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# **STUDYING THE PERFORMANCE OF A LOCAL SOLAR DISTILLER**

**A Research Submitted to the  
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بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

(قَالُوا سُبْحَانَكَ لَا عِلْمَ لَنَا إِلَّا مَا عَلَّمْتَنَا

إِنَّكَ أَنْتَ الْعَلِيمُ الْحَكِيمُ)

صدق الله العلي العظيم

# Certification

I certify that this research entitled " **Studying The Performance of a Local Solar Distiller** " has been prepared by "*Husham Jassim Abd Al-Ameer*" under my supervision at the department of Mechanical Engineering, College of Engineering, University of Babylon as a partial fulfillment of the requirements for the Degree of Higher Diploma of Science in Mechanical Engineering / Fuel and Power.

I recommend that this research be forwarded for examination in accordance with the regulation of the University of Babylon.

Signature

***Prof. Dr. Ahmed Kadhim Hussien***

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Data: / / 2022

# *Dedication*

*To*

*My dear father and mother, May God protect them for me*

*My dear brothers and the flowers of my life, my sisters*

*My dear wife and sons*

*I dedicate my modest effort.*

*Husham.*

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*(In The Name of Allah, The Gracious, The Merciful)*

*(Thanks to Allah for his guidance and help)*

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*Husham*

*/ / 2022*

## Abstract

In this research, a single slope solar distiller was fabricated and tested under the climate of Al- Hilla city with a tilt angle of  $(32.5^\circ)$  according to the latitude of it. The experimental tests were done in November 2021. Two types of the distiller were examined, the first one is a classical type, while the another is modified by adding a twenty-five spherical salt balls and seventeen sponges in its basin. Moreover, the effect of the depth of the water was investigated also. Therefore, four cases were tested as follows:

(Case 1) (25) salt balls and depth of water is (1.5 cm).

(Case 2) (25) salt balls and depth of water is (2 cm).

(Case 3) (25) salt balls + (17) sponges and depth of water is (1.5 cm).

(Case 4) (25) salt balls + (17) sponge and depth of water is (2 cm).

It was found that, using the salt balls and sponges has a good role to increase the productivity for both classical and modified solar distillers. Also, the daily accumulated productivity of modified solar still (MSS) for (Case 3) was higher than that for (Case 1), (Case 2) and (Case 4) by about (26%), (33%) and (24%) respectively. The results show that, the maximum productivity was attained for (Case 3) which was  $(1934 \text{ g/m}^2)$  and  $(1655 \text{ g/m}^2)$  for both modified solar still (MSS) and conventional solar still (CSS) respectively and the payback for this case was (320 days).

Finally, it was found that, the increase in the productivity between (CSS) and (MSS) was about (13.5%), (13.4%), (17%) and (16.1%) for Case 1,2,3 and 4 respectively.

## Nomenclature

Symbols	Definition	Units
A	Area	m <sup>2</sup>
I(t)	Solar radiation intensity	W/m <sup>2</sup>
K	Thermal conductivity	W/m.k
L	Length	m
P	productivity	Kg/m <sup>2</sup>
T	Temperature	C°
V	Wind velocity	m/s
W	Width	m
X	Water depth	cm

### Greek symbols

Θ	Angle of inclination	Degree
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### Sub scripts

Amb	Ambient
B	Ball
Gi	Internal glass surface
Go	External glass surface
Pb	Plate basin
Wb	Water basin

## Abbreviations

CSS	Conventional solar still
CSS-BPW	Conventional solar still with black painted walls
CSS- RAFW	Conventional solar still with reflective aluminum foil sheet walls
CSS- RGMW	Conventional solar still with reflective glass mirror walls
DSSS	Double slope solar still
ETC	Evacuated tube collector
FPCB	Flat plate collector basin
MBSSSD	Modified basin- type single slope solar distiller
MSS	Modified solar still
NPCM	Nanoparticles phase change material
PCM	Phase change material
PPM	Part per million
PW	Paraffin wax
SD	Solar distillation
SSP	Shallow solar pond
SSSS	Single slope solar still
SWF	Steel wool fiber
VRW	Vertical rotating wick

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# CHAPTER ONE

## INTRODUCTION

## Chapter One: Introduction

### 1.1 Introduction

Renewable energy can be defined as one type of energy sources which can be provide light, electricity and heat without polluting the environment. Energy generation from fossil fuels has been identified as the main reason of environmental pollution. The obvious advantage of renewable energy is that no fuel is required, which eliminates the emission of carbon dioxide. The current global energy problem can be returned to insufficient fossil fuel supplies and excessive gas emissions resulting from increasing fossil fuel consumption. It was reported that the present petroleum consumption was  $10^5$  times faster than the nature can create and at this huge rate of consumption, the world's fossil fuel reserves will be diminished by 2050 [1]. Also, it is interesting to mention that the global demand for energy is predicted to be approximately (30 and 46 TW) by 2050 and 2100, respectively [2]. Fossil fuels cover crude oil, coal and natural gas.

These sources supply more than (90%) of our energy demand, but carry a steep environmental cost. For example, the concentration of  $\text{CO}_2$  in the environment have increased from (280 to 370 ppm) over the past 150 years. It's expected to pass (550 ppm) in this century [3]. However, due to the huge demand of energy and lesser availability of fossil fuels, there is a shift towards renewable energy sources. Examples of these sources of energy include solar, wind, biomass, hydrogen and geothermal energies. These clean sources can be used instead of conventional fossil fuels and nuclear energy. Nowadays, there is a huge interest in this subject since. It is expected to provide (50%) of the world's primary energy by 2040.

Moreover, renewable energy can be playing a crucial role to reduce gas emissions to the environment by about (70%) during 2050[4].

## **1.2 Kinds of Renewable Energies**

### **1.2.1 Solar Energy**

Solar energy is one of best sources of renewable energy. It can be used efficiently in various practical applications like solar power plants, solar cell, seawater desalination, solar collectors. etc. In fact, sunlight falling on Earth offers a solution, since the hourly solar flux incident on Earth's surface is greater than the annual human consumption of energy in a year [5]. The Sun emits energy at a rate of  $(3.8 \times 10^{23})$  kW, of which, approximately  $(1.8 \times 10^{14})$  kW is intercepted by the earth.

### **1.2.2 Hydrogen Energy**

Hydrogen is not an energy source, but just an atomic energy carrier. Hydrogen and fuel cell technologies emerged as one of the most favorable solutions to diversity energy resources and to energy sustainability and environment [6]. Fuel cell is usually considered in the framework of hydrogen, since it changes hydrogen and oxygen into water, producing electricity and heat in the process. This occurs in an environmentally friendly way, with no harmful carbon dioxide (CO<sub>2</sub>) emissions.

### **1.2.3 Biomass/Bioenergy**

Biomass is a term called to all organic materials that stem from plants (including algae, trees and crops). Biomass is produced by green plants converting sunlight into plant material through photosynthesis and includes all land and water-based vegetation, together with organic wastes. The biomass resource can be considered as an organic matter, in which the energy of sunlight is stored in chemical bonds. When the bonds between adjacent carbon, hydrogen and oxygen molecules are broken by digestion

or combustion, these substances release their stored chemical energy. Biomass is presently estimated to contribute of about (10–14%) of the world's energy supply [7]. In fact, Bioenergy is the only alternative and cheap source of energy which can be made easily available to the world. Bioenergy is defined as the energy stored in materials made with the help of living things. There are many types of bioenergy sources which can be summarized as follows [8]:

- 1-Biofuels (Bio-oil and Bio-diesel)
- 2-Biogas (Methane and Carbon dioxide)
- 3-Vegetable oil (microalgae and Olive oil)

#### **1.2.4 Wind Energy**

Wind energy is another type of renewable energies which can be defined as the use of the wind as an energy source. A wind energy system (i.e., wind turbine) converts the kinetic (moving) energy of the wind into mechanical or electrical energy that can be utilized for practical use. In fact, wind turbines don't need to burn the fuel. Therefore, they considered friendly to the environment. From the other side, the wind is connected to the sun, so as the sun shines the wind exists on the earth. The effects of wind energy on the environment are generally less problematic than those result from other power sources. Recently, more than (23 billion kW/h) of clean and cheap electricity are being produced annually around the world. For example, India power production utilizing wind energy is estimated around (1000 MW), while Germany produced about (4400 MW) of electricity from wind energy [9].

#### **1.2.5 Geothermal Energy**

Geothermal energy can be defined as the thermal energy extracting from the earth's crust that varies in length between (5 and 10 km). At these

high depths, the temperature is very high. Geothermal energy sources are classified in terms of the measured temperature as low (0-100 °C), medium (100–150 °C) and high temperature (4150 °C) while they extracted by using a ground heat exchanger [10].

### **1.2.6 Tidal/Water Energy**

As the Earth spins on its axis, it rotates through the oceanic tidal bulge raised by the Moon. This leads to the well-known rise and fall of the tides, roughly at (12.5 h) intervals along the seacoast. This process is repeated every day, so the tidal energy represents another source of renewable energy [11].

### **1.3 Solar Distillation**

In general, the distillation is a very old energy intensive method which is utilized for more than hundred years in land-based plants and by the crew of the sailing ships to get the drinking water in the open sea. In desalination process, the thermal energy evaporates brackish or saline water from the basin, as a result, the water steam is collected on the cover which is then condensed as a final product, leaving all salts, inorganic and organic components and microbes behind it. Solar Distillation (SD) is a very energy efficient method, since it uses only the free solar energy [12].

The system is fed by salt water, the output of the system consists of two streams, pure potable water and wastewater with high concentration of salt. Taking the thermodynamic limits into account, the production of a small amount of fresh water as (1.0 m<sup>3</sup>) would approximately consumes energy of (0.71 kW/h) [13]. Also, it is estimated that (10,000 ton) of oil per year is needed to produce (1000 m<sup>3</sup>) of the clean water on daily basis. Using solar energy in desalination process is considered as one of the most promising applications of renewable energy. This method is also intensive

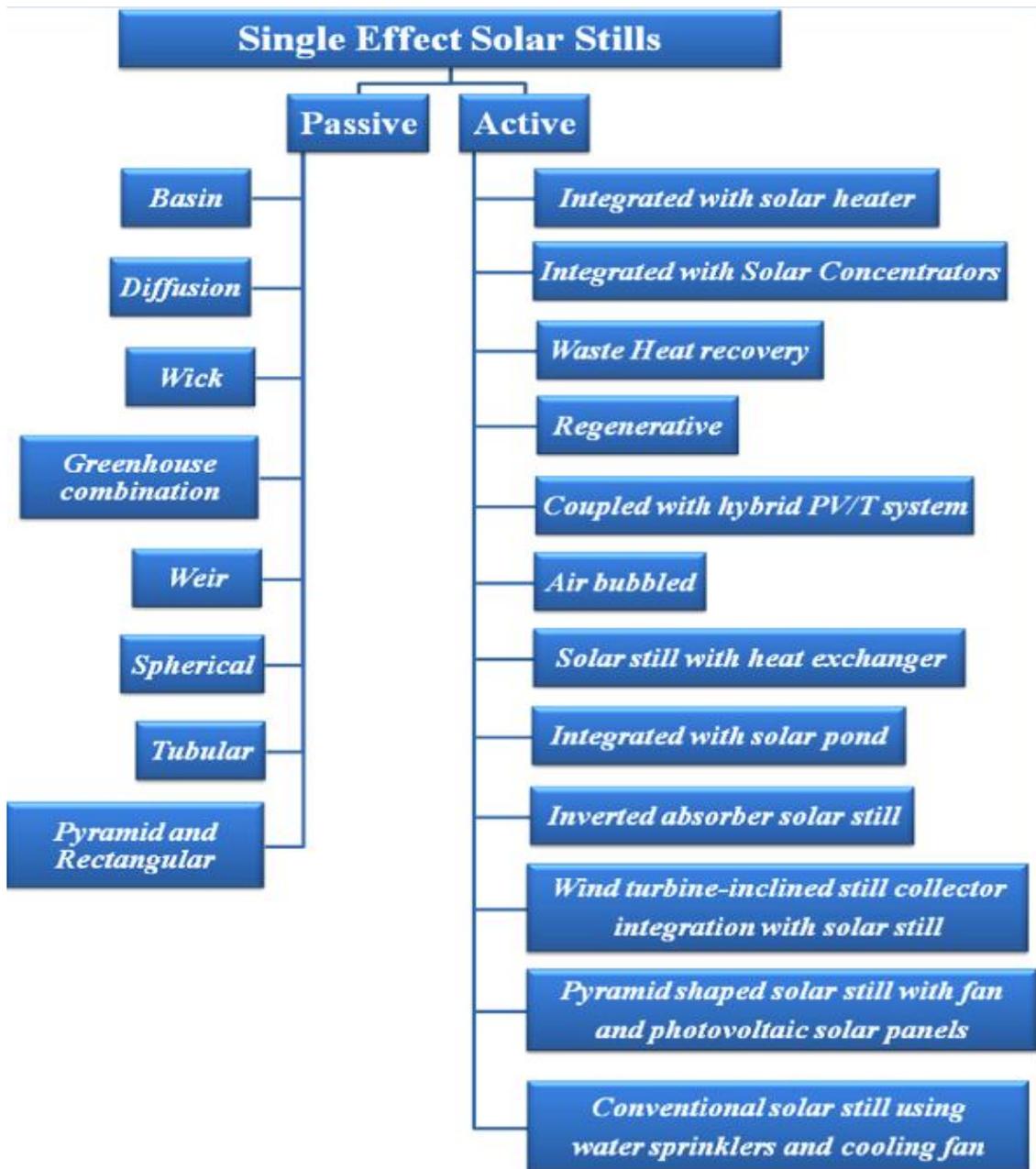
and environment friendly water purification technique [14]. Since, it reduces the emitted amount of greenhouse gas to the environment.

#### **1.4 Solar Still**

The solar still is considered as the most essential component of a solar energy utilization for converting sea, brackish or waste water to a freshwater. It consists of various components such as the glass cover, water basin, absorber plate, insulation and distillate trough channel. It can be defined as an efficient solar device for water distillation that directly uses the heat of the sun. Solar still provides the solar-powered desalination based upon the concept that the solar energy drives directly the evaporation of water. Solar still can be used for distilling, collecting and supplying high quality drinkable water that is essential for the daily survival of the people that live in remote areas or in isolated small communities [15].

Solar stills are simple with no moving parts, cheap to build using locally available materials, friendly to the environment with free pollution, having a low maintenance cost and can be used in arid and salty areas, but its problem is their low water productivity and large area occupancy. Solar stills are suitable for small capacity and self-reliant water supply systems as they are able to produce potable water by the solar energy only. The solar distilled water has better taste compared to commercially distilled water. The main reason is that in solar distillation the water is not subjected to boiling process and hence its pH value is maintained. The most important solar still performance parameter is the productivity. It was defined as the amount of daily water output per unit area of the solar still. The solar stills productivity is determined by the temperature difference between the water in the basin and the inner surface glass cover [16]. Therefore, it mainly depends on evaporation rate of the water from basin and condensation rate of vapor at lower surface of the glass cover. Generally, there are two main

categories for solar stills classification, active and passive stills. A schematic representation is shown in Fig. (1.1) [17].



**Fig. (1.1) Various designs of single effect passive and active solar stills.**

For active solar still, an additional thermal energy is delivered to the basin by an external mode (such as collector/concentrator pane or waste thermal energy from chemical plants) so as to enhance the evaporation rate and hence the productivity is enhanced. Moreover, the temperature difference between evaporating and condensing area is increased in this

type. While, the solar still is called passive, if this external mode is negligible. Therefore, the evaporation and condensation processes take place naturally. In this type, the basin water directly receives the solar energy and it is considered the solely source of energy heats the water. So, the evaporation of the saline water leads to a low productivity which is considered as the biggest disadvantage of the passive still. However, the passive solar stills are inexpensive in providing potable water. Whereas, the active ones are economical from a commercial point of view such as distilled water for selling purposes [18]. the active solar distillation techniques can be classified as follow [19]:

**1-** Active solar distillation of high temperature: In this method, the hot water is fed into the basin by adding more thermal energy to it using solar collectors. In this technique, the temperature is raised from (20–50°C) to (70–80°C) to achieve a better evaporation. The solar still is attached with a flat plate solar collector or a parabolic concentrator, evacuated tube collector, heat pipe, solar pond, Photovoltaic-Thermal energy (PV/T) modules are examples of this technique. The efficiency of the solar still working by this technique decreases with increasing the solar collector area [20]. Regenerative active solar still and air bubble solar still are other examples which are working by using the high temperature active solar distillation.

