by balancing the trough, by setting independently from the other structures of a tubular solar still. Therefore, they concluded that the suggested model can expected the brine temperature, the moist air temperature, the tubular air temperature and production under a semi steady condition. Islam and Fukuhara [3] Studied attempts were made to provide a collection of complete heat and mass transfer correlations, and to suggest a new heat and mass transfer model for a Tubular Solar Still (TSS) by taking account of thermal properties of the moist air inside the still. They developed a new experimental technique for directly measuring the evaporation rate from the brine surface in the (TSS) and evaluated the evaporative mass transfer coefficient. The veracity of the model was evaluated from the comparison with field experiments in Fukui, Japan and in Hamuraniyah, UAE. Fukuhara and Ahsan [4] Studied developed a Tubular Solar Still (TSS) by their research collection and a transparent vinyl chloride sheet of 0.5mm in thickness was used for the tubular cover of the first model. As a result, the cover weight of the second model was one twelfth lighter than that of the first model. An experiment was conducted to study the evaporation and production performance of the second model and the thermal properties of the tubular cover, moist air and water in a trough inside the still. Fukuhara et.al [5] Developed a studied of the production model relied on a film-wise condensation theory for a Tubular Solar Still (TSS) taking account of the thermal resistance of the unsaturated moist air inside the still. The overall heat transfer coefficient between the moist and surrounding air outside the still utilized newly in the present model, because the measurement of surrounding air temperature is easier than that of the inner surface temperature of the tubular cover. Islam et.al [6] In another study scientists compared between their first model of a Tubular Solar Still (TSS) and a second one. The transparent tubular cover of the first model was made up with vinyl chloride sheet, the second model cover was made up using a polythene film, where the assembly, economy and maintenance has been improved as a result of using polythene film instead of vinyl chloride sheet, the weight and cost of the cover of the second model were reduced and the durability was increased. As a result, an empirical equation was suggested relied on this relation to expect the hourly output flux. The applicability of this equation was searched from the comparison with experimental field in Fukui, Japan and in Ras Al Khaimah, UAE. Fukuhara and Ahsan [7] Investigated, a new mass and heat transfer model of a Tubular Solar Still (TSS) suggested incorporating various mass and heat transfer coefficients taking account of the moist air properties inside the still. As a result, the suggested model enabled to calculate the diurnal differences of the water vapor density, temperature and relative humidity of the humid air, and to expect the hourly condensation flux besides the temperatures of the cover, water and trough, and the hourly evaporation flux. The validity of the suggested model was verified using the field experimental results conducted in Fukui, Japan and Muscat, Oman in (2008). Ahsan et.al [8] A detailed comparison was made by group of scientists between an old tubular solar still and improved one the comparison included the design, fabrication, cost and water production. The coefficients of evaporation mass transfer (MTCs) and the coefficients of the heat transfer (HTCs) are higher than the coefficient of condensation. A few field experiments on the new (TSS) were conducted in Fukui, Japan and Muscat, Oman and the observed results are compared with the old one. Arunkumar et.al [9] Studied the experimental work reported an innovative design of tubular solar still with a rectangular basin for water desalination with flowing water and air over the cover. The potable water output performance of a new still has been observed in Sri Ramakrishna Mission Vidyalaya College of Arts and Science, Coimbatore (11_ North, 77_ East), India. The water output rate with no cooling flow was (2050 mL/day (410 ml/trough), but with cooling airflow, output increased to (3050 ml/ day), and with cooling water flow, it further increased to (5000 ml/day). Khudhur [10] Studied attempt to increase the productivity of a tubular solar still. A tubular solar still was designed, fabricated and tested in climatic conditions of Allahabad, India. A fan is utilized to raise the rate of evaporation and condensation inside the still. It is observed that by utilizing fan inside the still, daily yield raised by (8.5%). Rahbar et.al [11] Investigated the ability of a 2-D CFD simulation in computation of mass and heat transfer in a tubular solar still (TSS). Furthermore, suggested new relations to estimate water yield, mass and heat transfer coefficients in the tubular solar still (TSS). Relied on these relations, proposed characteristic curves to estimate water-yield in variable operational conditions.

From surveying the above literatures, there was a wide interest since the start of the present century in the field of optimization of design and operational parameters. Several theoretical and experimental studies were carried out to investigate the effect of varying the parameters on the distillate output of the solar still. These parameters were brine depth, cover material, salinity percentage and the effect of covering the basin by a layer of black paint have also been studied. The climatic parameters have been studies too; they were solar radiation, wind speed and ambient temperature.

In this research, cover material Pyrex glass was used as an external tubular and a basin material is of polycarbonate material black color, where the experiments were conducted in Iraq, Najaf, (at latitude 32° N), which is the first time in Iraq.

In all experiments, tap water was used, where the salinity is between (760-1120) ppm. Experiments took place at the beginning of the month of March to a month August, where the study of the effect of salt water depth, relative humidity, solar radiation and temperature in various weather conditions (clear, partly cloudy and heavy cloudy).

