Increasing the Efficiency of the Solar Distillation Device Using Controlled, Concentrated Magnifying Lenses

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The study examines the efficiency of the solar distillation basin that operates on the principle of a thermal cooking mechanism, for a basin in standard dimensions (860 × 520 × 50), tilted to one side at an angle of 15º. The sun's rays were focused using a zoom lens with a diameter of 8 cm, with the sun's rays being tracked through a control system for the purpose of increase focusing it's at the specific location within the distillation basin. The control system consists of a low-cost electronic controller with accessories (direct current motors and structure with flexible joints) that allows the movement of parts to track the path of the sun's rays falling on the lens during the day and every day in the year after programming it by determining the movement path of the sun. After practical experiments with the distillation basin, which contains a control system that controls the location of the lens to focus rays into the basin for the four seasons of the year, with radiation intensity ranging between (0-980) w/m2. The results showed an increase in the amount of distilled water by 4% during the winter and 6% during the Spring and autumn, and 8% during the summer when compared with the same distillation basin but without the lens control system.

Keywords: Distillation water, Desalination of water using solar energy, Fresh water.

INTRODUCTION

Since the most ancient times, man has searched for water and lived near it, and this explains that civilizations have lived, prospered and settled wherever water is found, and since the world is currently facing an increasing shortage in the quantities of fresh water needed to meet its necessary needs in various aspects of civilized life and due to the scarcity of fresh water resources. The provision of fresh water has become an important issue and is considered one of the most problems affecting the lives of people in many regions around the world. Water covers nearly 70% of the Earth's area, with fresh water making up only 3% compared to salt water that makes up 97%, which is the water of the oceans and seas (Z.

Haddada; Abla Chakera, 2017).

Desalination, which is done by removing salt from brine, is expensive and requires very high energy. However, the researchers discovered that the solar distillation method may in the future will be the most viable candidate because it is the most economical system, unlike other systems, due to free energy and lower operating costs (S.A. Kalogirou, 2005). Therefore, desalination by solar energy is considered one of the most appropriate solutions to solve the problem of water scarcity that threatens human life in many regions around the world and it represents an environmentally friendly technology, especially in arid regions where solar energy is abundant and water resources are limited (M. A. Pakdela; M. Hedayatizadehb, 2017).

The other methods that are used to produce fresh drinking water are thermal and non-thermal

methods, most of which depend mainly on traditional energy sources such as oil, gas, coal and nuclear energy, and when used any energy of these causes pollution in the environment and this pollution is one of the biggest challenges of the future in the field of preserving the environment (G.N. Tiwari; H.N. Singh; R. Tripathi, 2003).

The World Health Organization (WHO), recommended that salinity in water is 500 parts per million, but can up to 1000 parts per million for special cases, while the salinity of most of the water available on Earth reaches 10,000 parts per million while sea water is usually its salinity. In the range of 35,000-45,000 ppm as total dissolved salts (G.N. Tiwari; H.N. Singh; R. Tripathi, 2003). For these reasons, researchers around the world are considering using solar distillers to provide sustainable, fresh water, especially in remote areas. There is a great concern because of the low productivity of distillates for these distillates, so various attempts are being made to enhance the distillation productivity of solar distillates.

The inventors (Wheeler and Evans, 1870) first described the greenhouse effect (convection cooking), Where a detailed analysis of water condensation after re-evaporation, through dark surface absorption, is presented. In 1872, the first large solar power plant was built by the Swedish engineer Carlos Wilson (E. Delyannis, 2003).

There are several types of solar distillates that depend on solar energy, namely (Solar basin distillers with single slope, and dual slope), (Pyramid Solar basin distillation) and (Vertical solar distillates) (Jassim M. Al-Asadi, Ahmed, 2013).

MATERIALS AND METHODS

System Definition design

Solar still description

There are many studies clarifying and showing that any work in the field of benefiting from solar energy will have encouraging results. Therefore, the direction has been made to the field of solar distillation and the optimal use of it. The solar distillation basin, which was chosen in this study, the basin area of the still is 0.447 m2 with dimensions (860×520×50) mm on one side and 300 mm on the other side, i.e., at an angle of 15°, considering that the inclination should range between (13° to 18°) °) (Nabil H. Hadi, Ban H. Kassab, 2019). fabricated using 1.0 mm thickness carbon iron (low cost) and painted with black spray paint to increase solar ray's absorption. The still glass cover is formed with four glass sheets of 6 mm thickness. that is installed in a tight manner by using rubber insulators to get a closed space, taking advantage of the possibility of the glass by allowing the sunlight to enter the closed space and not allowing the exit of rays of high wavelengths, so we get a (greenhouse effect).