**2-** Pre-heated water active solar distillation: The temperature of water basin is raised by using pre-heated water. The waste hot water can be obtained from different sources such as chemical or food industries and thermal power plants. It is directly delivered to the basin or throughout heat exchangers. This technique can be used to increase the still productivity by about (3.2 times) compared with the conventional still [21].

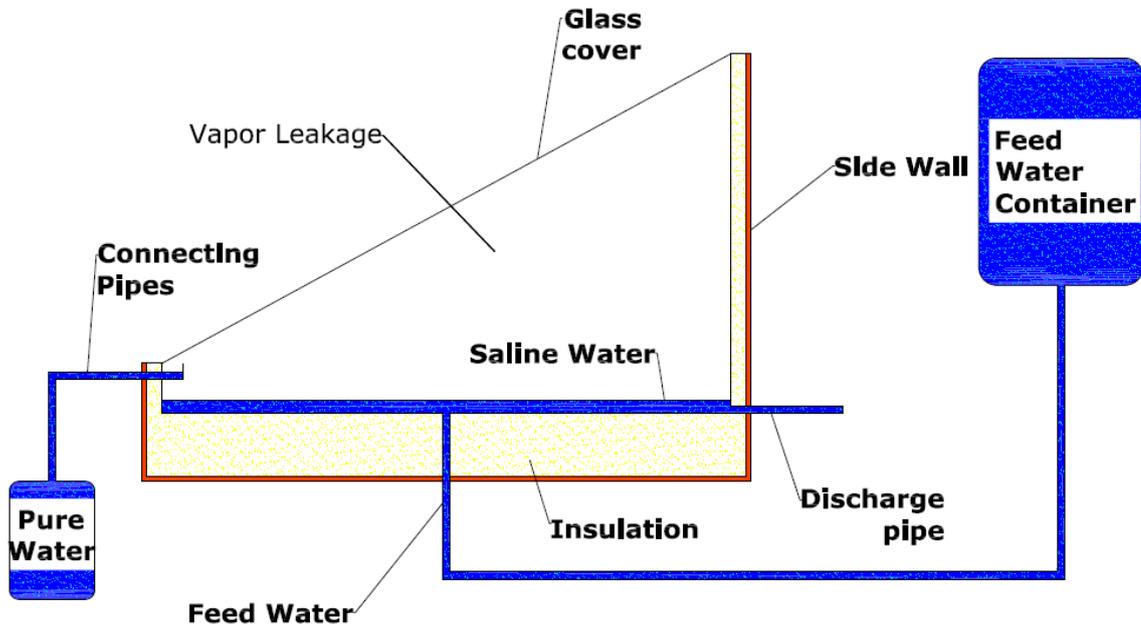
**3-Nocturnal active solar distillation:** In this technique, the hot water is fed into the basin only one time per day. The nocturnal distillation can be defined as working of a solar still when sunlight is unavailable. This normally achieved by using the daily stored solar energy through the night or by supplying waste heat which is available from different sources [22].

Solar stills absolutely employ the same processes that encountered in nature for rainfall generation, (i.e., evaporation and condensation). In this device, the impure water is placed in a container. The solar radiation crosses the glass cover and then absorbed by the lower surface which is coated by a black paint. The absorbed radiation is converted directly into a heat. This heat is absorbed by sea water and partial evaporation of it takes place. The evaporated seawater then condensed into distilled water on the internal side of the cover. After that, the drops of the distilled water begin to slide down due to the gravity, and being collected at the lower section of the tilted glass cover. Whereas, the evaporated water leaves all the contaminants in the basin. Solar stills consist from the following components [23]

- 1- Glass cover, where the water vapor condensation takes place.
- 2- Saline water (brine) body
- 3- Collector plate or basin-liner, where saline water is reserved to absorb the solar radiation.
- 4- Base with insulation to reduce the heat loss.
- 5- Sidewalls or edges.
- 6- Feed water container.
- 7- Distillate output.
- 8- Vapor leakage.

## 9- Connecting pipes.

These components are shown in Fig. (1.2).



*Fig. (1.2) component of the (SSSS)*

The supreme objective of solar stills is to maximize the distillate output. Distillate output depends on many different factors such as climate parameters (e.g. solar intensity, ambient air temperature, wind velocity, humidity of the atmosphere, water-glass temperature difference, and sky conditions), design parameters (like orientation of still, and tilt angle of cover), and operating parameters (like water depth in the basin, and salinity of water) [24].

Types of solar still may include:

- 1- Single-slope solar still.
- 2- Double slope solar still.
- 3- Basin type solar still with internal and external reflectors.

- 4-Inverted absorber solar still.
- 5-Tubular solar still.
- 6-Hemispherical solar still.
- 7-Triangular or pyramidal solar still.

### **1.5 Single-Slope Solar Still**

This is a common popular passive still, two different process occur within the same equipment, namely the distillation and heat collection process [25]. One of the main advantages of this equipment is that it can be fabricated at lower costs due to it is simple design as shown in Figure (1-3) [26]. It composes of a black painted basin, sealed in a fully airtight surface created from a transparent glass or plastic cover. The solar radiation passes throughout the cover and absorbed by the black basin. As a result of solar radiation absorption, the basin water evaporated. The vapor rises until it impacts with the cover inner surface and condensed into the clean water. After that, it runs down alongside the cover bottom surface and collected using the glass stopper. This kind of stills has the ability to supply large quantities of water especially for arid remote areas. It has also relatively low productivity which is less than  $6 \text{ L/m}^2/\text{day}$ . According to these values, an area of one square meter as minimum is need to provide the essential needs for one person [27]. This low productivity is due to the condensation heat loss to the surrounding throughout the glass cover, so some useful heat carried away by the warm condensate.

A single- slope solar still collects more radiation than a double-slope solar still at low and high latitude stations. However, the productivity of this type can be improved by using sponge cubes, phase change materials and fins. Anyway, the single-slope solar still has some advantages such as:

1- It is a very simple solar device used for converting available brackish or waste water into potable water.

2- It can be fabricated easily with locally available materials.

3-The maintenance is cheap and no skill labor is required.

4-It can be a suitable solution to solve drinking water problem.



*Fig. (1-3) photograph of the single slope solar still (Elango et al.[26])*

### **1.6 Objective of the present work:**

The objective of the present study is to investigate the enhancement of productivity of fresh water of the (SSSS) by using two different depths (1.5,2 cm) with two different cases:

- 1- Modified solar still with (25) salt balls.
- 2- Modified solar still with (25) salt balls and (17) sponges.

The results of these cases are compared with conventional solar still.

CHAPTER TWO  
LITERATURE  
REVIEW

## Chapter Two: Literature Reviews

### 2.1 Introduction

The main object of this chapter is to present and summarize most of the published works related with the single slope solar still. Also, the experimental and the numerical analysis of this type of the solar still together with its modification and developments carried out by many authors are outlined and reviewed to give the reader a good over view about the subject studied in the present work. In addition, all the reviewed papers are collected and described in a table. (2.1) at the end of this chapter.

The experimental and theoretical analysis of the (SSSS) were carried out by **El-sebaili et al. [28],2000**, A movable baffle suspended absorber was designed and integrated in the still basin. The results indicated that, the preheating time required for evaporating the water in the still basin was decreased by adding the baffle. Also, it was observed that the daily productivity of the modified still was about 18-20% more than the classical still. The optimum position of the baffle absorber was found to be in the middle of the basin water.

**Shanmugam et al. [29],2012**, investigated experimentally the enhancement of a (SSSS) by using a white marble, pebbles, black stones, calcium stones, and iron scraps individually in the basin. It was found that, the productivity of the solar still with calcium stones was increased by about (5.78 kg/m<sup>2</sup>/day).

**Srivastava and Agrawal [30],2013**, carried out an experimental study to evaluate the performance of the single basin solar still by using porous fins made up of blackened old cotton rags partially dipping in the basin water, while the rest of fins extended above the basin water surface.

They investigated the effect of these fins in winter and summer on the still productivity. They concluded that, the productivity of the modified still was ( $7.5 \text{ kg/m}^2/\text{day}$ ), while the distillate output from the conventional still was ( $6.5 \text{ kg/m}^2/\text{day}$ ).

**Ali and Khalifa [31],2013**, studied experimentally and numerically the enhancement of a (SSSS) by using an indoor solar still with brine depths of 1.5cm, 2cm, 4cm and 5.5cm with an input power of (326.16W). It was found that, the productivity of the solar still was decreased by about (24%) with the increase of the water depth.

**El-Sebail and Shalaby [32],2015**, analyzed mathematically the performance of the solar still by using “v”-corrugated basin. The basin area of the corrugated solar still was ( $0.437 \text{ m}^2$ ). It was found that, the maximum productivity of the solar still was increased by about ( $8.679 \text{ kg/m}^2/\text{day}$ ) by using “v”-corrugated basin.

**Chaichan and Kazem [33],2015**, investigated experimentally the enhancement of a (SSSS) productivity by adding PCM (paraffin wax) to the still base and side. The aluminum powder was mixed also with paraffin wax to enhance its thermal conductivity. It was found that, the productivity of the solar still was increased to ( $2.7875 \text{ l/day}$ ) compared to the traditional still which was ( $1.91 \text{ l/day}$ ).

**El-sebail et al. [34],2015**, carried out an experimental and theoretical study to investigate the productivity of the single basin solar still by using fins in the basin liner. They investigated the effect of the fin geometry parameters such as fin number, its height and thickness on the still productivity and efficiency. They concluded that, the productivity of the modified still was ( $5.377 \text{ kg/m}^2 /\text{day}$ ), which was increased by increasing the fin height. While, it was decreased by increasing both of the fin thickness and its number. The productivity increased by 13.7% higher

than that of the CSS, the number of the fin ( $n_f$ ), height of the fin ( $h_f$ ) and thickness of the fin ( $x_f$ ) equal 7, 0.04 m and 0.001 m, respectively.

**EL-Agouz et al. [35],2015**, carried out a theoretical study to investigate the productivity of a continuous water flow over an inclined solar still desalination system. Three models were studied for this system with and without close loop. Also, they studied the effects of the water mass, water film thickness, and its velocity and air velocity. They concluded that, the productivity of the inclined solar still with makeup water was enhanced by (57.2%) compared with conventional solar still.

**Kabeel and Abdelgaied [36],2016**, investigated experimentally the enhancement of a (SSSS) by using a phase change material (PCM) as a heat storage medium. It was found that, the productivity of the solar still was increased by about (7.54 l/m<sup>2</sup>/day) as compared to a conventional solar still with (4.51 l/m<sup>2</sup>/ day). The results showed that the daily fresh water productivity for modified solar still was (67.18%) higher than that of the (CSS).

**Kabeel et al. [37],2016**, carried out an experimental study to investigate the productivity of the single basin solar still by using a (PCM) and hot air injection. The absorber material of the solar still was copper with an area of (0.615m<sup>2</sup>). It was found that, the productivity of the solar still was increased by about (9.36 l/m<sup>2</sup>/day) as compared to a conventional solar still with (4.5 l/m<sup>2</sup>/day).

**Harris Samuel et al. [38],2016**, investigated the possibility of improving the productivity of a single slope solar still (SSSS) by using different energy storage material such as the heat storage spherical salt balls and sponge materials. The salt was encapsulated in a plastic spherical ball of diameter (62.3 mm). each ball was filled with (127 g) of rock salt and placed axially vertically at a distance of (200mm) in the still basin .It

was found that, the productivity was ( $3.7 \text{ kg/m}^2$ ) by using spherical balls compared with ( $2.7 \text{ kg/m}^2$ ) and ( $2.2 \text{ kg/m}^2$ ) with sponge and without any energy storage materials respectively .

**Haddad et al. [39],2017**, studied experimentally the enhancement of a (SSSS) by using a vertical rotating wick (VRW) to act as an additional collector-evaporation area. It was found that, the productivity of the solar still with (VRW) was increased by about ( $7.17 \text{ kg/m}^2/\text{day}$ ) in summer and ( $5.03 \text{ kg/m}^2/\text{day}$ ) in winter compared to a conventional solar still.

**Rufuss et al. [40],2017**, investigated experimentally and theoretically the enhancement of a (SSSS) by using a nanoparticle and paraffin wax. It was found that, the productivity of the solar still with and without nanoparticle PCM (NPCM) was ( $5.28 \text{ kg/m}^2/\text{day}$ ) and ( $3.92 \text{ kg/m}^2/\text{day}$ ), respectively. Therefore, there was (35%) improvement in productivity observed in solar still with (NPCM) against solar still with (PCM) only.

**Pal and Dev [41],2018**, investigated experimentally the enhancement of a (SSSS) by using a modified basin. The basin was fabricated from fiber-reinforced plastic sheet and acrylic. It was found that, the productivity of the solar still was ( $3200 \text{ ml/m}^2/\text{day}$ ) and ( $2756 \text{ ml/m}^2/\text{day}$ ) at (1 cm) and (2 cm) water depths, respectively.

**Yousef and Hassan [42],2019**, studied experimentally the enhancement of a (SSSS) by using (PCM), pins fins and steel wool fibers(SWF). They examined the performance of the still by using five cases: case 1(CSS), case2(SSSS with PCM), case3 (SSSS with fins and PCM), case4(SSSS with PCM and SWF) case5(SSSS with SWF). It was found that, the productivity of the solar still was increased by (3.262, 3.572, 3.8094, 3.685,  $4.08 \text{ kg/m}^2$ ), respectively.

**Saeed et al. [43],2019**, presented an experimental and numerical study to investigate the productivity of the single slope solar still by using a heat storage material to increase evaporation. They investigated the optimum parameter of (PCM) mass, (NPCM) mass, water mass and solar radiation to give the best productivity. They concluded that, the using of (NPCM) enhanced the productivity by (20%) compared with conventional solar still.

**Attia et al. [44],2020**, investigated experimentally the enhancement of (SSSS) by using a forty-two aluminum balls with a diameter of (2 cm) inside a solar distillates box. It was found that, the productivity of the solar still increased by about (27.16%) when the aluminum balls were used in the basin of (SSSS). Also, they concluded, that the thermal efficiency of the still increased by about (31.6%).

**Essa et al. [45],2020**, investigated experimentally the possibility of improving the productivity of (SSSS) by adding coffee-based colloid as an organic, low cost and eco-friendly alternative to increase the productivity of the fresh water. The coffee-based colloid was prepared by mixing (92g) of distilled water with (7.25g) of Arabic coffee powder. It was found that, the productivity of the modified solar still was (4865.73 ml/m<sup>2</sup>) which was greater than that of conventional solar still by about (35.14%).

**Attia et al. [46],2020**, studied and analyzed experimentally the possibility of improving the productivity of (SSSS) by using energy storage materials such as sand bags (25 cylindrical bags with equal diameter and high of 4 cm). Each bag filled with El Oued sand and placed in the basin of the still. It was found that, the productivity of the modified still was (5.06 l/m<sup>2</sup> /day) while, the conventional solar still productivity was (3.76 l/m<sup>2</sup> /day), therefore it was increased by (34.57%).