2. Mechanism of fresh water output

The mechanism of potable water production in a TSS is illustrated in Figure 1. The parts of the tubular solar still (TSS) are a transparent tubular cover and a blackened rectangular trough inside the cover. Most of the heat of solar radiation after transmitting the cover is absorbed by the brine water in the basin. The remaining is absorbed by the cover and the basin. Thus, the brine water is heated up and evaporates. The water vapor density of the humid air raises linked with the evaporation from the water surface and then the water vapor is condensed on the inner surface of the cover, releasing its latent heat because of evaporation. Finally, the condensed water trickles down naturally toward the bottom of the cover because of gravity and is stored in a collector.

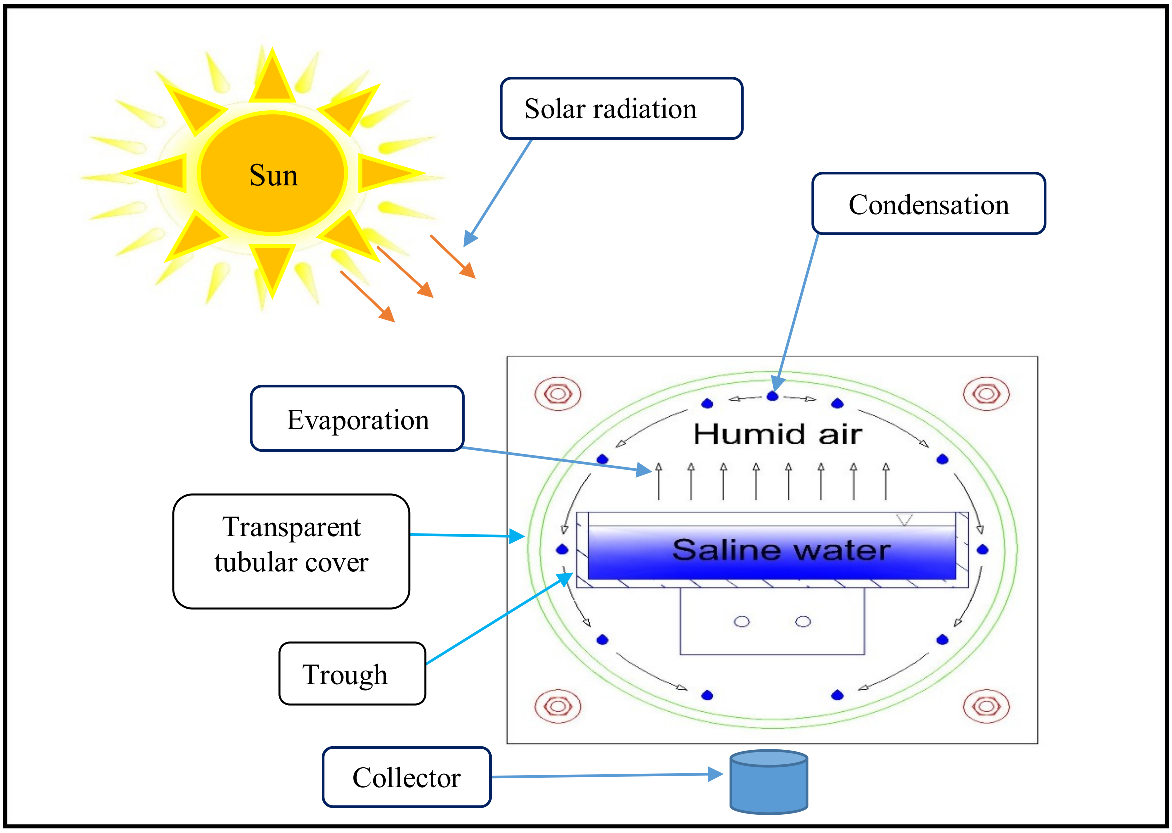

Figure 1. Mechanism of fresh water output in a TSS

3. Model specification

The materials used for the purpose of building the experimental model was a tube of Pyrex glass, two pieces of hard Teflon, several pieces of black plastic, and iron rods, as well as material for gluing and silicon.

The Pyrex glass tube length is (0.6 m), external diameter (0.24 m), internal diameter (0.22 m), the trough has been configured by plastic pieces glued to each other with an adhesive of a rectangular shape, (0.045 m) height, (0.18 m) width and length of (0.54 m), and was glued to supporting frame of the same material on the external aspects of the trough for the purpose of strengthening the structure of the basin, then four pieces glued on the (L) shaped perforated from one side, where the glued pieces to basin bottom in orderly manner, then the bars are inserted through the holes and then fastened by nut with the hard Teflon for the purpose of installing the basin structure distilled. Table 1 Show Specifications of Tubular Solar Still.

The two pieces of hard Teflon is a rectangular shaped with length of (0.26 m), width of (0.26 m) and thickness of (0.15 m). These pieces close the glass tube from both sides, and fasted the trough and is considered a mainstay of the tube glass plus it's base of the solar distilled to put it on the ground.