Note that this arrangement was chosen to increase the condensation rate in order to obtain more solar rays that reach the basin. The device is placed southward to be more exposed to the sun, and the inlet hole is designed with the height of the water inside the basin, and the exit hole for distilled Note that this arrangement was chosen to increase the condensation rate in order to obtain more solar rays that reach the basin. The device is placed southward to be more exposed to the sun, and the inlet hole is designed with the height of the water inside the basin, and the exit hole for distilled water is at the bottom of the channel that drains the condensed water on the bottle that collects the channel.

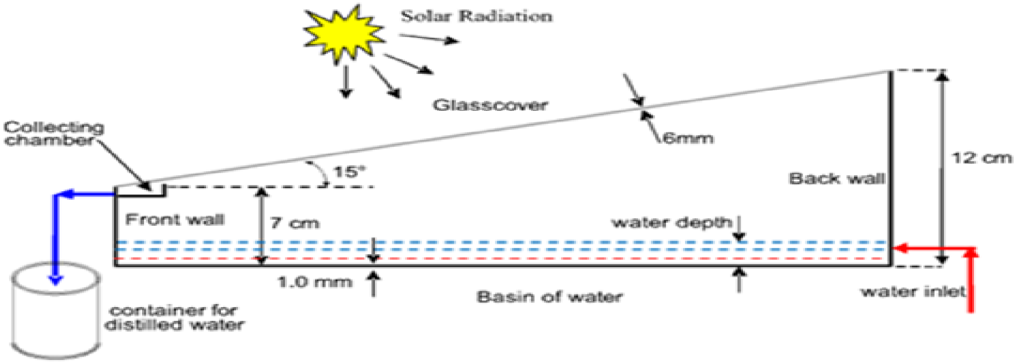

Fig. 1. Schematic Diagram of The Proposed Solar Still

Operating Component

A control system has been added that works to move the Magnifying Lenses with the movement of the sun within the daily and seasonal arc according path as shown in figure (2) with specific time, by using control system consist of the following items

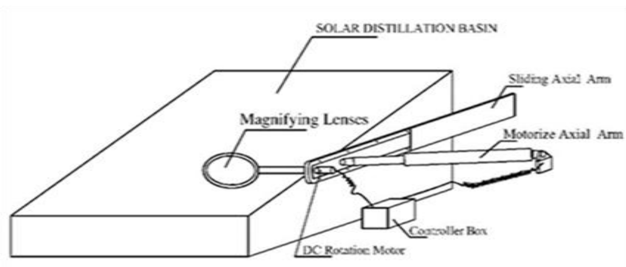

Fig. 2. Components of The Control System

The Raspberry Pi is a single-board computer created by the Raspberry Pi Foundation Tim Cox, (2014). The general specifications of the Microcontroller summarized in Table (1).

Table 1. specifications of the Microcontroller

Parameters	Values

CPU	1.2 GHz 64-bit quad-core ARM Cortex -A53
SD-RAM: Memory	1 GB – CPU Shared
Two USB Port	4 (on-board)
Storage	Micro SDHC
Network: On board	802.11 n, wireless, Bluetooth 4.1
Power Source	5 v Dc via Micro USB

In an SD card of Raspberry Pi must be include the operating system NOOBS, provides an initial start menu that provides options for installing many operating systems available by using SD card, the movement of lenses at specific path can obtain by using programs written in python or C langue.

Movement Parts

As described previously the use of axial direction movement by using DC motor can move an axial direction (depend on the current supplied). Motor specification was, input voltage DC 12V, required power was 20-watt, output shift revolution 10 rpm, as shown in Figure (3).

Fig. 3. Movement Part Mechanism (Axial & Rotation DC Motor)

The operating principle must use another type of DC motor to rotate lenses and maintain the sun's rays perpendicular to the surface of the water inside the basin, during the daytime and maybe along the year a DC motor can rotate in both clock and counter clockwise directions: input voltage DC 12 V, the required power was 2-watt, revolution 5 rpm.

The two DC motors can move a mechanism collection of arms linked together by flexible connections with specific dimensions that allow linear and rotational movement to ensure the movement of the lenses in a path that corresponds to the movement of the sun within the day.

DC Electric Motor Drive.

A complementary accessory to the control system is a 300-ampere, 12-volt rechargeable battery for operating a microcomputer and DC electric motors, and operating the system for an hour in the event of a power failure.