**Chandrika et al. [47],2021**, compared experimentally the performance of three types of (SSSS). The first distiller was conventional

solar still with black painted walls (CSS-BPW), the second one was conventional solar still with reflective aluminum foil sheet walls (CSS-RAFW). While, the third distiller was conventional solar still with glass mirror walls (CSS-RGMW). It was found that, the productivity of the (CSS-BPW), (CSS-RAFW) and (CSS-RGMW) was (3.41), (5.1) and (5.54 kg/m<sup>2</sup>), respectively. Compared to the (CSS-BPW), the productivity was increased by (68.57%) when using the reflective glass mirror and (48.57%) when using the reflective aluminum foil sheet.

Author	year	Method of investigation	Place of study	modifications	Conclusions
El-sebaili et al. [28]	2000	E&T	Tanta - Egypt	Using a baffle suspended absorber	The daily productivity of the modified still was about 18-20% more than the classical still.
Shanmugam et al. [29]	2012	E	India	Using of calcium stone, black stone, white marbles, pebbles and iron scraps	Still productivity was increased by (5.78 kg/m <sup>2</sup> /day) using calcium stone.
Srivastava and Agarwal [30]	2013	E	India	Using of porous fin absorber	Still productivity was increased by (7.5 kg/m <sup>2</sup> /day) using of porous fin absorber.
Ali and Khalifa [31]	2013	E&N	Baghdad -Iraq	Using of indoor solar still with brine depths of 1.5cm, 2cm, 4cm and 5.5cm with an input power of 326.16W	Still productivity was decreased by (24%) with increasing the water depth.
El-Sebaili and Shalaby [32]	2015	M	Tanta-Egypt	Using v-corrugated basin.	Still productivity was increased by (8.679 l/m <sup>2</sup> /day) by using v-corrugated basin.
Chaichan and Kazem [33]	2015	E	Baghdad -Iraq	Using of aluminum powder mixed with paraffin wax to enhance its thermal conductivity	Still productivity was increased up to (25.51%) by adding aluminum powder to paraffin wax.
El-sebaili et al. [34]	2015	E&T	Tanta, Egypt	Using fins	The productivity was found to be (5.377 kg/m <sup>2</sup> /day) which is about (13.7%) higher than that of the CSS.
EL-Agouz et al. [35]	2015	T	Egypt	Using of continuous water flow over an inclined solar still.	Still productivity of the inclined solar still with makeup water was enhanced by (57.2%) compared to the conventional solar still.
Kabeel and Abdelgaied [36]	2016	E	Egypt, Tanta	Using of PCM (paraffin wax) with a copper absorber.	Still productivity was improved by about (67.18%) by using PCM.
Kabeel et al. [37]	2016	E	Egypt	Using of PCM (paraffin wax)	Still productivity was increased by (9.36 l/m <sup>2</sup> /day) using PCM

Author	year	Method of investigation	Place of study	modifications	Conclusions
				with copper absorber and hot air injection.	(paraffin wax) and hot air injection.
Harris Samuel et al. [38]	2016	E&T	Chennai -India	Using of spherical ball salt storage materials	still productivity was increased by 3.7 kg/m <sup>2</sup> /day using spherical ball salt storage materials.
Haddad et al. [39]	2017	E	Algeria	Using of a vertical rotating wick (VRW)	The daily productivity of the modified solar still with(VRW) during the summer season was about( 7.17 kg/m <sup>2</sup> )higher than that of the CSS(without VRW) by about( 14.72%).Under winter condition the still daily productivity was( 5.03 kg/m <sup>2</sup> )which higher than by about( 51%) in comparison to the CSS.
Rufuss et al. [40]	2017	E&T	Chennai -India	Using of mixture from CuO and paraffin wax.	Still productivity was increased by (5.28 kg/m <sup>2</sup> ) using mixture from CuO and paraffin wax.
Pal1& Dev [41]	2018	E	Uttar Pradesh-India	Using of fiber-reinforced plastic sheet and acrylic.	Still productivity was increased by (3.2 l/m <sup>2</sup> /day) and (2.756 l/m <sup>2</sup> /day) at (1 cm) and (2 cm) water depths, respectively.
Yousef and Hassan [42]	2019	E	Egypt	Using of (PCM), pin fins and steel wool fibers (SWF)	Still productivity of the solar still increased by (3.262, 3.572, 3.8094, 3.685, 4.08 kg/m <sup>2</sup> ), respectively, using five cases: case 1(CSS), case2(SSSS with PCM), case3 (SSSS with fins and PCM) , case4(SSSS with PCM and SWF) case5(SSSS with SWF).
Saeed et al. [43]	2019	E&N	Najaf-Iraq	Using of PCM -nanoparticles.	The daily productivity reached its maximum value (i.e. 6 l/m <sup>2</sup> ) by using (NPCM).
Attia et al. [44]	2020	E	El-Oued city Algeria	Using of (42) aluminum balls with a diameter of (2 cm) inside a solar distillates box.	Still productivity was increased by (27.16%) when the aluminum balls were used in the basin of (SSSS).
Essa et al. [45]	2020	E	Egypt	Using of coffee-based colloid as eco-	The productivity was enhanced by (35.14%) more than conventional solar still.

Author	year	Method of investigation	Place of study	modifications	Conclusions
				friendly material.	
Attia et al. [46]	2020	E	El-Oued Algeria	Using of an energy storage material such as sand bags	The productivity was improved by (34.57%), by using sand bags compared with conventional solar still.
chandrik et al. [47]	2021	E	El-Oued city Algeria	Using of 1-reflective glass mirrors 2-reflective aluminum foil sheets	The yield of the stills (CSS-BPW), (CSS-RAFW) and (CSS-RGMW) was (3.41), (5.1) and (5.54 kg/m <sup>2</sup> ), respectively. 2-The productivity was increased by 68.57% by using (CSS-RGMW) and 48.57% by using (CSS-RAFW), Compared to (CSS-BPW).
Present study	2022	E	Al-Hilla Iraq	Using of spherical salt balls and sponges	The daily accumulated productivity of (MSS) for (Case 3) was higher than that for (Case 1), (Case 2) and (Case 4) by about (26%), (33%) and (24%), respectively.

# CHAPTER THREE

## Experimental Work

## **Chapter Three: Experimental Work**

### **3.1 Introduction**

The aim of the experimental test in this research is to investigate the effect of some parameters like (solar intensity, ambient temperature and wind speed) on solar distiller performance during the day of the test. In addition, studying the effect of adding a heat storage material like (spherical salt balls and sponges) to the basin of the distiller.

### **3.2 Construction Materials**

The solar distiller was designed and fabricated, it was a single slope solar still which is manufactured from different kind of local materials to get a suitable performance. The schematic and pictorial views of the experimental model are illustrated in Fig. (3.1 and 3.2) respectively. The materials utilized to fabricate the solar still have the following characteristics:

- 1-Materials should have a long time under exposed conditions or be cheap enough to be change upon degradation.
- 2-They should be strong enough to resist the weather conditions.
- 3-They should be non-toxic and not distasteful water under high temperature level.
- 4-They should be able to resist corrosion from saline water and distiller water.
- 5-They should be easy to deal with in the field.

All parts of the solar still constructed in local industrial zone and be described as follows:

### **3.2.1 Basin liner**

A sheet of galvanized iron with (1mm) thickness used to construct the basin liner with dimensions (75cmx75cm). The basin parts were tucked and welded together and painted by a black matt paint to increase the absorption of the solar radiation and protect the basin from corrosion. Also, the lower free edge of the body was welded with a galvanized channel slightly inclined to collect distilled water. Fig. (3.3) illustrates the basin liner.

### **3.2.2 Glass cover**

Solar still cover chosen from transparent window glass to let solar radiation transmitted through it to reach the absorbent basin plate. It has (4 mm) thick and average transmissivity of (0.88) and set up with a tilt angle of (32.5°), according to the latitude and longitude of Babylon city. The glass cover used for condensation of the water vapor that evaporate from the basin. Also, adjustable materials are used to set the glass part on the still structure such as silicon rubber, adhesive and clamps. The dimension of the glass cover is (79cm) in width and (92.5 cm) in length.

### **3.2.3 Insulation**

The material was used for insulating the base and the sides of the solar still has to resist high temperature. In this work glass wool with (5 cm) thickness and (0.04) W/m.K thermal conductivity at (25° )is used as the insulating material to reduce the heat losses from the bottom and side walls of the still .The glass wool sheets placed with in a wooden box .The base of the still and the back wall insulated by (10 cm) thickness from glass wool but the sides are insulated by (5 cm) thickness.

### **3.2.4 Sealant**

A suitable sealant of the glass covers in a solar still is necessary to prevent vapor leakage and leakage of distilled water from joint between cover and the distilled trough. Glass cover has been usually sealant by several materials. While, silicon rubber is the best one, it will adhere strongly to glass and many other materials. It is inert, flexible and can be easily to used, and it remains elastic for quite long time. Therefore, the whole system is made vapor –tight using silicon rubber as a sealant.

### **3.2.5 Piping ports**

Three types of piping ports were used, fill-drain and distilled water are made from copper pipes. The discharge pipe is made from PVC pipe.

### **3.2.6 Solar still frame**

A ply wood sheets with (1.8 cm) thick, used to construct the still frame. Wood frame designed to take the shape of the still and contained all parts of still inside it. Also, a wood stand is built up to lift the wood frame.

### **3.2.7 Feed tank**

A plastic tank with (20L) capacity is used to feed the brine water of the solar still.

### **3.2.8 Level tank**

A plastic tank with floater is used to adjust the level of water inside the basin of the distiller which is connect to the fill-drain hose.

### **3.2.9 Collector of fresh water**

A transparent plastic tank bottle is used to collect the distilled water from the solar still.

### **3.3 Measurements**

The main types of the measurements are used in the experimental test can be classify in to the following parts:

#### **3.3.1 Weight of distiller water**

The amount of distilled water output is measured at each hour from (8:00 AM) to (5:00 PM) by using balance weight device.

#### **3.3.2 Temperature**

The temperature at a various place in the still are measured by K- type thermocouples connected to a 12- channels temperature recorder (model BTM -4208 SD) shown in Fig. (3.4). The measurements include the temperature of the internal and external glass cover, vapor, water brain, basin plate, salt balls and ambient temperature as shown in Fig. (3.5).

#### **3.3.3 Intensity of solar radiation**

It is recorded from metrological center in the department of Mechanical Engineering- Babylon university.

#### **3.3.4 Wind speed**

It is recorded from metrological center in the department of Mechanical Engineering- Babylon university.

### **3.4 Experimental procedure**

A two single slope solar stills were fabricated and assembled from local construction materials:

#### **1-Conventional solar still (CSS)**

It was built up and installed after prepared the required construction materials, the material that used to build up the (CSS) is:

- a) A ply wood with thickness of (1.8 cm), insulation of a glass wool with (5 cm) thickness, window glass cover with (4 mm) thickness, galvanized iron plate with (1mm) thickness.
- b) The basin liner was welded by welding material to form the basin of water, with dimension of (75x75 cm), the high side of (56 cm) and the low side of (10 cm). The trough has been fabricated from a galvanized iron plate with length of (75 cm) and welded inside the basin with a slope of (5%) to collect the fresh water toward the fresh water pipe.
- c) The dimensions of the base of the wooden frame is (85x85 cm) and high side of (60 cm) and low side of (15 cm). The wooden frame is insulated from inside by a glass wool with two layers. Each layer has a thickness of (5 cm) to prevent the heat loss from the basin frame.
- d) The glass cover is installed at angle of (32.5°) with horizontal. The dimensions of the glass are (92x78 cm) and it is sticker by silicon glue to prevent vapor leakage.
- e) There are four holes in the basin frame of the still, the first hole made in the base of the basin to deliver the saline water automatically from the tank level. The second one is made in the rear side of the basin to discharge the salty water. The third one is made in the end of the collecting channel through which the collecting pure water pipe passes out the still and the forth one is made to insert wires of thermocouples.

## 2- Modified solar still (MSS)

It has the same specification of the conventional solar still except adding seventeen pieces of sponge with dimensions of (7x5x4 cm) and a twenty-five spherical plastic balls with a diameter of (4 cm). Each ball filled with (38g) of rock salt and placed at a distance of (12.5 cm) in the

longitudinal and transverse directions as shown in Fig. (3.6). A wooden stand is constructed to hold the experimental rig.

The experimental test examined in two different depths of water which are (1.5 and 2 cm) respectively.

The other experimental test examined just (25 balls) in two different depths of water which are (1.5 and 2 cm) respectively as shown in Fig. (3.7).

When the parts of the solar still device have been assembled, the apparatuses and instrumentation of measurements connected to the device which are:

a) Thermocouples, the temperature is measured at seven places that chosen inside and outside of the still.

(1) glass cover out ( $T_{go}$ ), (2) glass cover in ( $T_{gi}$ ), (3) vapor ( $T_v$ ), (4) basin water ( $T_{wb}$ ), (5) basin plate ( $T_{bp}$ ), (6) salt ball ( $T_b$ ) and (7) ambient temperature ( $T_{amb}$ ).

b) The thermometer device records the data automatically.

c) fresh water collected from the solar still and weigh at each hour of the interval.

d) The experimental data are collected at an interval of 1 hr, starting from (8:00 AM) to (5:00 PM).

### **3.5 Design construction**

#### **1- Basin liner**

A sheet of galvanized iron with dimension of (0.1 x 122 x 244 cm) used to construct the basin liner with dimension of (75 x 75 cm). Also, its high side (56 cm) and low side (10 cm).

## 2- Frame

A sheet of ply wood with dimension of (1.8 x 122 x 244 cm), which is used to fabricate the wooden box with base dimension (85 x 85 cm). Also, the high side (60 cm) and the low side (15 cm).

## 3- Glass cover

A transparent window glass with thickness of ( 4 mm) and dimension of (79 x 92.5 cm) , the surface area of the glass is (0.73 m<sup>2</sup>) and the tilt angle is (32.5 °) , the transmissivity of the glass is (0.88).

## 4- Spherical salt ball

A ball with diameter of (4 cm), volume ( $3.35 \times 10^{-5}$  m<sup>3</sup>) and the number of the specimens (25). The thermal conductivity of the rock salt was (6 W/m.k). Each ball content (38 g) of rock salt, total salt weight (950 g).

## 5- Sponge

A sponge with dimension of (7 x 5 x 4 cm), volume of ( $1.4 \times 10^{-4}$  m<sup>3</sup>) , number of specimens (17). The thermal conductivity (0.674 W/m.k), total weight in the basin (0.058 kg) and the density (25 kg/m<sup>3</sup>).