There are two holes in one of the two pieces of hard Teflon, the first aperture is to insert wires to measure relative humidity and temperature devices (thermocouples), and to sully water through raw water supply hose to the basin, and the other aperture is below at same alignment with the end of the distilled used to collect the output of the solar distilled water, which is controlled by plastic tap, eventually silicon material are added between the ends of the glass tube and two pieces of hard Teflon to prevent any leak could happen, Figure 2 illustrates the dimensions of the model. Experiments were conducted in the technical college, Najaf, Iraq. Figure 3 shows the photograph of the experiment setup.

Table 1. Specifications of tubular solar still

Parameters	Values [m]
Length of tubular cover	0.6
Outer diameter of tubular cover	0.24
Inner diameter of tubular cover	0.22
Thickness of the tubular cover	0.01
Length of trough	0.54
Thickness of trough	0.006
Width of trough	0.18
High of trough	0.045

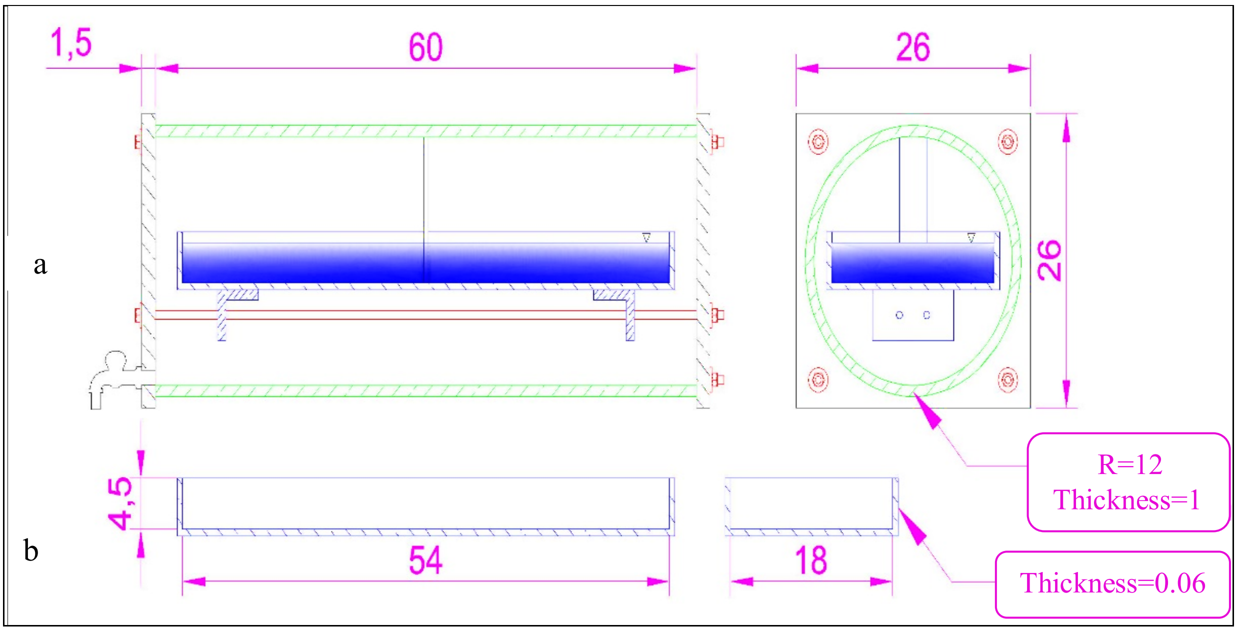

Figure 2. (a) Dimensions of cover, (b) Dimensions of trough. All dimensions in cm

4. Experimental procedures

Thermocouples have been calibrated with a standard mercury thermometer and sketch calibration curves. The digital multimedia is used to save the reading automatically. Temperature is measured at thirteen locations inside the still and four locations outside the still.

Four thermocouples were installed on a ruler length of (0.12 m) is fastened in to the middle of the trough, the first four thermocouples from the top measure temperatures of water vapor and the last one is to measure temperature of the water surface, there are four sites to measure the temperature of water inside trough to be installed in different locations in the trough, as well as the thermocouple installed on the ruler. Temperatures of the inner surface of the tube are measured at five different locations. In addition, the temperatures of the outer surface of the tube were measured at three different locations, as well as the temperature of the ambient was measured by mercury thermometer. Thermocouples and relative humidity locations are shown in Figure 4.