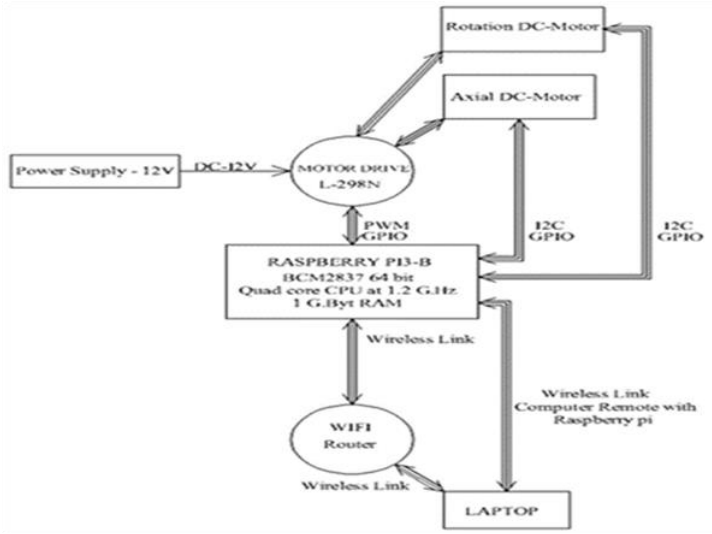

Fig. 4. Schematic Diagram of The Control System

Other accessories include the DC electric motor drive, where the link between the microcomputer and DC Motors, to get high accuracy in the movement, whether linear or rotational movements, according to Pulse-width modulation (PWM) or duty-cycle variation methods are commonly used in speed control of DC motors, as shown in Figure (4).

It is a type of convex lens that is considered one of the most common and simple lenses used. It consists of two convex faces made of the same material, and they have the same convex diameter. Therefore, this lens collects the incoming rays at one point, which is called the focal center. When a beam of light rays falls on the lens, it is refracted when it penetrates the surface of the lens, deviates from its path, and refracts again when it leaves the lens.

The lens directs the light rays that pass through it towards a point called the focal center (the focal point), and it is symbolized by the symbol F, and we call the distance between the eyepiece and the optical center of the lens in focal length (eye length) as shown in Figure (5).

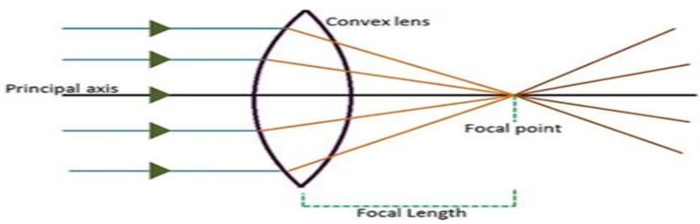

Fig. 5. Schematic Diagram of Rays Falling on The Magnifying Lens (Convex Type)

Theoretical analysis of solar distillation

In this part, a mathematical model will be presented to describe the process that occurs in the solar energy basin. This model helps to determine the equilibrium and loss components of thermal energy in a conventional inclined solar distillation basin with the determination of the hourly saturated vapor pressure of water on the glass, and the coefficients of heat loss and evaporation from the surface of the water to the glass. Various assumptions have been made to simplify the analysis [8]:

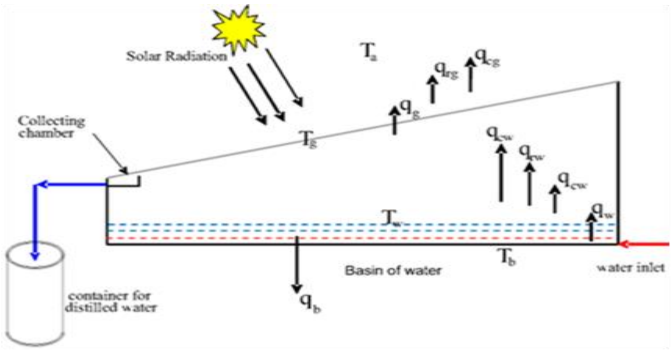

Fig. 6. The process of heat transfer in the solar basin

- There is no leakage for the vapor in a still.
- Dry air and water vapor are ideal gases.
- Considering that the insulating materials used in the aquarium have a very low heat capacity compared to the heat capacity of the aquarium water
- At different temperatures the physical properties of water remain constant even.

External Heat Transfer

External heat transfer is the loss of heat from the still stator and occurs between the stator basin and surrounding areas. The loss of heat transfer, radiation and external convection from the glass cover to the outer atmosphere q_g can be expressed as [10]:

$$q_g = q_{Cg} + q_{Rg} \qquad \text{…. (1)}$$

when:

$$q_{Cg} = h_{cg}(T_g - T_a) \qquad \text{…. (2)}$$

and

$$q_{Rg} = \sigma\, \varepsilon_g \left[\left(T_g + 273\right)^4 - (T_a + 273)^4 \right] \qquad \text{…. (3)}$$

h_{Cg} : Heat transfer coefficient from the glass to the surrounding air (W/m^2 °C).

T_g : Temperature of the glass and may be assumed to be uniform due to the small thickness of the glass cover (°C).