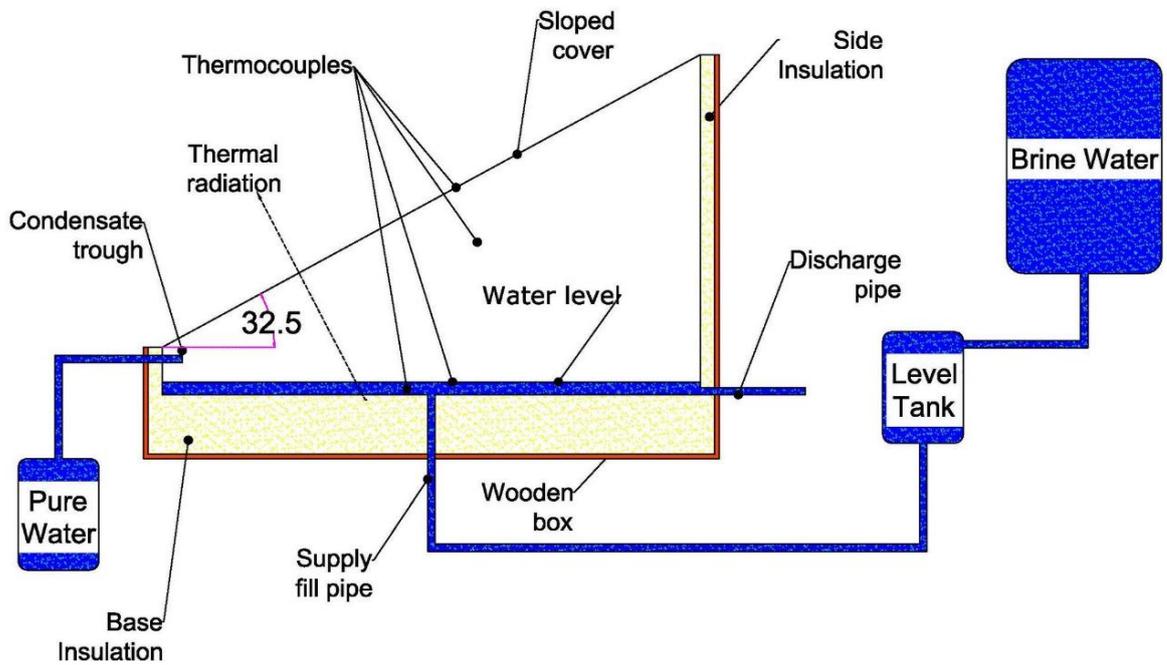
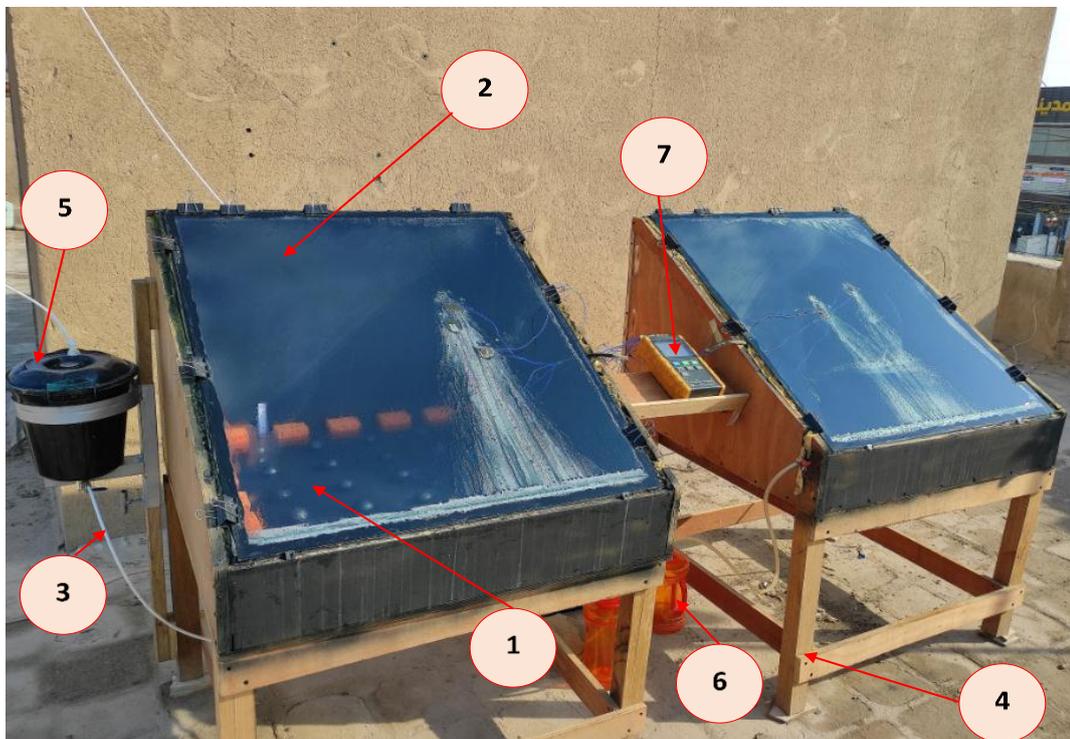


Figure (3.1) The schematic diagram of the experimental prototype.



1	basin liner	5	level tank
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2	<i>glass cover</i>	6	<i>collector of fresh water</i>
3	<i>pipng ports</i>	7	<i>temperature recorder</i>
4	<i>solar still frame</i>		

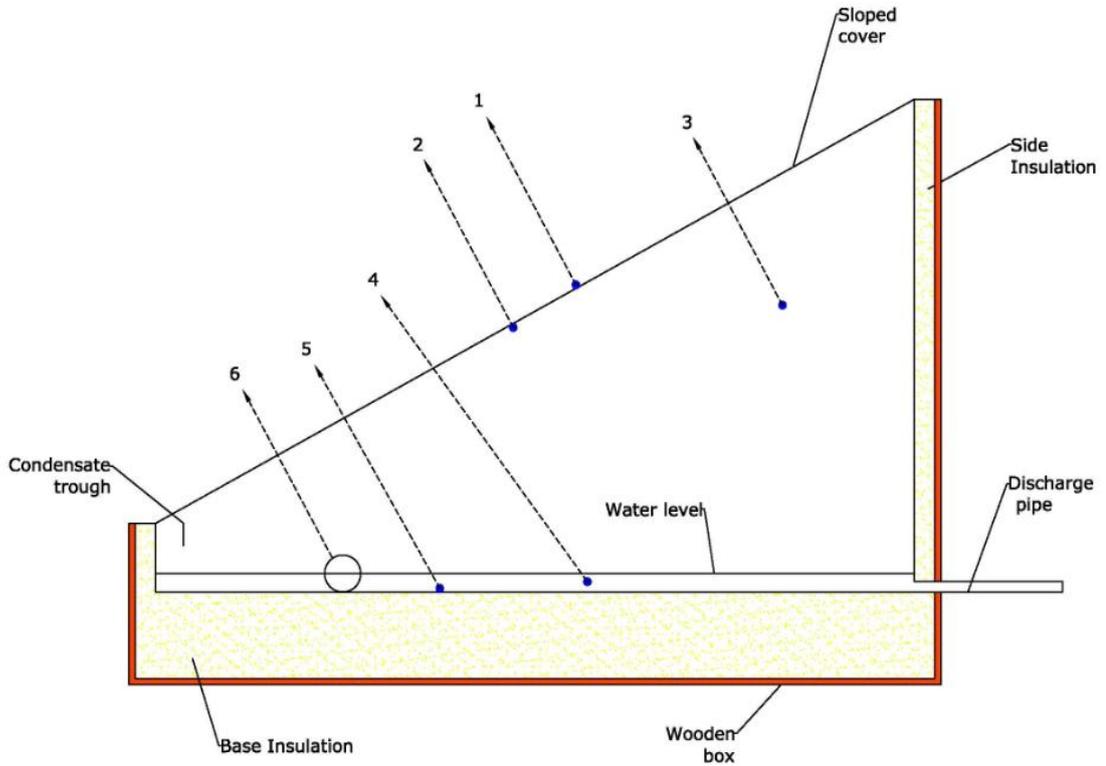
**Figure (3.2) The experimental prototype.**



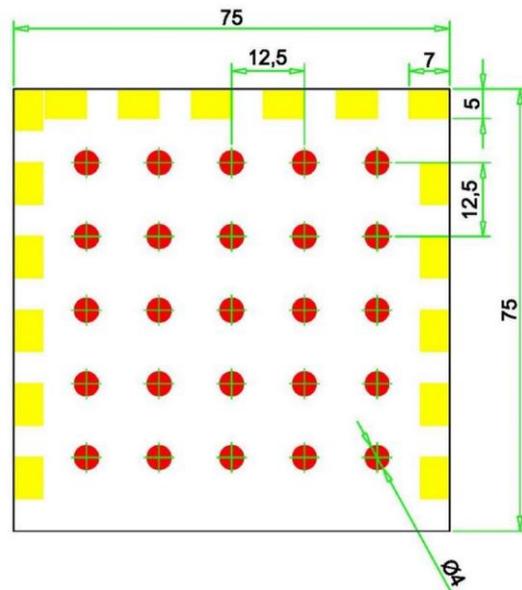
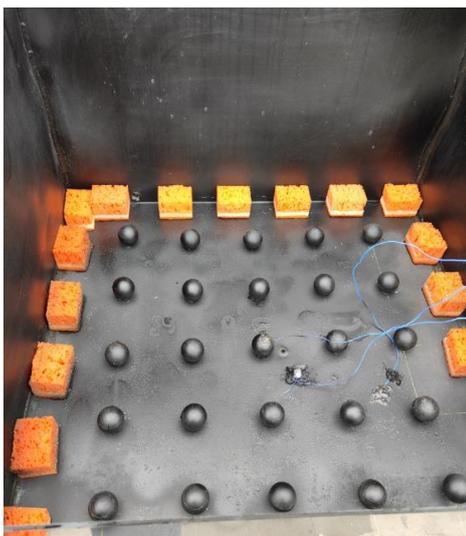
**Figure (3.3) The basin liner.**



**Figure (3.4) 12-channels temperature recorder (model BTM-4208 SD)**

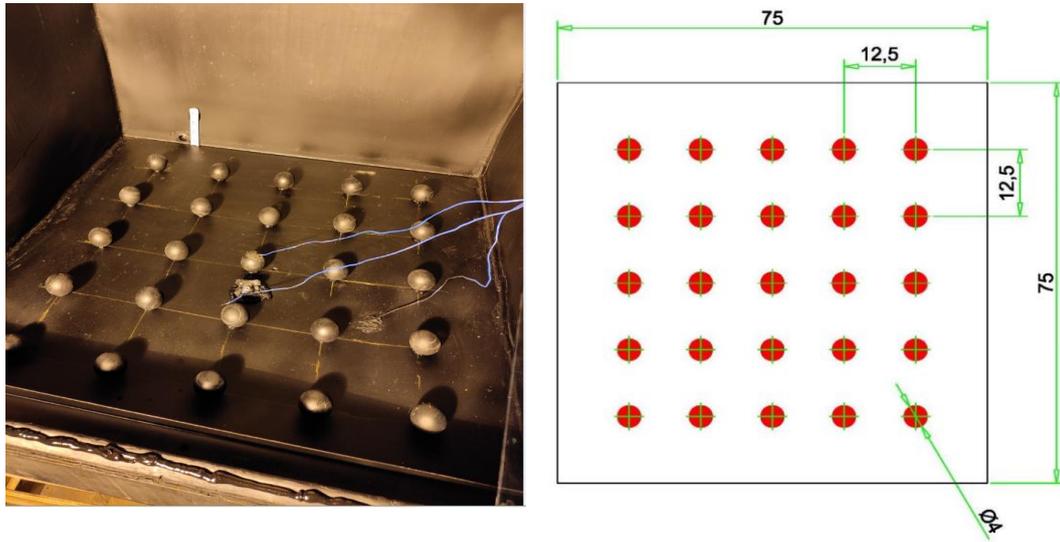


**Figure. (3.5) The location of thermocouples (1) glass cover out, (2) glass cover in, (3) vapor, (4) basin water, (5) basin and (6) salt ball.**



*all dimensions in (cm)*

**Figure. (3.6) Distribution of balls and sponges inside the basin.**



*all dimensions in (cm)*

**Figure. (3.7) Distribution of balls inside the basin.**

### 3.6 Cost analysis.

The payback period of the conventional and modified solar stills depends on the overall manufactured, operating and maintenance costs. It is analyzed for three cases as follows:

#### 3.6.1 Case 1. Conventional solar still (CSS)

Overall fabrication cost to be considered	190000 ID (127\$)
Cost per liter of distilled water	0.48 ID (0.34\$)
Average productivity of the solar still	1.4 kg/m <sup>2</sup> /day
Cost of water produced per day	cost of water/l *productivity=500*1.4=700 ID (0.48\$)

	Maintenance cost	225 ID/day (0.15\$)
	Net earnings =cost of water produced-maintenance	700-225=475 ID (0.32\$)
	Payback period =investment/net earnings	190000/475=400 days

### 3.6.2 Case2. Modified solar still (25 salt balls)

	Overall fabrication cost to be considered	198000 ID (132\$)
	Cost per liter of distilled water	0.34 ID (0.34\$)
	Average productivity of the solar still	1.5 Kg/m <sup>2</sup> /day
	Cost of water produced per day	cost of water/l *productivity=500*1.5=750 ID (0.51\$)
	Maintenance cost	250 ID/day (0.17\$)
	Net earnings =cost of water produced-maintenance	750-250=500 ID (0.34\$)
	Payback period =investment/net earnings	198000/500= 396 days

### 3.6.3 Case 3. Modified solar still (25 balls and 17 sponges)

	Overall fabrication cost to be considered	200000 ID (133\$)
	Cost per liter of distilled water	0.34 ID (0.34\$)
	Average productivity of the	1.75 Kg/m <sup>2</sup> /day

	solar still	
	Cost of water produced per day	cost of water/l *productivity=500*1.75=875 ID (0.6\$)
	Maintenance cost	250 ID/day (0.17\$)
	Net earnings =cost of water produced-maintenance	875-250=625 ID (0.43\$)
	Payback period =investment/net earnings	200000/625= 320 days

# CHAPTER FOUR

## Results and Discussion

## Chapter Four: Results and Discussion

### 4.1 Introduction

In this chapter, the results which are obtained from the experimental tests are presented and discussed. The outdoor ambient conditions during the experiment time in November 2021 include, the maximum ambient temperature is (26.7 C°), while the average wind speed is about (1.2 m/s) and the maximum solar intensity is (494 W/m<sup>2</sup>). As mentioned previously four cases were considered: -

Case 1 (25) salt balls and depth of water is (1.5 cm)

Case 2 (25) salt balls and depth of water is (2 cm)

Case 3 (25) salt balls +(17) sponges and depth of water is (1.5 cm)

Case 4 (25) salt balls + (17) sponges and depth of water is (2 cm)

### 4.2 Case 1 (25) balls (1.5 cm)

Fig. (4-1) shows the variation of the solar intensity and ambient temperature with time for (Case 1) during 24 November 2021. It can be seen from the results, that at the beginning of the experiment at (8:00 am) the intensity of the solar radiation was about (141 W/m<sup>2</sup>) and then increases with the increase in the time until it reaches as expected its peak value at (12:00 pm). After this time, the solar intensity begins to decrease gradually until attains its minimum value at (5:00 pm).

With respect to the variation of the ambient temperature with time. It can be observed from Fig. (4-1), that its variation was similar to that noted previously for the solar intensity. It starts from (13 C°) at (8:00 am) and increases with time until it reaches its maximum value (25.5 C°) at (2:00 pm). Then, a clear drop in (T amb.) can be noted until reaches its minimum value (T amb. =21.1 C°) at (5:00 pm).

Fig. (4-2) illustrates the variation of various temperatures considered in the test with respect to time for both (CSS) and (MSS). These include temperatures of basin water, inner and outer surfaces of glass cover in addition to the temperature of the salt balls. It can be observed from this figure that; the using of the salt spherical balls leads to increase the temperature of the (MSS) compared with the corresponding (CSS). This increasing can be observed during all the time of the test. The reason of this increasing can be going back to the increase of the thermal properties due to the existence of the salt balls. Also, it can be seen from Fig. (4-2) that the deviation in the temperature of the basin water increases gradually until reaches its maximum value at (2:00 pm). These maximum values are about (64 C°) and (61 C°) for both (MSS) and (CSS) respectively. In fact, the absorbed solar energy by the basin of the distiller was converted into a heat and this heat increases the (T wb.) for both (CSS) and (MSS). After that, the air near the water in the basin was heated also which leads to evaporate the water adjacent to it.

With respect to the variation of temperature of the outer surface of the glass cover, it can be noted from Fig. (4-2) that there is a very small difference for it in both (CSS) and (MSS). It increases with time until reaches its peak value at (1:00 pm). After that, it decreases along the time until attains its lowest value at (5:00 pm) which is about (25 C°). This behavior can be seen for both (CSS) and (MSS).

Also, Fig, (4-2) explains the variation in the temperature of the inner surface of the glass cover with the time. The results explain that at (9:00 am) The (T gi) for (CSS) is greater than the corresponding value for (MSS). While, both of them approach to each other at (1:00 pm) and this approaching continues until the end of the experiment at (5:00 pm). Again

at (1:00 pm) the ( $T_{gi}$ ) for (CSS) and (MSS) reaches its highest value which is about ( $59\text{ C}^\circ$ ).