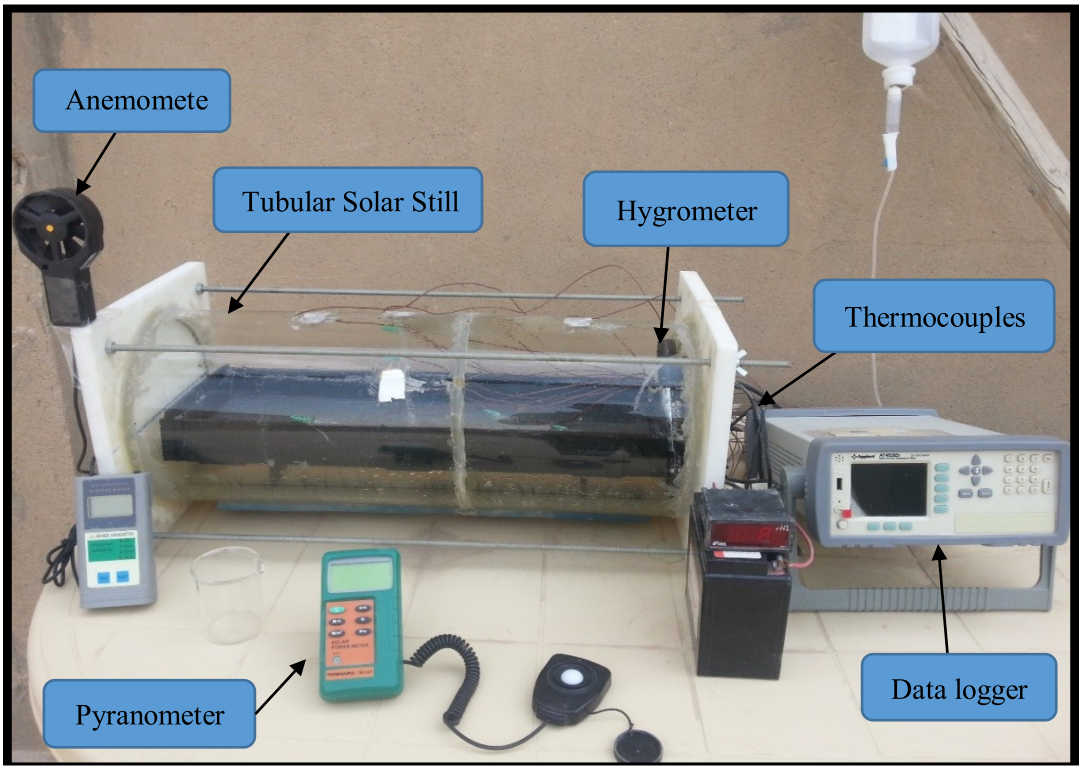

Figure 3. Photograph of the experiment setup

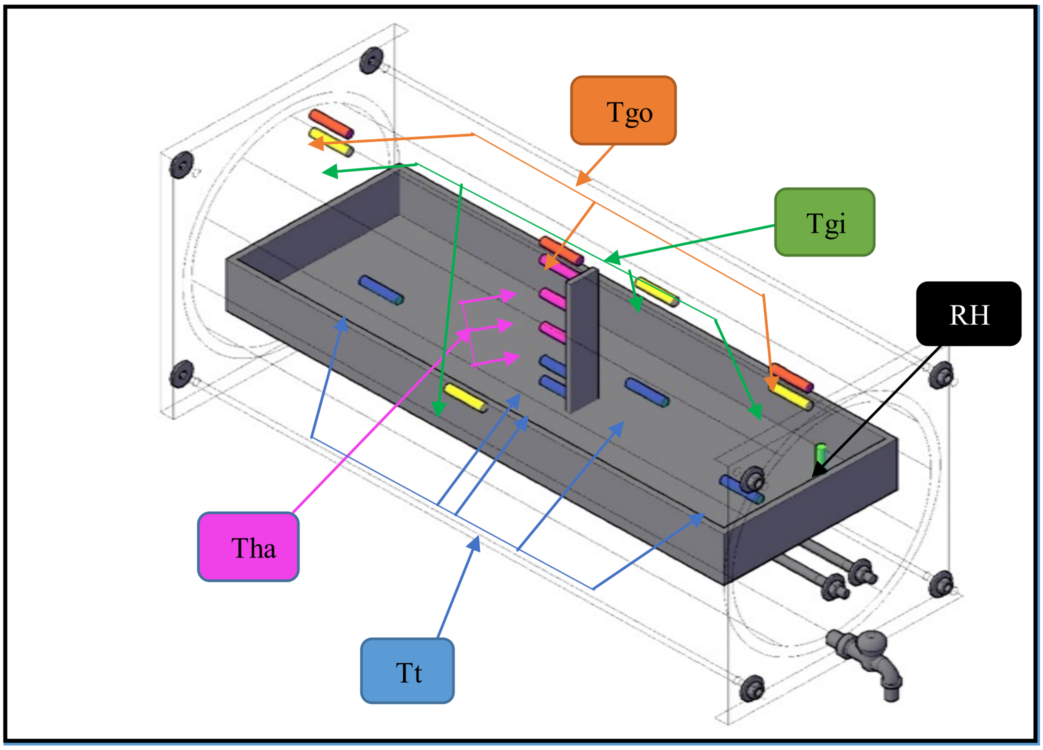

Figure 4. Locations of thermocouples and relative humidity

5. Results and discussions

Figure 5 shows the variation productivity of tubular solar still (TSS) for July 24, 2015, we note the maximum productivity is about (0.88 $kg/m^2.hr$) from 12pm to 13pm, where at this time max solar radiation.

Figure 6 shows the observed diurnal variations of T_{ha}, T_a, T_t, T_c, and T_w obtained in Najaf, Iraq on July 24, 2015. The temperatures, T_{ha}, T_w, T_t, and T_c increase rapidly after sunrise (approximately 7:00 am) and peak between 13:00pm and 14:00pm.