T_a : Sky temperature (°C).

ε_g : Emissivity of glass cover equal to (0.89)

σ : Stefan– Boltzmann constant equal to (5.669 x 10-8 10/m2. K4)

The convection heat transfer coefficient, h_{cg}, depends on the wind speed, as shown in Equation (4.a & 4.b) (Hiroshi Tanaka, Yasuhito Nakatake, 2007).

a) $h_{Cg} = 2.8 + 3.0\ W_s$ if wind velocity, $W_s \leq 5$ m/s …. (4.a)

b) $h_{Cg} = 5.7 + 3.8\ W_s$ if wind velocity, $W_s > 5$ m/s …. (4.b)

Internal Heat Transfer

The heat transfer generated inside the solar basin is an internal heat transfer process that will be responsible for the evaporation process that produces water vapor from impure water, to get pure fresh water. The internal heat transfer q_w, are (convection, evaporation, radiation heat losses from the water to the outside atmosphere and conduction heat transfer between the surroundings and the basin) can be expressed as [12]:

$$q_w = q_{Ew} + q_{Rw} + q_{Cw} + q_b \quad \text{…. (5)}$$

when:

$$q_{Cw} = h_{Cw}(T_w - T_g) \quad \text{…. (6)}$$

$$q_{Ew} = h_{Ew}(T_w - T_g) \quad \text{…. (7)}$$

$$q_{Rw} = h_{Rw}(T_w - T_g) \quad \text{…. (8)}$$

$$q_b = h_b(T_b - T_a) \quad \text{…. (9)}$$

h_{cw} :is the heat transfer coefficient (W/m2 °C) between the inner glass surface and water can expressed:

$$h_{Cw} = 0.88\left[\left(T_w - T_g\right) + \frac{(P_w - P_g)(T_w + 273)}{268900 - P_w}\right]^{1/3} \quad \text{…. (10)}$$

T_w : Temperature of internal glass evaporation heat transfer (°C).

h_{Ew}: Glass evaporation heat transfer coefficient (W/m2 °C), is calculated as

$$h_{Ew} = 16.28 \times 10^{-3} h_{cw}\left[\frac{(P_w - P_g)}{(T_w - T_g)}\right] \quad \text{…. (11)}$$

P_g : Partial vapor pressure.

P_w : Water pressure.

By the following equations can get [13]:

$$P_g = \exp\left(25.317 - \frac{5144}{T_g + 273}\right) \quad \text{…. (12)}$$

$$P_w = \exp\left(25.317 - \frac{5144}{T_w + 273}\right) \quad \text{…. (13)}$$

$$h_{Rw} = \varepsilon_{eff}\sigma\frac{[(T_w - 273)^4 - (T_g - 273)^4]}{(T_w - T_g)} \quad \text{…. (14)}$$

ε_{eff} :is the effective emissivity between the mass of water and the glass cover that depends on the emissivity of water (ε_w) and emissivity of glass (ε_g) and is given by the following expression:

$$\varepsilon_{eff} = \left(\frac{1}{\varepsilon_w} + \frac{1}{\varepsilon_g} - 1\right)^{-1} \qquad \text{…. (15)}$$

T_b : Is the temperature of basin (°C).

h_b : The conduction heat transfer coefficient between the basin and the surroundings (W/m2 °C), is calculated as:

$$h_b = \left(\frac{L_i}{K_i} + \frac{1}{h_{ba}}\right)^{-1} \qquad \text{…. (16)}$$

L_i : is the wall thickness of basin (mm).

K_i: is the wall material thermal conductivity of basin (W/m °C).

h_{ba}:is the total heat transfer coefficient that takes into account the effect of both convection and free conduction:

$$h_{ba} = 5.7 + 3.8\,W_s \qquad \text{…. (17)}$$

h_b: is equal to h_{ba}in case with no insulation

Productivity

The hourly productivity in a solar still can be calculated by (Dr. Atul A. Patil, Prof. V. H. Patil, 2016):

$$m_w = \frac{q_E\,A_w}{L}\,3600 \qquad \text{…. (18)}$$

m_w : mass of water evaporated (kg)

A_w : surface area of water (m2)

L : Latent heat of water evaporation (Kj/Kg) is calculated as:

$$L = 2500.8 - 2.36T + 0.006T^2 - 0.00006T^3 \qquad \text{…. (19)}$$

By using the above formulas, the theoretical solar output can be calculated.

The daily productivity of solar energy can be obtained as follows:

$$M_w = \sum_{i=1}^{24} m_w \qquad \text{…. (20)}$$

Experimentation

The experimental jobs after completing the solar distillation basin with the addition (Magnifying Lenses and accessories for its movement) as shown in Figure (7). To verify the effect of different climatic and operational factors on the productivity of the basin, the test was carried out at the site of the central part of Iraq in Baghdad (latitude: 33° 13'15.34 "north, longitude: 43° 41' 5.13" east).