Also, it can be noticed from Fig. (4-2) the variation in the temperature of the salt balls ( $T_b$ ) with respect to time. It can be noted that at the period from (8:00 am) until about (11:00 am), the temperature of the basin water is greater than the corresponding temperature of the salt ball. This is due to low values of the solar intensity at this period of time which makes the salt balls not absorb the solar radiation efficiently.

But, as the solar intensity increases after (11:00 am), the temperature of the ball begins to increase clearly until it exceeds the ( $T_{wb}$ ). The difference between ( $T_b$ ) and ( $T_{wb}$ ) becomes clear especially at (1:00 pm). After this time, the ( $T_b$ ) begins to decrease gradually until it becomes less than ( $T_{wb}$ ) at (5:00 pm). This decreasing is due to the drop in the solar intensity at this time as explained previously in Fig. (4-1).

Moreover, it is useful to mention that the existence of the balls leads to make ( $T_{wb}$ ) of (MSS) are higher than the corresponding temperature of (CSS) even in the afternoon. The reason beyond this behavior is due to the effect of the salt inside the balls which is plays as a thermal energy storage. This energy helps the distiller to evaporate the water after the period of afternoon.

Fig. (4-3) shows accumulated fresh water productivity for (CSS) and (MSS) for Case 1. It can be noted that, the productivity for both of them are approximately the same from (8:00 am) until (12:00 pm). After that, the productivity of (MSS) becomes more than (CSS) and this increasing continues until the end of the experiment at (5:00 pm). At this time, the productivity of (MSS) was increased by about (13.5%) more than (CSS). This increasing indicates that the addition of the salt balls inside the basin

of the distiller has a good contribution to increase the productivity of the fresh water.

### **4.3 Case 2 (25) balls (2 cm)**

The relationship between the solar intensity and ambient temperature with time related to (Case 2) was illustrated in Fig. (4-4). The test of this case was done in 27 November 2021. The solar intensity at (8:00 am) is about (129 W/m<sup>2</sup>) and with progress of the day, it increases gradually until it attains the maximum value of it (i.e., 441 W/m<sup>2</sup>) at the mid of the day. Then, with the increase in the time, the values of the solar intensity begin to drop until it reaches (50 W/m<sup>2</sup>) at the end of the experiment test.

Also, the relationship between the ambient temperature and the time was illustrated in the same figure. A similar trend to that found for the solar intensity can be noted. As expected, at the beginning of the test, the ambient temperature is (14.7 C°) at (8:00 am) and then increases until the peak value of it (i.e., 26.7 C°) is recorded at (2:00 pm). With the progress of the day and due to the drop in the solar intensity, the values of (T amb.) begin to drop and the lowest value of it (i.e., 22 C°) can be observed at (5:00 pm).

The hourly variation of different temperatures for both (CSS) and (MSS) from (8:00 am) to (5:00 pm) was displayed in Fig. (4-5). Again, it can be noted that using of the salt balls leads to make (T wb) for (MSS) overcomes the corresponding value for (CSS). The reason of this increasing is explained previously. In addition, the salt balls can be considered as an excellent tool to serve the thermal energy and liberated it into the water of the basin. The maximum values of (T wb) for both (MSS) and (CSS) are respectively (62 C°) and (59 C°) and both of them are recorded at (2:00 pm). In this time, the solar energy which are absorbed by the water basin leads to this jump in (T wb) for both solar distillers.

From another hand, it can be noted that the increase in ( $T_{wb}$ ) leads to increase the rate of evaporation inside the basin and reaches rapidly to the saturated vapor phase. Moreover, it can be deduced from the results of Fig. (4-5), that the rate of evaporation was inversely proportional to the depth of water basin. So, if a comparison was done between ( $T_{wb}$ ) for both distillers used in (Case 1) and (Case 2), it can be seen that ( $T_{wb}$ ) for (Case 1) are greater than the corresponding value in (Case 2). For example, at (Case 1), at (2:00 pm) they are ( $61\text{ C}^\circ$ ) and ( $64\text{ C}^\circ$ ) for both (CSS) and (MSS) respectively. While, for (Case 2) they are ( $59\text{ C}^\circ$ ) and ( $62\text{ C}^\circ$ ) at the same time. The reason of this behavior is due to the decrease in the latent heat which was transferred to the glass cover. This makes the heat loss overcomes the heat gain when the water depth increases and therefore, the values of ( $T_{wb}$ ) decrease. Furthermore, the hourly variation in ( $T_{go}$ ) for both (CSS) and (MSS) was shown in Fig. (4-5). The results indicated a high matching between the value of ( $T_{go}$ ) for both distillers. They increase with the progress of the day until reach their maximum value (i.e.,  $48\text{ C}^\circ$ ) at (1:00 pm). Then they decrease with the drop in the solar intensity until they reach ( $25\text{ C}^\circ$ ) at (5:00 pm). Again, this trend can be seen for both (CSS) and (MSS). With respect to the hourly variation in ( $T_{gi}$ ). It can be seen that its value for (CSS) are greater than that for (MSS) for the time from (8:00 am – 10:00 am). After that, a different variation can be seen for its behavior up to (1:00 pm). At this time, ( $T_{gi}$ ) reaches its maximum value (i.e.,  $56\text{ C}^\circ$ ). This value was recorded for both distillers. With the reduction in the solar energy, a drop in ( $T_{gi}$ ) values can be seen and this continues up to (5:00 pm).

It is useful to mention that, ( $T_{gi}$ ) has an important role in the productivity of the distilled water. Since, the latter increases as the difference between ( $T_{wb}$ ) and ( $T_{gi}$ ) increases.

Moreover, the hourly variation in (T b) can be noted in Fig. (4-5). As discussed in (Case 1) the effect of the salt balls is slight from (8:00 am to 11:45 am). Since, the ball does not absorb efficiently the enough solar radiation at this range. After this range and due to the increase in the solar intensity, the values of (T b) begin to overcome the values of (T wb) especially at (2:00 pm). As expected, this difference begins to decrease with the progress of the day until the effect of the balls become useless at (5:00 pm).

From another side, it can be noted that the increase of the water depth from (1.5 cm) in (Case 1) to (2 cm) in (Case 2) decreases the values of (T b).

The hourly variation of the accumulated fresh water productivity for both (CSS) and (MSS) related to (Case 2) was presented in Fig. (4-6). It can be noted again that, the productivity for both distillers are very close to each other for the time period from (8:00 am – 12:00 pm). After this period and due to the existence of the salt balls, the productivity of (MSS) begins to exceed that for (CSS) until the end of the test. The increase in productivity was about (13.4%). Moreover, it can be observed by comparing Fig. (4-3) and Fig. (4-6) that the increase in the water depth decreases the accumulated productivity. Therefore, the productivity of (Case 2) are less than that noted in (Case 1). This is because the solar distiller with the lower depth (Case 1) begins to product the fresh water early than that of larger depth (Case 2).

#### **4.4 Case 3 (25) balls + (17) sponges (1.5 cm)**

The hourly variation of the solar intensity and ambient temperature related to (Case 3) during 18 November 2021 was illustrated in Fig. (4-7). It can be seen a periodic variation for both ambient temperature and solar intensity. The latter increases gradually until it attains its maximum value

which was (494 W/m<sup>2</sup>) at the mid of the day. With the further progress of the day, it begins drop little by little until reaches its minimum value at (5:00 pm).

From the other side, the tendency of the ambient temperature is approximately similar to that noted for the solar intensity. It varies from (13.5 °C) at (8:00 am) to (22.6 °C) at (5:00 pm). The maximum value of it was recorded at (12:00 pm) which was about (26.1 °C).

The hourly changes of different temperatures of this case for both (CSS) and (MSS) were represented in Fig. (4-8). The temperature of the basin for (MSS) increases from (13.7 °C) at (8:00 am) to (35.9 °C) at (5:00 pm) reaching its topmost value (i.e., 67 °C) at (1:00 pm). While, it increases from (13.9 °C) at (8:00 am) to (29.1 °C) at (5:00 pm) reaching its topmost value (i.e. 65.2 °C) at (1:00 pm) for (CSS). This increasing in the (T<sub>wb</sub>) between (CSS) and (MSS) is very useful to improve the productivity of the (MSS) as will discussed later. Therefore, it can be concluded that the addition of both the salt balls and sponges leads to increase the (T<sub>wb</sub>) values for (MSS). The reason beyond this is due to their capability to store the thermal energy in the sunrise and enhances it in the sunset. Moreover, both the balls and sponges have a good another benefit. Since, it increases the surface area of the water inside the basin instead of using another expensive method like fins and nano encapsulated (PCM). Also, it can be noted from Fig. (4-8), that the (T<sub>wb</sub>) for both (CSS) and (MSS) is maximum for maximum solar intensity at (13:00 pm). Moreover, the thermal energy saved in the upper surface layer of salt balls dissipates to its lower surface and leads to increase (T<sub>wb</sub>).

From the other side, Fig. (4-8) shows also the variation related to (T<sub>gi</sub>) and (T<sub>go</sub>) for both (MSS) and (CSS). The (T<sub>gi</sub>) for (CSS) is higher than (MSS) due to the delay in the evaporation of water for (MSS) at the

beginning of the test from (8:00 am) to (10:00 am). The maximum value of ( $T_{gi}$ ) for both (MSS) and (CSS) is ( $60\text{ }^{\circ}\text{C}$ ) which is recorded at (1:00 pm).

With respect to ( $T_{go}$ ), the results indicated a similar trend in it for both (CSS) and (MSS). Again, the highest value of ( $T_{go}$ ) for both of them is ( $51\text{ }^{\circ}\text{C}$ ) at (1:00 pm). Furthermore, the hourly behavior of ( $T_{ball}$ ) was illustrated in Fig. (4-8). As mentioned in the previous cases, the effect of the salt balls does not start immediately after the beginning of the test. This can be confirmed from the exceeding of ( $T_{wb}$ ) of both (MSS) and (CSS) to ( $T_{ball}$ ) until about (11:30 am). After that, a clear increase in the values of ( $T_{ball}$ ) can be observed until reaches its highest value (i.e.,  $71.7\text{ }^{\circ}\text{C}$ ) at (1:00 pm). This rapid increasing is due to the hot layer of salts which leads to increase the water temperature in the basin. After that, the ( $T_{ball}$ ) begins to drop gradually until it becomes comparable to ( $T_{wb}$ ) of (MSS) at (5:00 pm).

The variation of the accumulated productivity of the fresh water presented in Fig. (4-9) related to (Case 3). It can be seen that, the productivity of (MSS) is greater than the corresponding values of (CSS) especially after (11:00 am). This difference between them increases with the increase in the time until it reaches its peak values at (5:00 pm). The maximum productivity of (MSS) and (CSS) is ( $1934\text{ g/m}^2$ ) and ( $1655\text{ g/m}^2$ ) respectively.

So, this indicated that the addition of both salt balls and sponges has a positive effect on the productivity of the solar still.

The maximum improvement was about (17%) compared with the (CSS). This increasing is due to the reduction in the heat losses inside the basin by using both balls and sponges and also to the enhancement in the thermal conductivity of the water.

Also, it can be noted that the productivity of the (MSS) in (Case 3) is greater than that noted in both (Case 1) and (Case 2). This ensures that using of sponges together with the salt balls is efficient.

#### **4.5 Case 4 (25) balls + (17) sponges (2 cm)**

In this case, both the effects of the addition of the salt balls and sponges together with the increase in the depth of water were investigated and discussed.

Fig. (4-10) illustrates the variation of both the solar intensity and ambient temperature with respect to the time undertaken in the experiment. The test was done at (23 November 2021). As been discussed in the previous cases, both the solar intensity and ( $T_{amb}$ ) were increased with the time. The peak of the solar intensity can be found at (12:00 pm) and recorded as ( $453 \text{ W/m}^2$ ). In the same trend, the value of ( $T_{amb}$ ) increases also with the time from ( $14.3 \text{ C}^\circ$ ) at (8:00 am) until it attains the peak value (i.e.,  $25.8 \text{ C}^\circ$ ) at (2:00 pm). Again, with progress of the time both the solar intensity and ( $T_{amb}$ ) decrease until they reach their lowest values ( $40 \text{ W/m}^2$  and  $20.7 \text{ C}^\circ$ ) respectively at (5:00 pm).

Fig. (4-11) explains the variation in ( $T_{wb}$ ), ( $T_{gi}$ ), ( $T_{go}$ ) and ( $T_b$ ) for both (CSS) and (MSS) with respect to the time adopted in the experiment. It can be seen from the results that ( $T_{wb}$ ) for (MSS) are greater than the corresponding value for (CSS). This result can be returned to the role of the salt balls and sponges in the distiller basin. For (MSS), it varies from ( $14.2 \text{ C}^\circ$ ) at (8:00 am) to ( $30.5 \text{ C}^\circ$ ) at (5:00 pm) and its maximum value was recorded (i.e.,  $61.4 \text{ C}^\circ$ ) at (2:00 pm). Whereas, for (CSS) it varies from ( $17 \text{ C}^\circ$ ) at (8:00 am) to ( $24.3 \text{ C}^\circ$ ) at (5:00 pm) and its highest value can be found again at (2:00 pm) which was ( $58.6 \text{ C}^\circ$ ). It is useful to mention that the increase in ( $T_{wb}$ ) between (CSS) and (MSS) is due to the addition of sponges and balls in (MSS). The advantage of the salt

balls was explained in (Case 3). While, the merits of using sponges it increases the surface area of the water in the basin and reduces the surface tension between the water particles. These two merits improve the process of the water evaporation.

With respect to the hourly variation of ( $T_{go}$ ) and ( $T_{gi}$ ) for both (CSS) and (MSS), it can be seen from Fig. (4-11) that there is a clear matching between the values of ( $T_{gi}$ ) for both (CSS) and (MSS). This matching continues until the end of the test at (5:00 pm). For ( $T_{go}$ ), it was noted that it increases for both (CSS) and (MSS) with increase in the time and the maximum values of it was recorded at (1:00 pm). After that, a drop can be shown until it reaches its minimum value at (5:00 pm).

Again, it can be shown from Fig. (4-11) that there is a clear delay in the effect of the salt balls. This can be confirmed from low values of ( $T_b$ ) in the period from (8:00 am) to (10.45 am). Then, the values of ( $T_b$ ) increase until it reaches its peak value (i.e.,  $65\text{ C}^\circ$ ) at (1:00 pm). Since, the salt inside the balls leads to increase the temperature of the water in the basin. After this time, ( $T_b$ ) reduces but its values still above the values of ( $T_{wb}$ ) until the end of the test. This confirms that, the addition of the salt balls is beneficial.

The hourly variation in the accumulated productivity for both (CSS) and (MSS) was illustrated in Fig. (4-12). As was noted in previous cases, the productivity for both of them are very close to each other up to (10:00 am). After that, the productivity of (MSS) exceeds that for (CSS) until the end of the test. The maximum values of the productivity are ( $1557\text{ g/m}^2$ ) and ( $1340\text{ g/m}^2$ ) for both (MSS) and (CSS) respectively. SO, it can be concluded that the addition of balls and sponges increases the productivity by about (16.1%).

Now, in order to highlight about the effect of the increase in the depth of water on the distiller productivity, one can make a comparison between this case and (Case 3). It can be deduced from this comparison that, the productivity of (Case 4) is less than that noted in (Case 3). Since, the increase in the depth of water delay the process of the distillation and as a result decrease the productivity.

The variation of the accumulated productivity with respect to various studied cases for both (CSS) and (MSS) was shown in Fig. (4-13). For all studied cases, it can be observed that the productivity of (MSS) was higher than that for (CSS). This indicated that, the using of salt balls and sponges have a good role to modify the distiller productivity. From another side, it can be observed that the increase in the depth of basin water from (1.5 cm) in (Case 1) to (2 cm) in (Case 2) decreases the productivity of both (CSS) and (MSS). The same thing can be noted in (Case 3) and (Case 4).