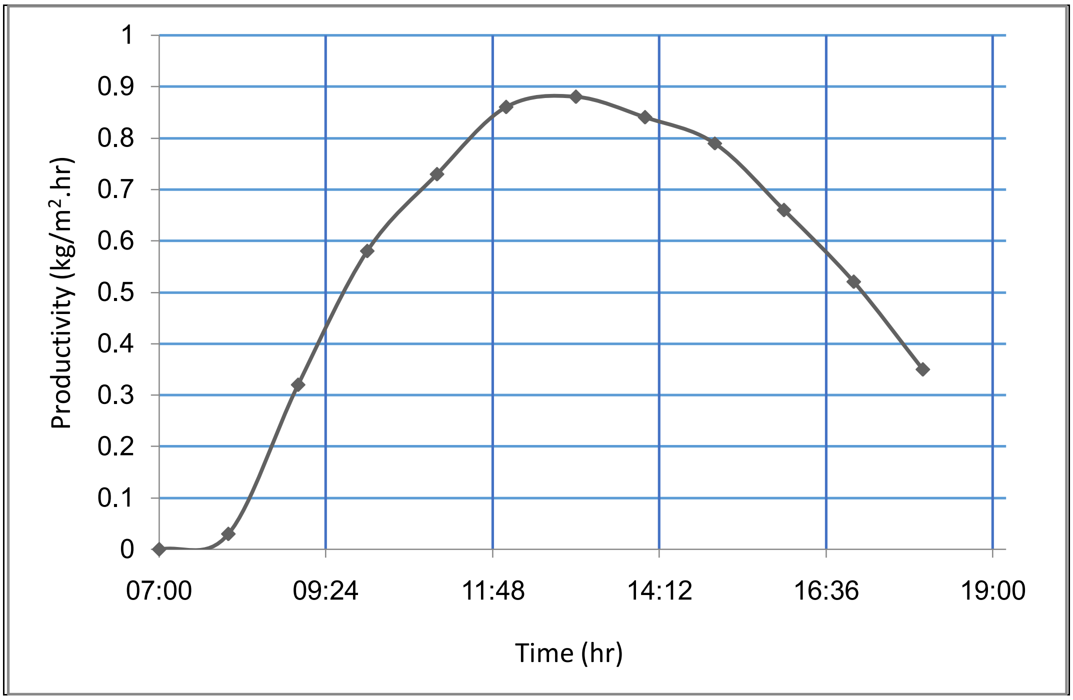

Figure 5. Hourly variations of productivity at water hight in basin at D=1cm (24-7-2015)

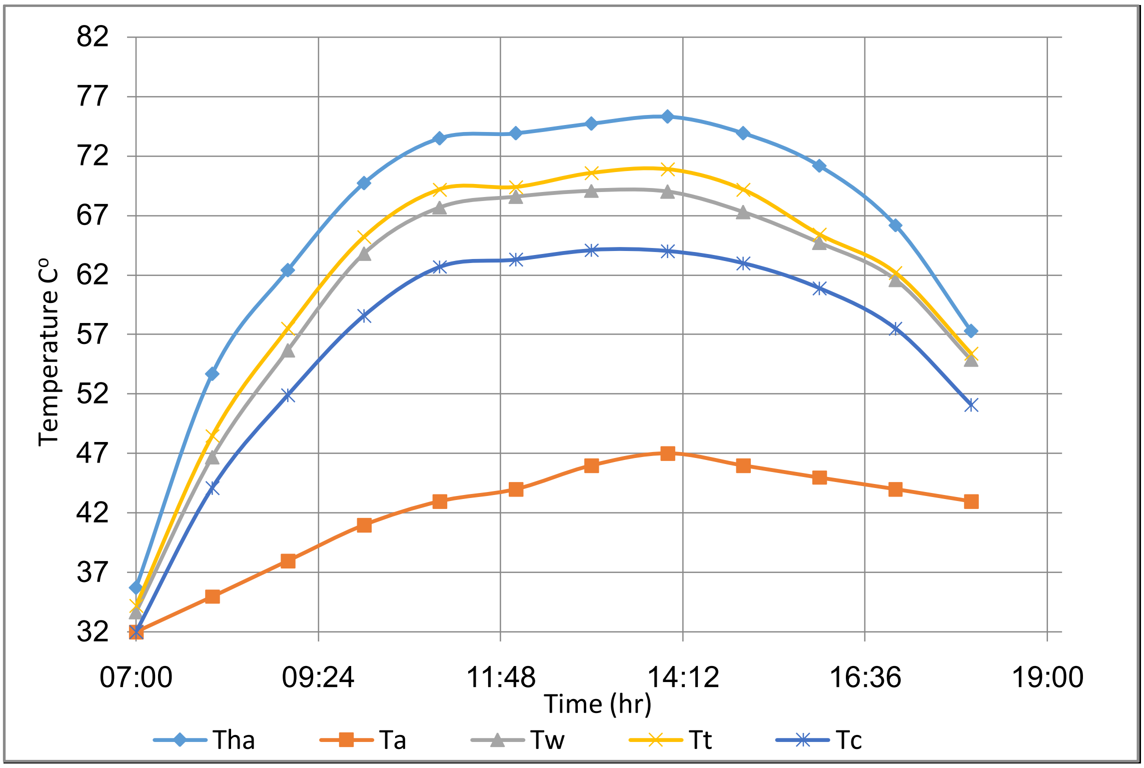

Figure 6. Hourly variations of temperatures at D=1cm (24-7-2015)

Figure 7 shows the variation amount of solar radiation. Solar radiation is the provider of the energy that operates the solar stills. As the brine receives the solar energy, it heats up, and the temperature rise depends on the amount of solar radiation absorbed by the brine or the whole system. This increase in brine temperature motivates it to evaporate rapidly. This motivation is directly affected by the solar radiation intensity, as the intensity increase the evaporation rate increases.