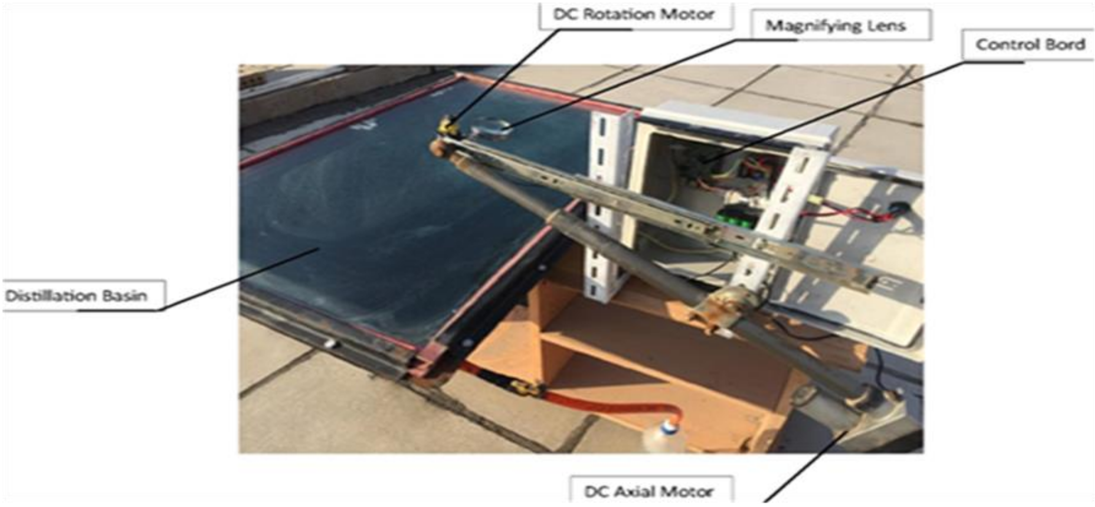

Fig. **7**. Solar distillation basin with controlled Magnifying Lenses

The magnifying glass works to focus the sunlight shining on it on a specific point (a small area) whose diameter does not exceed 3 mm inside the distillation basin at a specific location within the water space. This affects the temperature of the water inside the basin by a specific amount.

Due to the change in the position of the sun over time, as shown in Figure (8) due to the path of the sun, which is sometimes called the arc of the day, which refers to a seasonal and daily path, it is called (the arc of the daily and seasonal path), because the sun moves 360 degrees from east to west every day with respect to Any fixed location on the surface of the Earth, and because of the Earth's tilt, there is a difference in the duration of seeing the sun during one day, which determines the hours of daylight, the most period in the summer, and the shortest period in the winter)Jaafar A. Kadhum, (2018).

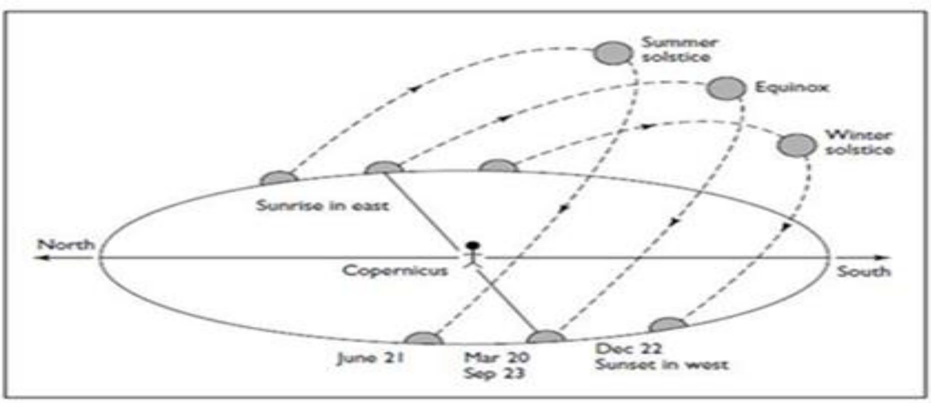

Fig. **8**. The path of sun during the different seasons

In practice, this arc path was tracked by programming the system by determining the movement of the electric motors, during which the process of moving the lenses takes place during the day and during the four seasons to make according to the path shown in Figure (8)

(Watmuff JH; Characters, 1977).

The linear distance that the lens moves over the inclined glass part of the basin during daylight hours was determined, and through it the time and speed

diameter does not exceed 3 mm inside the distillation basin at a specific location within the water space. This affects the temperature of the water inside the basin by a specific amount.

necessary for movement along the distance and for each season of the year were determined (DC Axial Motor) by recording data daylight hours and the time of the sun's movement in. The (geographical location of the study - the city of Baghdad) according to Figure (8). To achieve this path, it required changing the angle of the lens through rotational movement (DC Rotary Motor).