Moreover, it can be observed from Fig. (4-13) that the increase in the productivity between (CSS) and (MSS) was about (13.5%) and (13.4%) for (Case 1) and (Case 2) respectively. While, it was about (17%) and (16.1%) for (Case 3) and (Case 4) respectively. These results confirm that, the addition of salt balls only in (Case 1 and 2) and addition of these balls with sponges in (Case 3 and 4) increase the productivity.

Furthermore, it can be concluded that the optimum case was (Case 3) for both (CSS) and (MSS). So, the addition of balls and sponges with the decrease in the water depth can be adopted to increase the productivity. The reason of this behavior was explained previously. In fact, the daily accumulated productivity of (MSS) for (Case 3) was higher than that for (Case 1), (Case 2) and (Case 4) by about (26%), (33%) and (24%) respectively.

Finally, it was useful to mention that the productivity can be improved more than these values, if the tests were done in the summer season instead of the winter season.

The hourly variation in the accumulated productivity related to all cases for (CSS) was illustrated in Fig. (4-14). For all studied cases, it can be observed that the accumulated productivity for (Case 3) was higher than the other cases. This is because the solar still with lower water depth begins to produce the fresh water early than that of large water depth. Moreover, the increasing in the solar intensity leads to increase the productivity.

The variation of the accumulated productivity fresh water with respect to time for (MSS) related to all cases was presented in Fig. (4-15). It can be seen that the accumulated productivity for (Case 3) was higher than the other cases. This indicated that the addition of both salt balls and sponges has a positive effect on the productivity of the solar still. Also, this increasing is due to reduction in heat losses inside the basin by using both balls and sponges and also to the enhancement in the thermal conductivity of the water.

The variation of ball temperature with time for all cases was shown in Fig. (4-16). It can be seen that the ( $T_{ball}$ ) for (Case 3) was higher than the other cases. Again, this is due to the higher value of the solar intensity and lower value of the water depth.

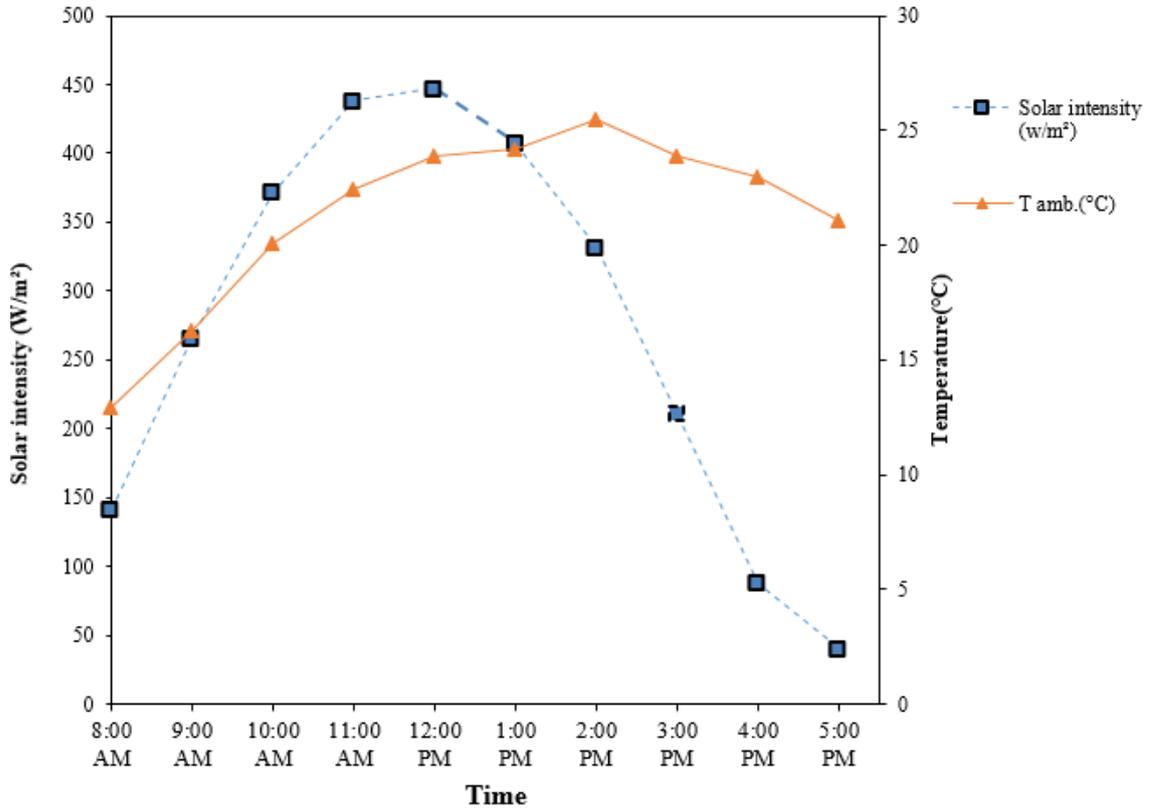


Figure (4- 1) The variation of solar intensity and ambient temperature with time

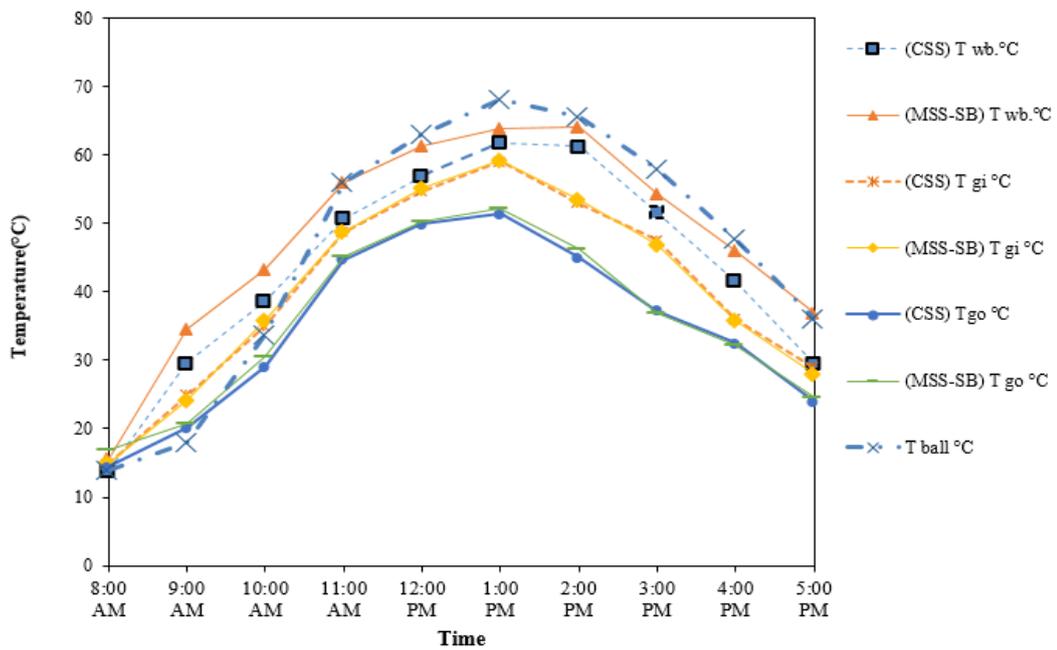


Figure (4- 2) The variation of various temperatures with time for both CSS and MSS related to (Case 1)

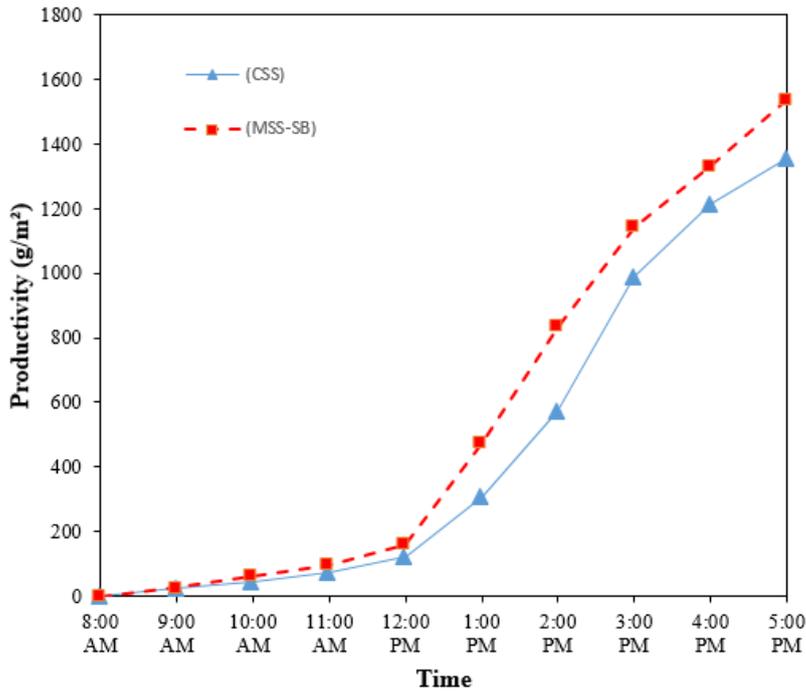


Figure (4- 3) The variation of productivity with respect to time for (CSS) and (MSS) related to (Case 1)

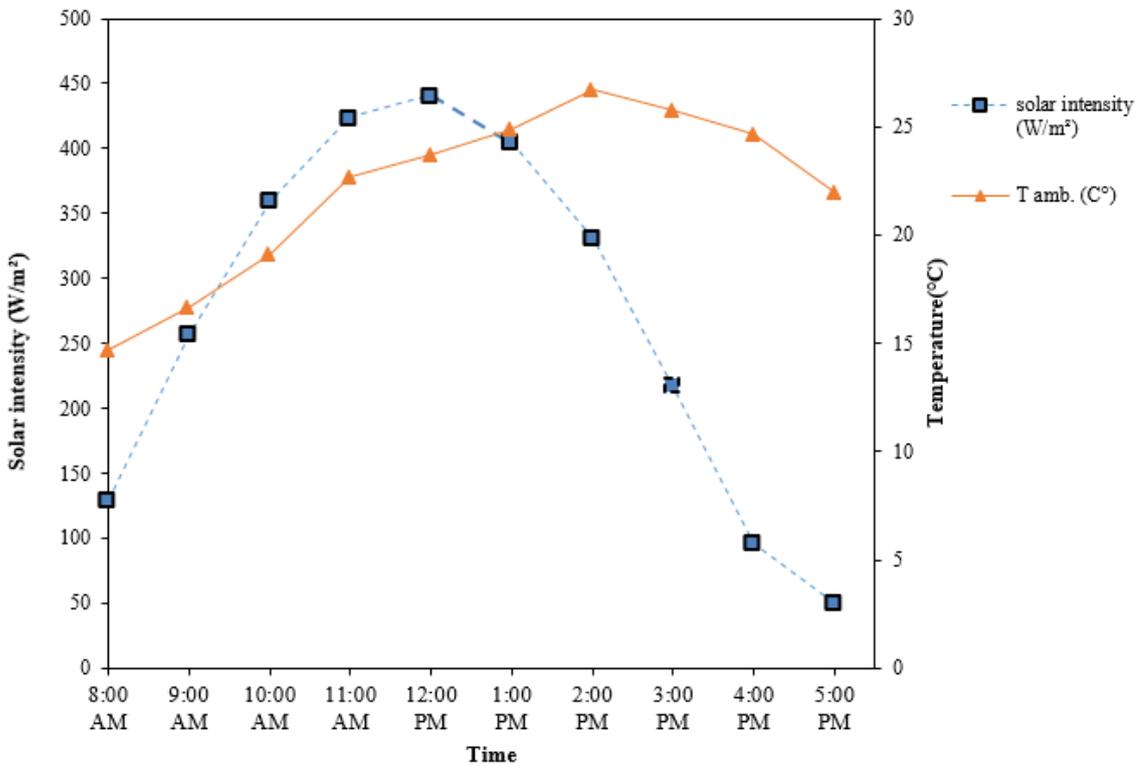


Figure (4- 4) The variation of solar intensity and ambient temperature with time

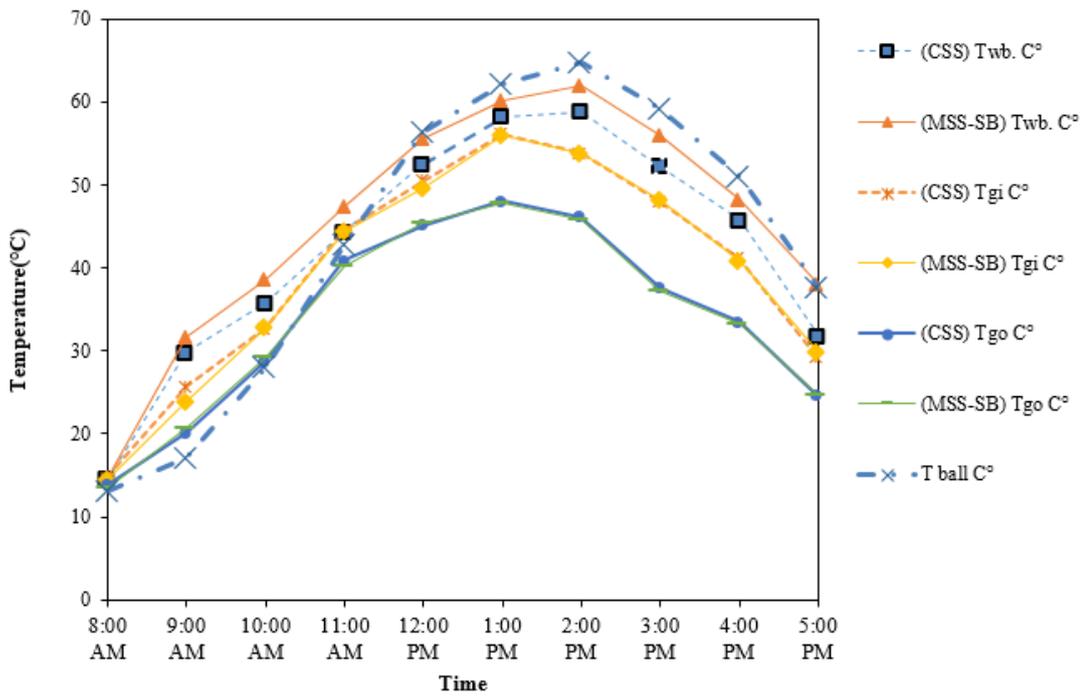


Figure (4- 5) The variation of various temperatures with time for both (CSS) and (MSS) related to (Case 2)

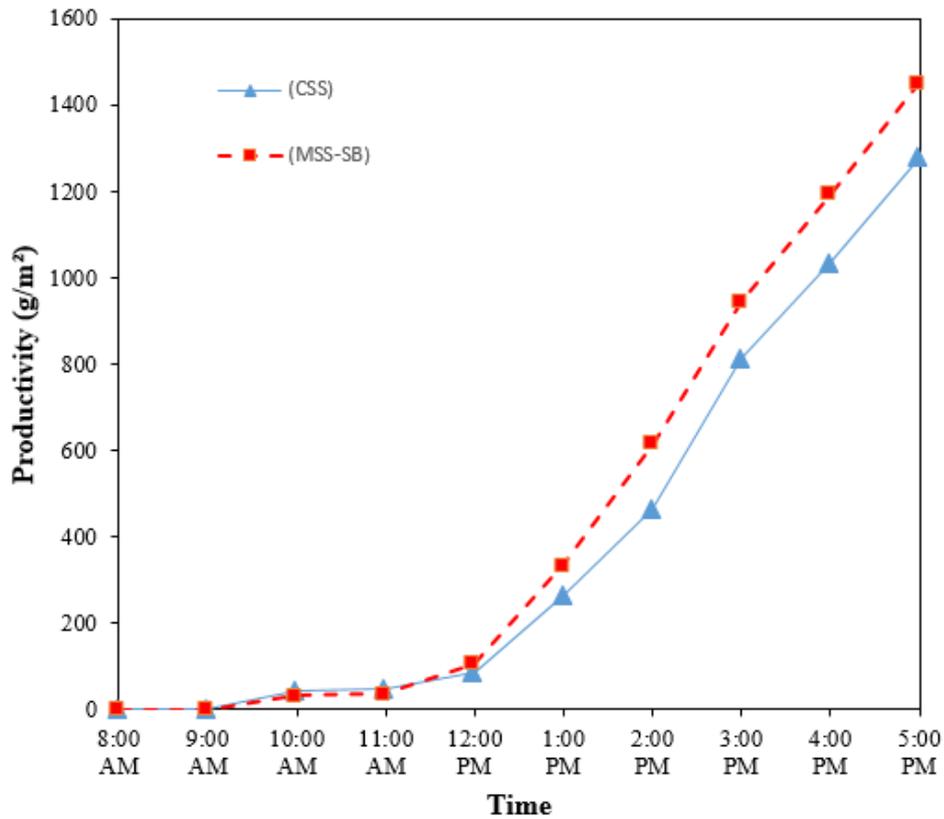


Figure (4- 6) The variation of productivity with time for (CSS) and (MSS) related to (Case 2)