Figure 8 shows Variation of still productivity with brine depth. Brine depth raises with the raise of mass of trough water or brine in the trough. This figure illustrate that increasing brine depth in the trough decreases the productivity of the Tubular solar still. Heat capacity of water is directly related to water mass, so the trough with higher brine depth will have higher heat capacity. The still with lower brine depth operates with temperatures higher than that with higher depths.

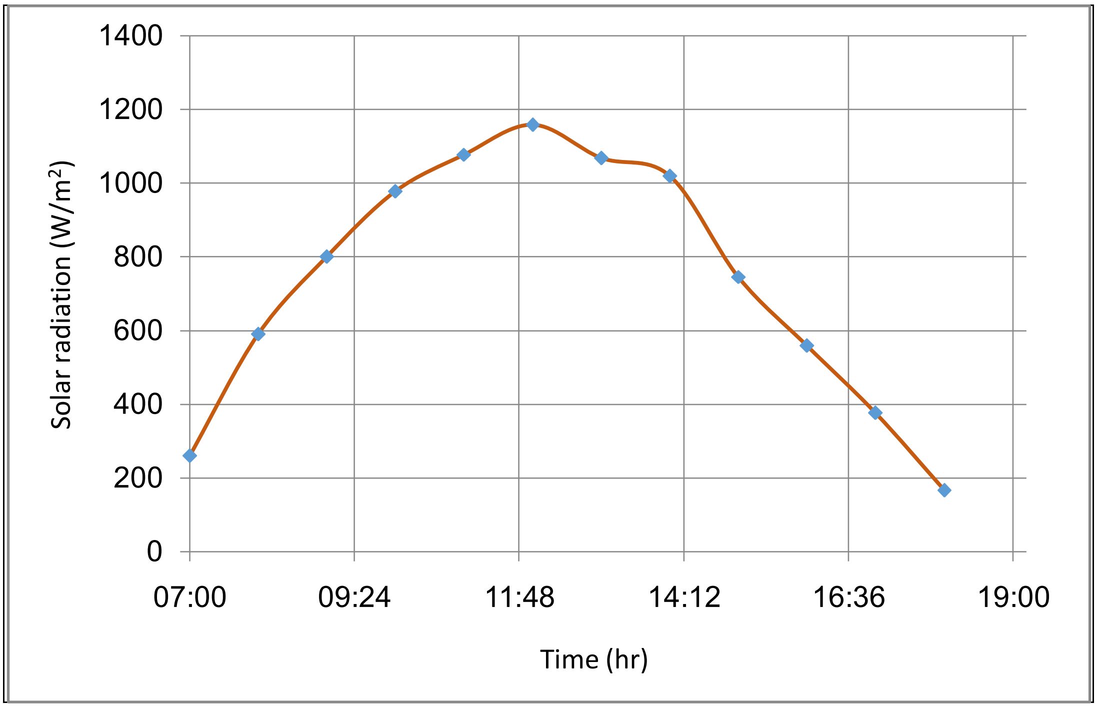

Figure 7. Hourly variations of solar radiation at D=1cm (24-7-2015)