Through an algorithm to control and direct the linear and rotary motor to change the position of the lens from the beginning of the day until the evening, the data was entered into the electronic controller, and the program is repeated daily, taking into account the change in daylight hours per day and the positions of the sun during the seasons of the year (creating integrated data for this purpose).

Theoretically, it is possible to adopt Figure (9), which shows the values of solar radiation on the skyline of the city of Baghdad by choosing specific days within four months of the year (in watts/m2), which were chosen to represent the four seasons of the year, through the use of a handheld sunlight intensity measuring device.

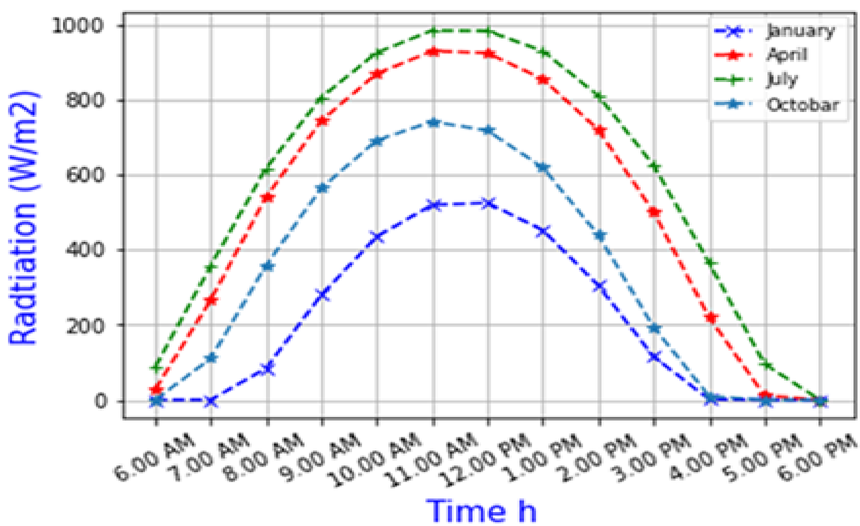

Fig. 9. Solar Radiation Values of Baghdad City

Result

The heated water vapor evaporates from the basin and condenses on the inside of the glass cover. In this process, the salts and microbes that were in the original water are left behind. Condensed water trickles down the inclined glass cover to an interior collection trough and out to a storage bottle. There are no moving parts in Solar basin and only the sun's energy is required for operation. The basin is filled each morning or evening, and the total water production for the day is collected at that time. The still will continue to produce distillate after sundown until the water temperature cools down. Feed water should be added each day that roughly exceeds the distillate production to provide proper flushing of the basin water and to clean out excess salts left behind during the evaporation process.

The temperature values inside the solar distillation basin were determined during specific days of the months (January, April, July, October), which represent the four seasons of the year, using a thermometer with and without lenses and recorded according to Figure (10), where the temperatures are recorded for four days. From each month, the average is taken.

The quantities of water produced from the solar distillation device shown in Figure (11) were calculated within the time periods specified in Figure (8), which represent the seasons of one year, and this was recorded and the results were shown as shown in Figure (11).