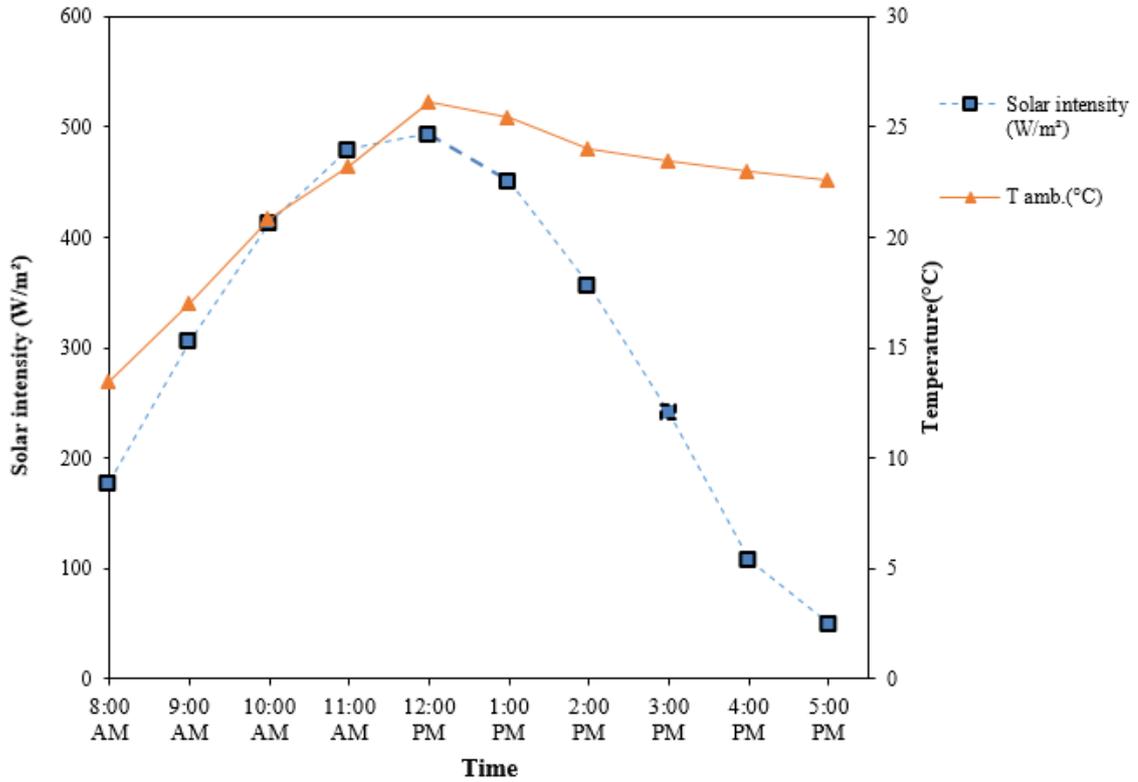


Figure (4- 7) The variation of solar intensity and ambient temperature with time

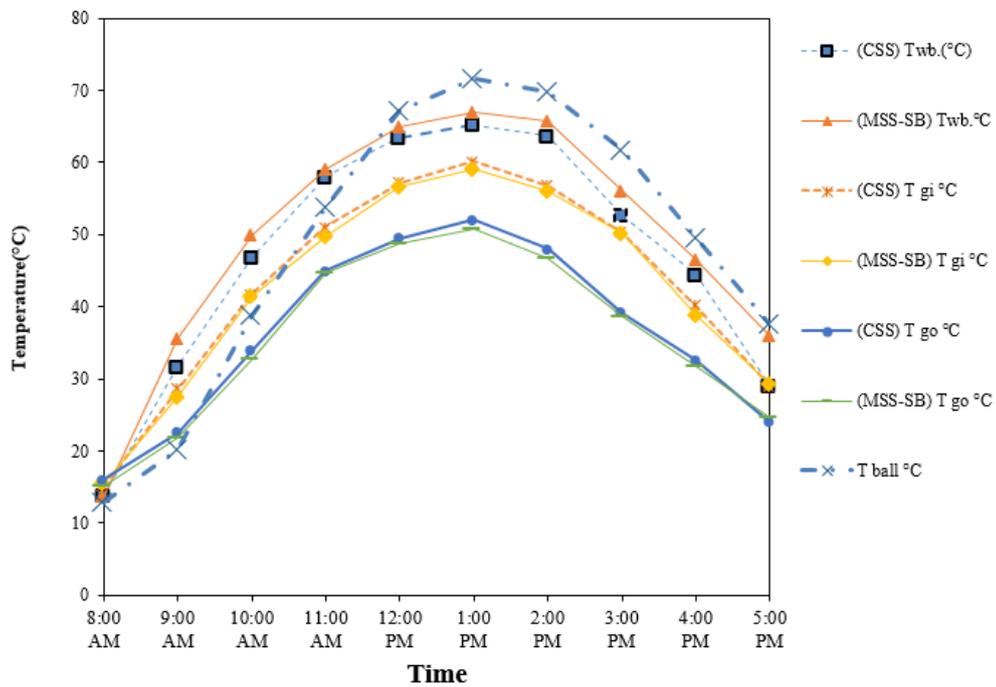


Figure (4- 8) The variation of various temperatures with time for both (CSS) and (MSS) related to (Case 3)

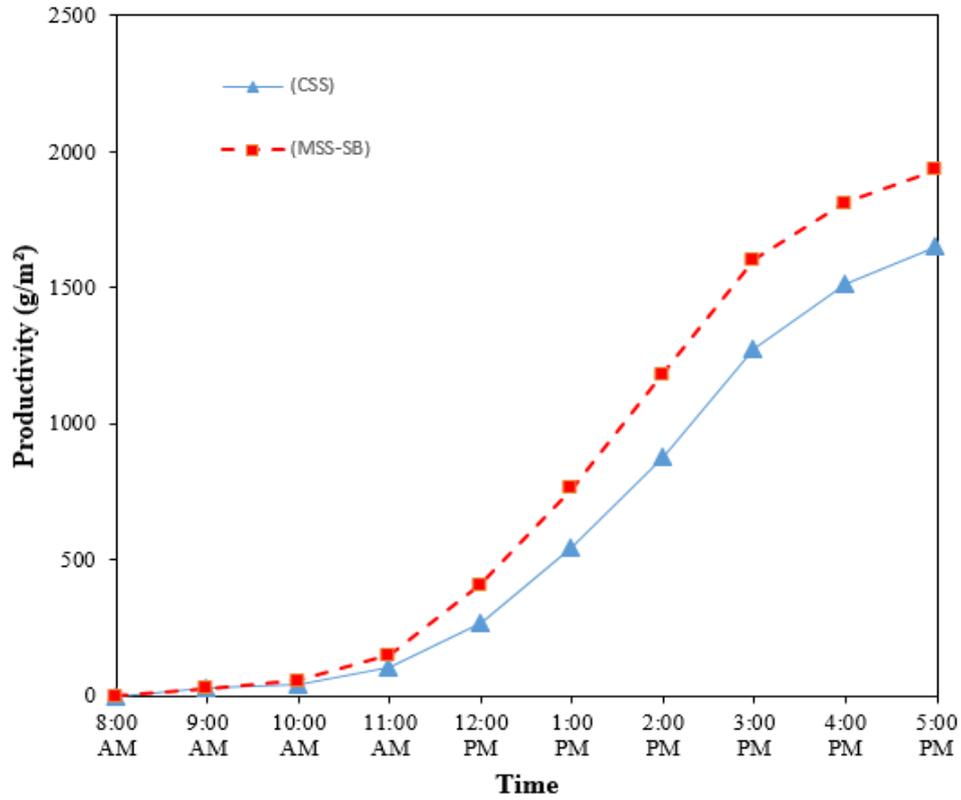


Figure (4- 9) The variation of productivity with respect to time for (CSS) and (MSS) related to (Case 3)

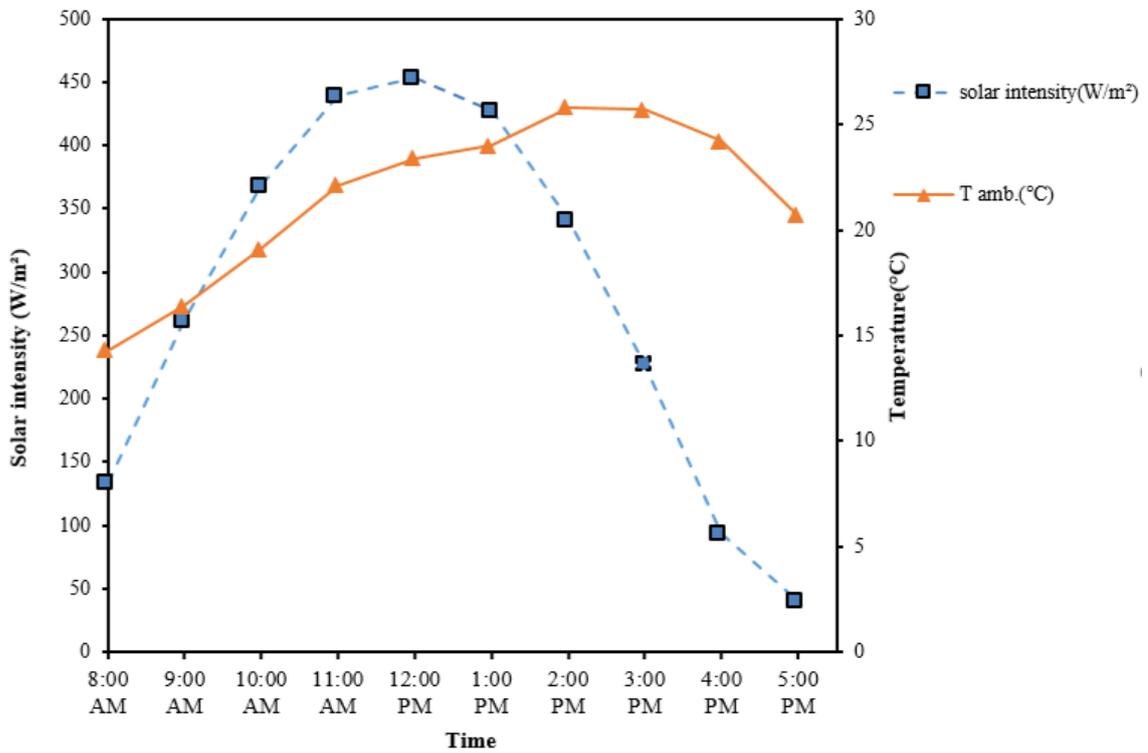


Figure (4- 10) The variation of solar intensity and ambient temperature with time

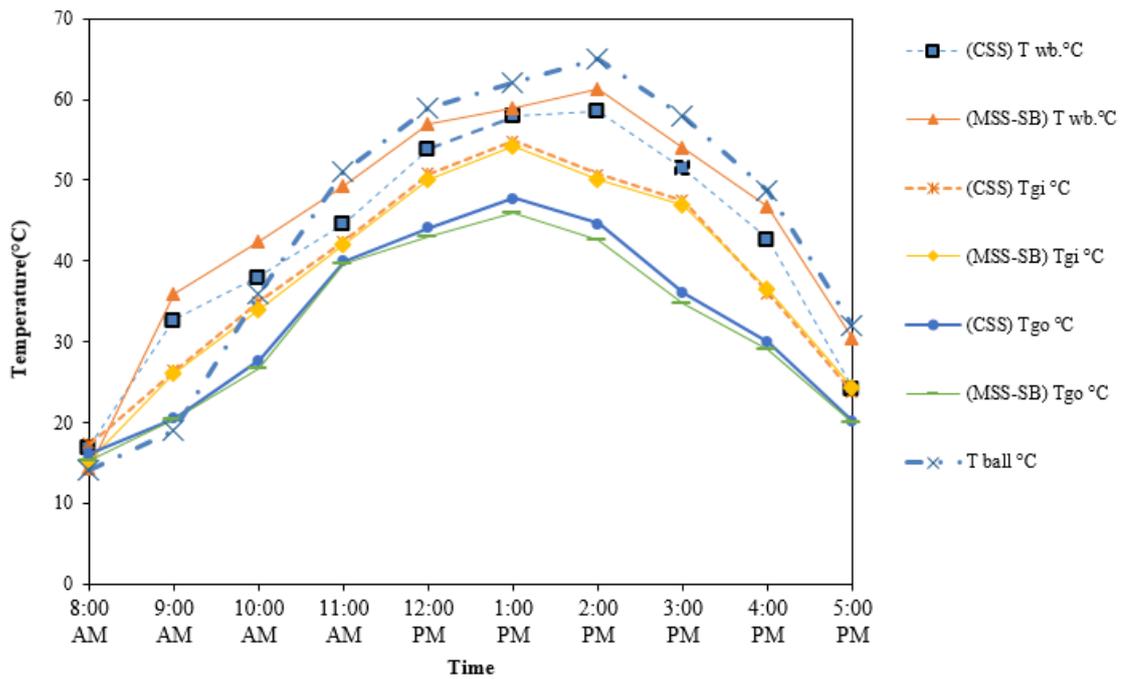


Figure (4- 11) The variation of various temperatures with time for both CSS and MSS related to (Case 4)

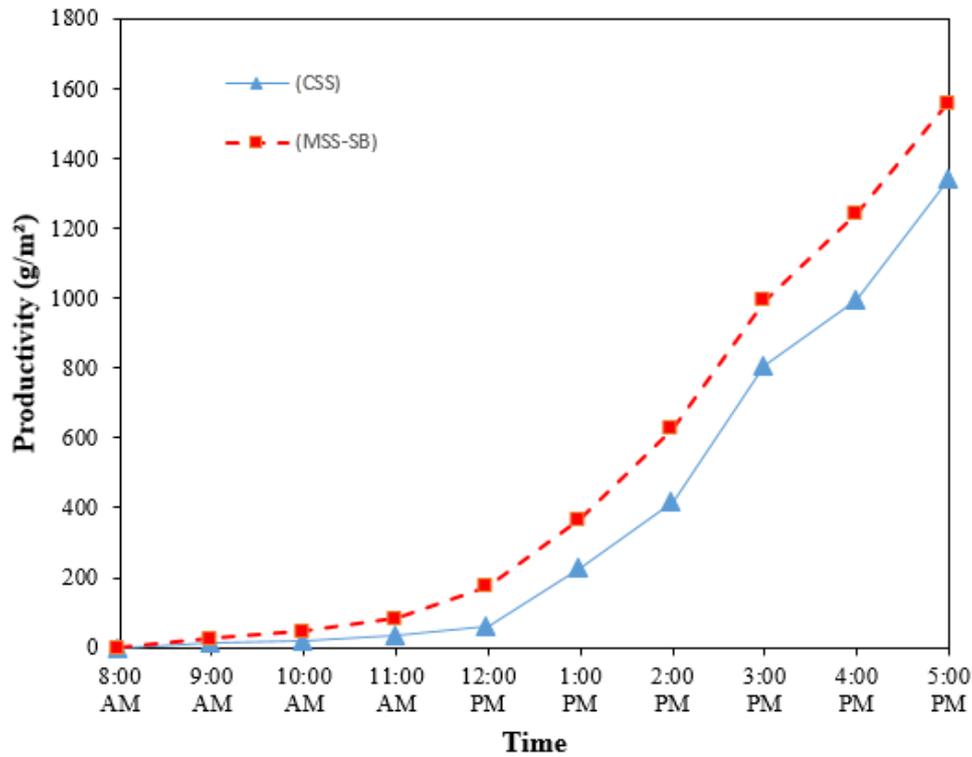


Figure (4- 12) The variation of productivity with respect to time for (CSS) and (MSS) related to (Case 4)