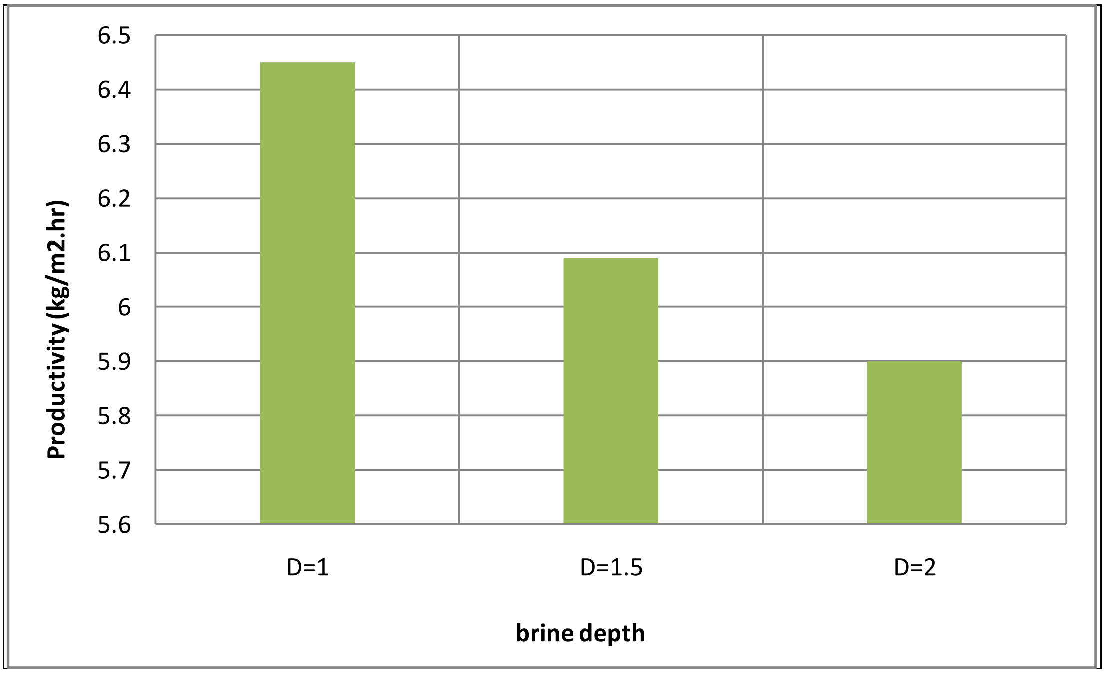

Figure 8. Variation of still productivity with brine depth

Figure 9 shows the observed diurnal Variation of still productivity with direction of TSS at constant brine depth. Where the maximum productivity is remarkably in direction North- South (N-S), because in this direction maximum solar radiation covers maximum area of trough in side TSS.
Figure 10 shows Variation of still productivity with month at basin depth (D=1cm) and fixed direction (North-South), we note that the maximum productivity is about (6.64 kg/m^2.day) at July 2015, because at this month the solar radiation is at maximum rate.