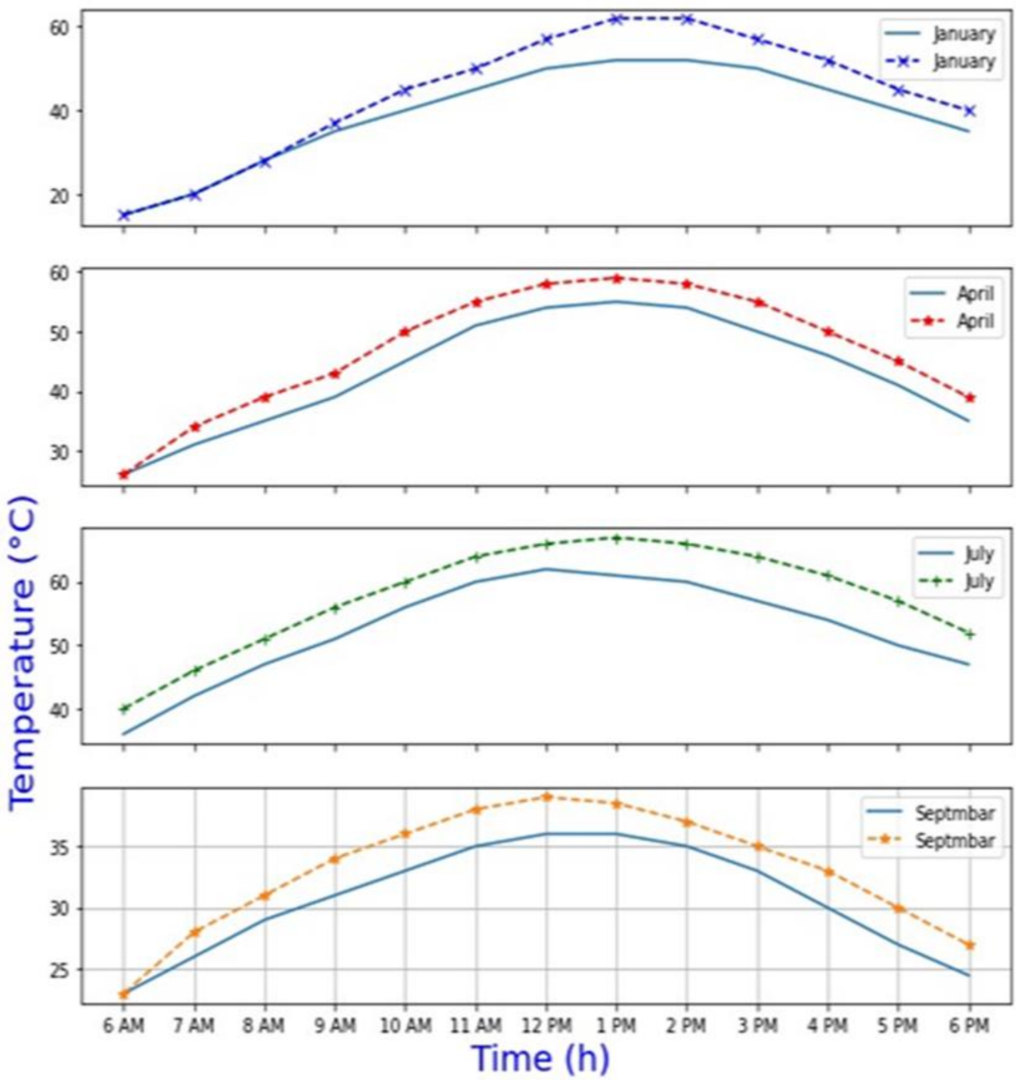

Fig. **10**. Lenses Effect on Average Temperature inside basin

According to the parameters of the practical part, which are the temperatures recorded inside the distillation basin according to Figure (10) and the values of solar radiation according to Figure (9), the quantities of water that we obtain from solar distillation were calculated theoretically according to equations (19-21) within the periods approved in the Figure (10).The results obtained were added to Figure (11) to compare the theoretical aspect with the practical aspect, noting that the quantities of water obtained in practice are for two cases (the case of a solar distillation basin without lenses and the case of a solar distillation basin with one lens as a shown in Figure (5).

Figure (11) is a Histogram Plots of the amount of water obtained by the solar distillation device of the three cases (the amount of water obtained theoretically, the amount of water obtained practically in the absence of the magnifying glass, the amount of water obtained with the use of the magnifying glass).

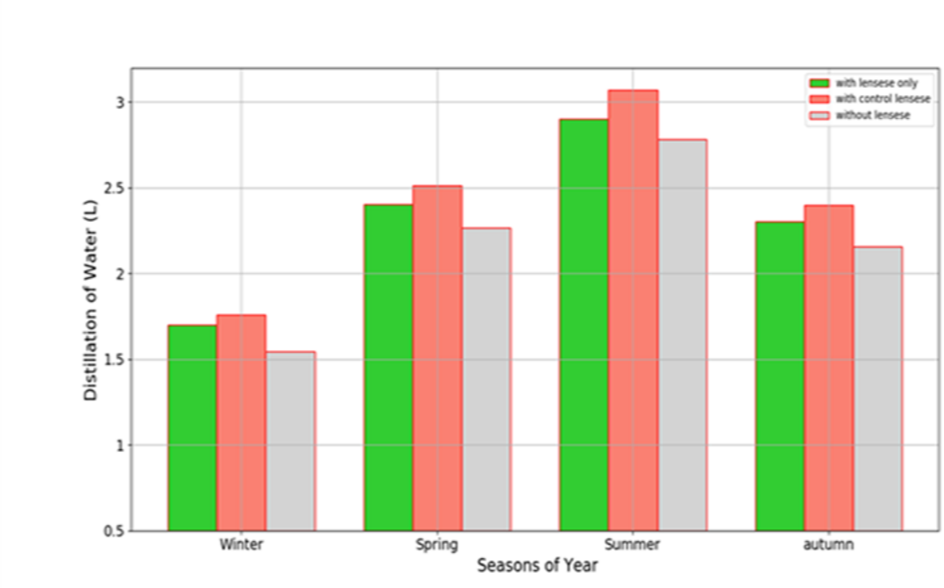

Fig. 1**1**. Theoretical and Experimental calculating the amount of distillation water for the seasons

The difference between the theoretical calculations and the practical ones is due to the presence of factors that were not taken into account theoretically, such as the presence of winds at different speeds during daylight hours, the inability to isolate to the required extent inside the distillation tank, as well as the presence of impurities in the water, which have an effect on the temperature by reducing the transmittance of radiation inside the tank. Or its effect as an insulator as well.