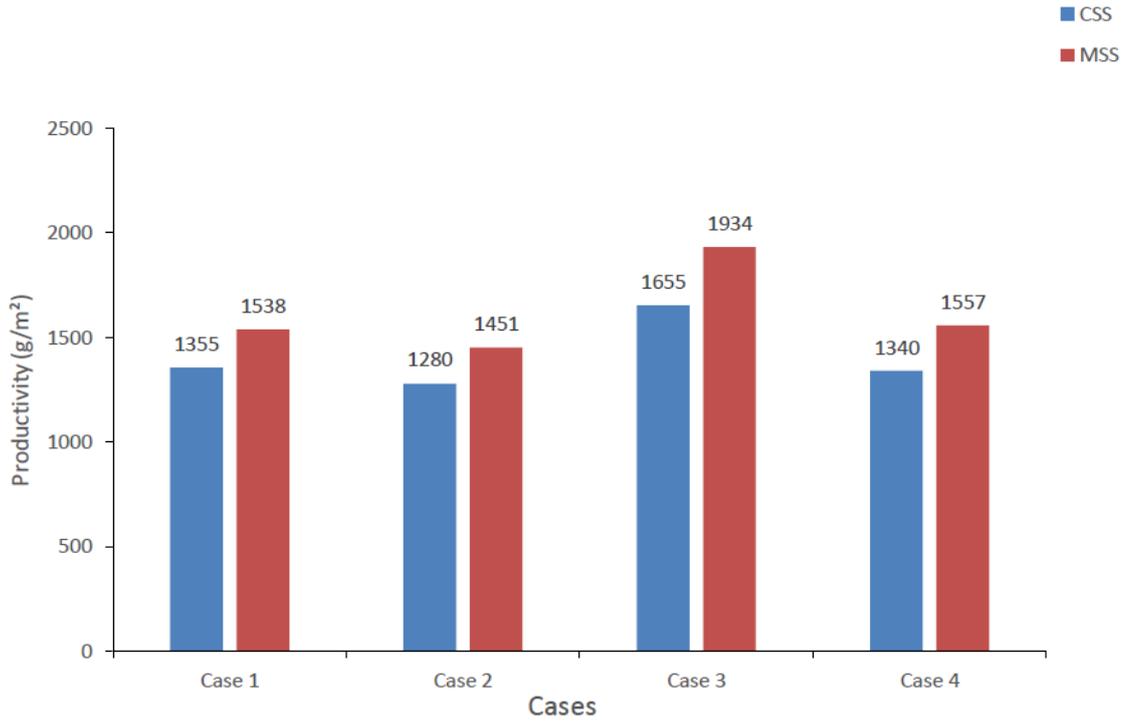


Figure (4- 13) The variation of productivity with respect to various studied cases for both (CSS) and (MSS)

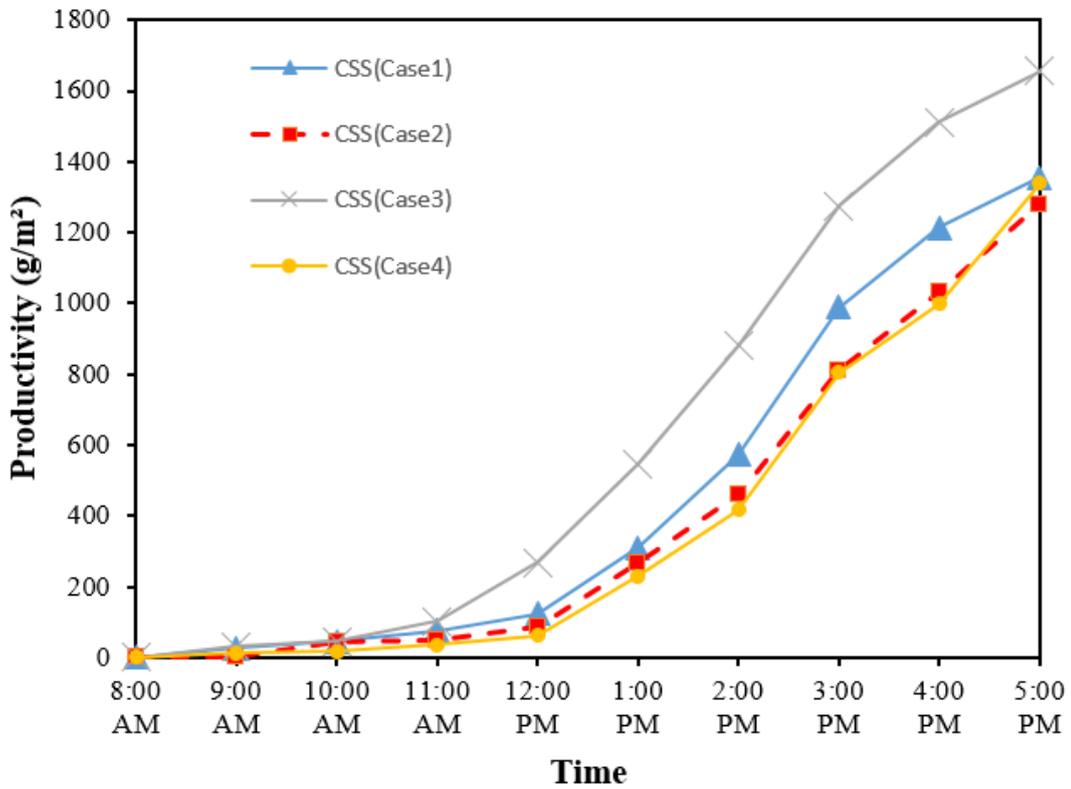


Figure (4- 14) The variation of productivity with respect to time for (CSS) related to all cases

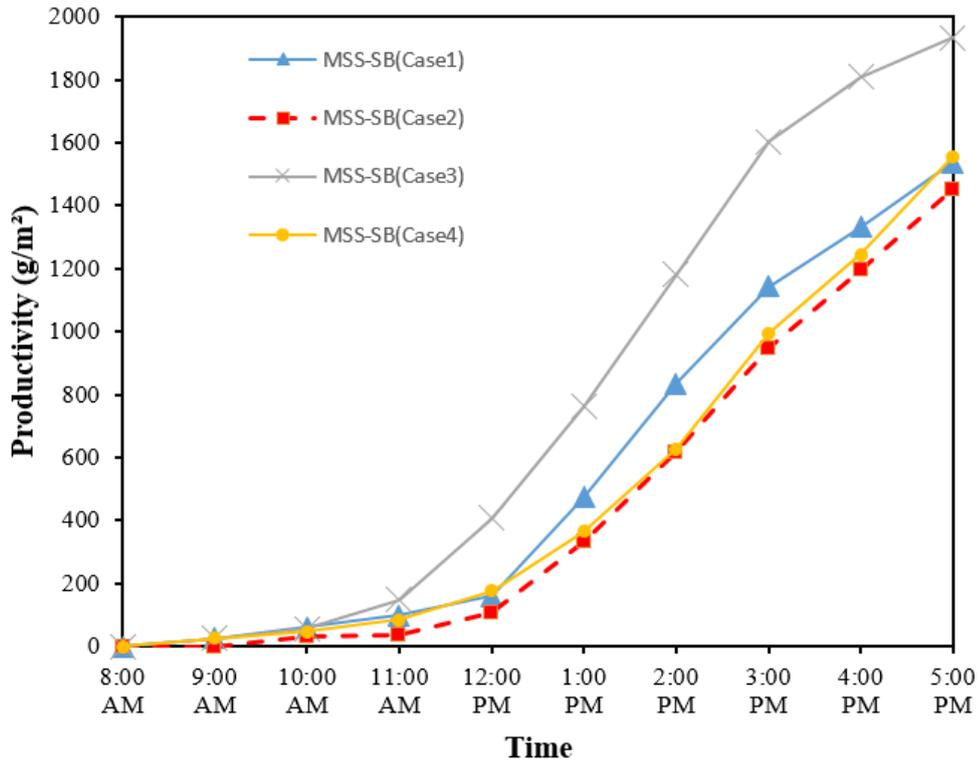


Figure (4- 15) The variation of productivity with respect to time for (MSS-SB) related to all cases

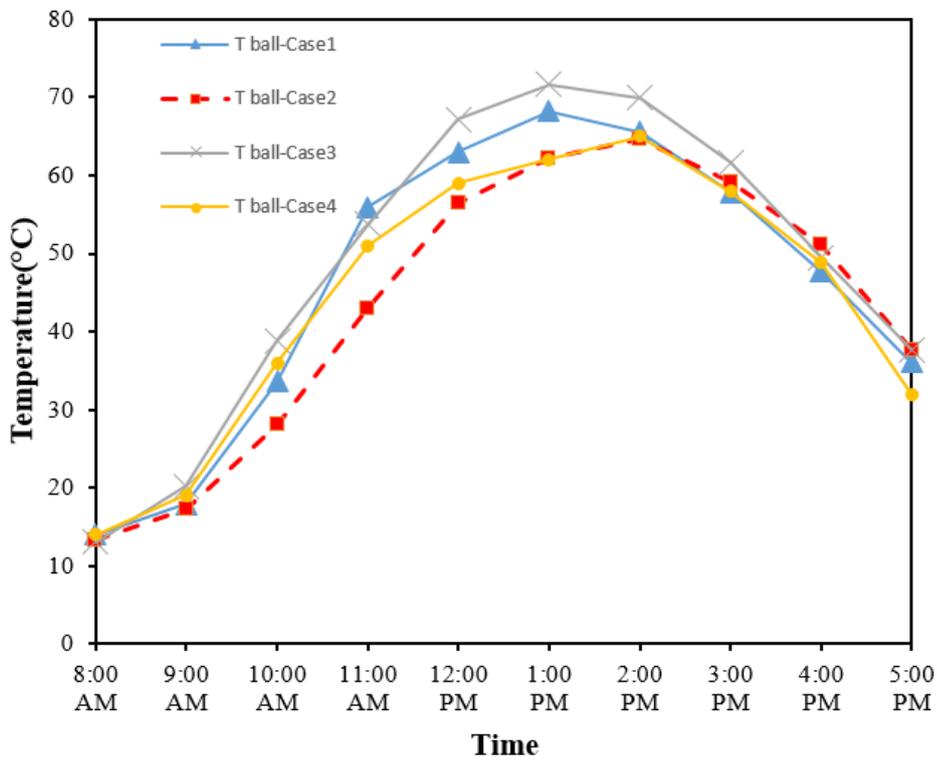


Figure (4- 16) The variation of ball temperatures with time for all cases

Chapter Five

Conclusions and  
Suggestions for  
Future Work

## **Chapter Five: Conclusions and Recommendations**

### **5.1 Conclusions**

Through the experimental study which conducted on the (CSS) and (MSS) for four cases, which was mentioned previously in this research. The following conclusions can be got:

1-The Productivity for both (CSS) and (MSS) was decrease with the increase in the depth of water.

2- The using of the salt balls and sponges has a good role to increase the productivity for both (CSS) and (MSS). Also, they decrease the cost of the fresh water production.

3- The maximum productivity was attained for (Case 3) which was (1934 g/m<sup>2</sup>) and (1655 g/m<sup>2</sup>) for both (MSS) and (CSS) respectively.

4- The daily accumulated productivity of (MSS) for (Case 3) was higher than that for (Case 1), (Case 2) and (Case 4) by about (26%), (33%) and (24%) respectively.

5- The payback for (Case 1), (Case 2) and (Case 3) was found to be (400 days), (396 days) and (320 days), respectively.

6- The productivity at the beginning of the day was low due to low temperature difference between (T<sub>wb</sub>) and (T<sub>gi</sub>).

7- The increase in the productivity between (CSS) and (MSS) was about (13.5%), (13.4%), (17%) and (16.1%) for Case 1,2,3 and 4 respectively.

### **5.2 Recommendations for future works**

To improve the performance of the (SSSS), the following suggestions have been recommended to study in climate of Al-Hilla city:

1- Studying the effect of adding nanoparticles in the basin and providing vacuum (exhaust fan) with the condenser tank.

2- Studying the performance of (SSSS) by using a shallow solar pond (SSP) to extracted heat from it and introduced into (SSSS).

3- Studying the effect of using (PCM) in a hollow cylindrical fin in the basin of the (SSSS) as a heat storage material.

4- Studying the influence of using a copper tray and painted with black matt color and placed it in the bottom of the basin.

5- Studying adding an evacuated tube collectors (ETC) with condenser and (PCM) to improve the productivity of (SSSS).

6- Studying the performance of the (SSSS) by adding eco-friendly coffee-based colloid to enhance the productivity of it.

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## الخلاصة

في هذا البحث ، تم تصنيع واختبار جهاز التقطير الشمسي احادي الميل في مناخ مدينة الحلة وبزاوية ميل (٣٢.٥ درجة) حسب خط العرض لها. اجريت الاختبارات التجريبية في تشرين الثاني ٢٠٢١ . وتم فحص نوعين من اجهزة التقطير ، الاول من النوع الكلاسيكي ، والاخر معدّل باضافة (٢٥) كرة ملح كروية (١٧) اسفنجية في حوضه . علاوة على ذلك ، تم فحص تأثير عمق الماء أيضاً. لذلك تم اختبار أربع حالات على النحو التالي:

(الحالة ١) (٢٥) كرة ملح وعمق الماء (١.٥ سم).

(الحالة ٢) (٢٥) كرة ملح وعمق الماء (٢ سم).

(الحالة ٣) (٢٥) كرة ملح + (١٧) اسفنجية وعمق الماء (١.٥ سم).

(حالة ٤) (٢٥) كرة ملح + (١٧) اسفنجية وعمق الماء (٢ سم).

وجد أن استخدام كرات الملح والإسفنجة له دور جيد في زيادة إنتاجية كل من المقطرات الشمسية الكلاسيكية والمعدّلة . كما أن الإنتاجية اليومية المتراكمة لـ (MSS) لـ (الحالة ٣) كانت أعلى من تلك الخاصة بـ (الحالة ١) و (الحالة ٢) و (الحالة ٤) بنحو (٢٦٪) و (٣٣٪) و (٢٤٪) على التوالي . بينت النتائج أنه تم تحقيق أقصى إنتاجية لـ (الحالة ٣) وهي (١٩٣٤ جم / م / ٢) و (١٦٥٥ جم / م / ٢) لكل من (MSS) و (CSS) على التوالي . فترة الاسترداد لهذه (حالة ٣) كانت (٣٢٠ يوم).

أخيراً وجد أن الزيادة في الإنتاجية بين (CSS) و (MSS) كانت حوالي (١٣.٥٪) ، (١٣.٤٪) ، (١٧٪) و (١٦.١٪) للحالة ١ ، ٢ ، ٣ ، و ٤ . على التوالي.



جمهورية العراق  
وزارة التعليم العالي والبحث العلمي  
جامعة بابل / كلية الهندسة  
قسم الهندسة الميكانيكية

## دراسة أداء المقطر الشمسي المحلي

بحث

مقدمة إلى كلية الهندسة – جامعة بابل وهي جزء من متطلبات نيل درجة الدبلوم  
العالي في الهندسة / الهندسة الميكانيكية/ وقود وطاقة

أعدت من قبل

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بإشراف

ا.د. احمد كاظم حسين

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