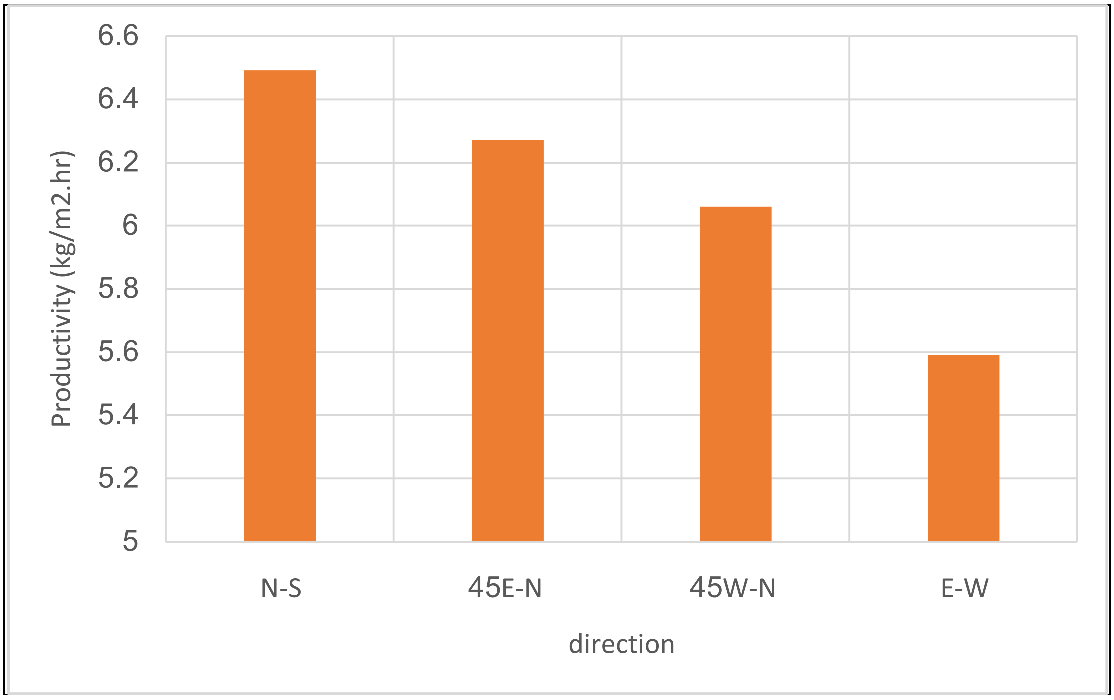

Figure 9. Variation of still productivity with direct

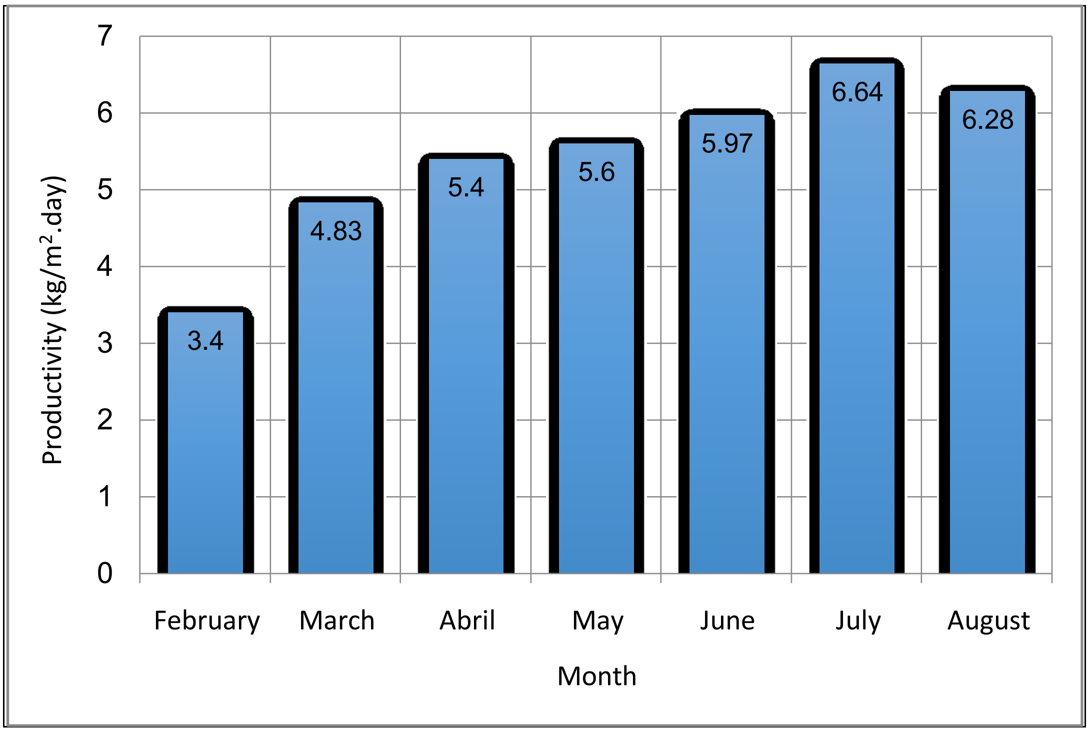

Figure 10. Variation of still productivity with month

Figure 11 shows the experimental productivity and brine temperatures of two days with different weather conditions, first one with sunny conditions and the other one with heavy cloudy weather.

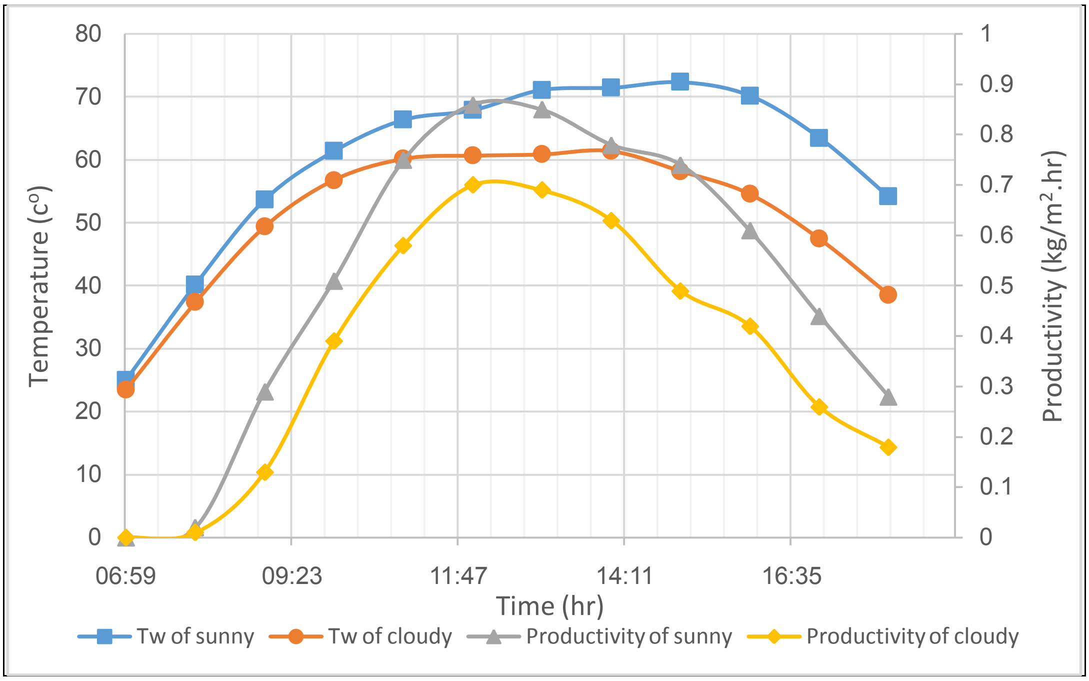

Figure 11. Hourly variations of productivity and brine temperature for sunny and cloudy weathers

6. Conclusions

A tubular solar still (TSS) with rectangular basin is designed, fabricated and tested in Najaf, Iraq (latitude 32°, longitude 44.36°). The productivity of TSS decrease with increase of water depth in basin, and maximum productivity observed in direction (North-South). The average productivity per month obtained maximum value at July, because in Najaf, Iraq at that month get high solar radiation.

Nomenclature

D	Brine depth (cm)	T_{ha}	Humid air temperature (°C)
T_a	Ambient air temperature (°C)	T_w	Brine water temperature (°C)
T_c	Tubular cover temperature (°C)	T_t	Trough temperature (°C)

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