Figure (11) clearly shows the effect of the lens by increasing the amounts of water obtained from the distillation device due to the increased effect of the heat resulting from the concentration of solar radiation by the lens inside the water in the basin. This heat is added to the heat gained inside the basin from the solar radiation dominating the entire basin. The temperature continues to increase for all months (the four months that represent the seasons of one year).

Conclusion

In this study, by adding a control system for the location of the Magnifying Lenses, positive results are gained. There is a possibility to increase the efficiency of the system when increasing the number of magnifying lenses using a single control system and selecting a suitable mechanism for the movements of the lens-bearing parts. The efficiency can be increased if the evaporation temperature is reduced by reducing the pressure inside the closed space in the basin by adding the exhaust fan to the system. The change in the angle of inclination of the glass cover and its effect on efficiency can be studied with the effect of the Magnifying Lenses. The effect of thermal insulation on the efficiency of solar distillation can be studied in the presence of magnifying lenses.

References

Z. Haddada, Abla Chakera, (2017)," Improving the basin type solar still performances using a vertical rotating wick", Elsevier – Desalination: 418, 71–78.

S.A. Kalogirou, (2005), "Seawater desalination using renewable energy sources", Elsevier - Prog. Energy Combust: Sci. 31, 242–281.

M. A. Pakdela, M. Hedayatizadehb, (2017), An experimental study of a single-slope solar still with innovative side - troughs under natural circulation mode, Elsevier – Desalination: 422, 174–181.

G.N. Tiwari, H.N. Singh, R. Tripathi, (2003), "Present status of solar distillation", Elsevier - Solar Energy: 75, 367-373.

E. Delyannis, (2003), "Historic background of desalination and renewable energies", Elsevier – Desalination: 75, 357–366.

Jassim M. Al-Asadi, Ahmed. J. Mohammed, Aqeel. Y. Hashim, (2013), "Types of the Passive Solar Still", Maysan Research Journal: 9-18.

Nabil H. Hadi, Ban H. Kassab, Ali M. Ali, (2019), "Distillation Using Solar Magnifying Lenses and Solar Panels", Association of Arab Universities Journal of Engineering Sciences: 83–90.

Ana Johnson, Lei Mu, Young Ho Park, (2019)," A Thermal Model for Predicting the Performance of a Solar Still with Fresnel Lens", www.mdpi /journal/ /water: 11,1860.

Abhay Agrawal, R. S. Rana, (2019)," Theoretical and experimental performance evaluation of single-slope single-basin solar still with multiple V-shaped floating wicks Abhay", Elsevier - Heliyon: 5, 2405-8440.

Dinesh Kumar, Patel Himanshu, Zameer Ahmad, (2013), "Performance Analysis of Single Slope Solar Still", www.ijetae.com - Certified Journal: Volume 3, Issue 3.

Hiroshi Tanaka, Yasuhito Nakatake, (2007), "Improvement of the tilted wick solar still by using a flat plate reflector", Elsevier – Desalination: 216, 139–146.

D. W. Medugu, L. G. Ndatuwong, (2009), "Theoretical analysis of water distillation using solar Still", www.academicjournals.org/ijps: Vol. 4 (11).

Abhay Agrawal a, R.S. Rana, Pankaj K. Srivastava, (2017), "Heat transfer coefficients and productivity of a single slope single basin solar still in Indian climatic condition: Experimental and theoretical comparison", Elsevier - Resource-Efficient Technologies: 3, 466-482.

Dr. Atul A., Patil, V. H. Patil, (2016), "Mathematical Analysis of Solar Water Distillation System Using Copper Basin", IJSSBT: Vol. 4, No. 2.

Jaafar A. Kadhum, (2018), "Design and Construction of a Tracking Device for Solar Electrical Systems", JSERBR ISSN: CODEN(USA): 2394-2630.

Watmuff JH, Characters, (1977), “Solar and Wind Induced External Coefficients for Solar Collectors”, Complex: Vol. 2, Proctor D.
Tim Cox, (2014), “Raspberry Pi Cookbook for Python Programmers”, Packt Publishing Ltd, Birmingham: B3 2PB, UK: ISBN 978-1-84969-662-3.