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EXPERIMENTAL STUDY AND EVALUATION OF SINGLE SLOPE SOLAR STILL COMBINED WITH PARABOLIC TROUGH USING NANOFLUID

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EXPERIMENTAL STUDY AND EVALUATION OF SINGLE SLOPE SOLAR STILL COMBINED WITH PARABOLIC TROUGH USING NANOFLUID

A THESIS

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(M.TECH.)

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2022/ / /

بسم الله الرحمن الرحيم

قَالُوا سُبْحَانَكَ لَا عِلْمَ لَنَا إِلَّا مَا عَلَّمْتَنَا إِنَّكَ أَنتَ الْعَلِيمُ الْحَكِيمُ

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DECLARATION

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Name: **Hawraa Fadhel Abd Hassan**

Date: /   /2022

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I certify that this thesis titled" **Experimental Study And Evaluation of Single Slope Solar Still Combined with Parabolic Trough Using Nanofluid "** which is being submitted by **Hawraa Fadhel Abd Hassan** was prepared under my supervision at the Department of Mechanical Engineering Techniques of Power, Engineering Technical College-Najaf, AL-Furat Al-Awsat Technical University, as a partial fulfilment of the requirements for the Master degree of Technical Thermal Engineering.

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In view of the available recommendation, I forward this thesis for debate by the examining committee.

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LANGUAGE CERTIFICATION

This is to certify that this thesis entitled**" Experimental Study and Evaluation of Single Slope Solar Still Combined with Parabolic Trough Using Nanofluid "** was reviewed linguistically. Its language was amended to meet the style of the English language.

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2022

ABSTRACT

Water is necessary for human survival, individuals consume between 20 and 50 liters of clean water each day for drinking, cooking, and other household activities. Contaminated water is not only unsanitary, but also dangerous to one's health. The main aim of this study is to reduce this problem and to improve the productivity of fresh water.The primary objective of this study was to explore and develop the design for a solar still system with PTC that has a positive effect on the cumulative productivity. The work done theoretical and experimental under the climatic circumstances of Najaf city in Iraq (32° 1' N / 44° 19' E). theoretically the best design for the single solar still is selected by a simulation was made in the COMSOL 5.5 program by use of two designs of heat exchanger, one of which winding is 8-pipe and the other is a incorporator (absorber plate and pipes) .as well as to improve productivity. Nanofluids are used as fluids that run inside the tubes. Using a heat exchanger inside the solar still which is an incorporator (absorber plate and pipes), we will get the highest temperatures from the winding heat exchanger. The highest water temperature inside the solar still when using the heat exchanger incorporator (absorber plate and pipes) was about 92.53°C and the temperature of the inner glass surface was 79.651°C at 2:00pm, higher than the winding heat exchanger temperatures of 86.78°C and 72.472°C, respectively. Also, the productivity of distilled water when using an incorporator (absorber plate and pipes) heat exchanger is higher than the other heat exchanger, reaching 5.35017 Kg/m^2/day. While the productivity when using a winding heat exchanger is 4.5 Kg/m^2/day. In this study, experiments are conducted from March to June. The results showed that when using the single solar still only, the highest productivity of distilled water was obtained in May at 4.16 kg/m^2/day and the thermal efficiency was 36.31%. A higher productivity is obtained when combined with PTC of 6.83382 kg/m^2/day under very close weather conditions, and at a thermal efficiency of 46.24%. The results of the comparison showed that, when using the nanofluid as a working fluid flowing inside the Parabolic Trough Collector (PTC) receiver tube, the outlet temperatures were rising for the same comparison days with an increase in the productivity of distilled water. The productivity improvement rate was 34.217%. The heat efficiency also increases, reaching about 62.14%.

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NOMENCLATURE

Symbol	Definition	Unit
A_s	Projected area for single solar still	m^2
C.R	Concentration ratio	
D_P	Diameter of pipe	m
G	The solar irradiation	W/m^2
h_{out}	Convective heat transfer coefficient	$W/m^2.^0C$
h_{ew} , h_{cwb} and h_{rw}	Evaporative, convective and radiative heat transfer coefficients from the water surface	$W/m^2.^0C$
I	Incident solar radiation	W/m^2
L	Length of solar still	m
L_in	Initial length of heat exchanger	m
L_{he}	Latent heat of evaporation	kJ/kg
n	Normal component of flow field	
P	The pressure of water flow	Pa
P_{np}	Static pressure of pump as function of the volumetric flow rate pump	pa
P_{pc}	Pressure difference between inlet and outlet of pump	pa
P_w	Output of pure water	kg/m^2
ρ	The density of steam	kg/m^3
Q_{wc} and Q_{wr}	Rate of heat transfer from water surface by convection and radiation	W/ m^2
Q_{cha} and Q_{rw}	Rate of heat transfer from inner glass surface by convection and radiation	W/m^2
Q_{cc} and Q_{rgs}	Rate of heat transfer from outer glass surface by convection and radiation	W/m^2
Q_{usf}	Useful energy	W
Q_b	The rate of heat transfer to the receiver tube	W/m^2
Q_{out}	The rate of heat transfer to the ambient	W/m^2
Q_{ew} and R_w	Rate of evaporated from water and heat absorbed.	W/m^2
t_w	Height of water in solar still	m
Q_{cdha} and R_g	Rate of condensate by glass and heat absorbed	W/m^2
T_{tube}	Temperatures of receiver tube	^0C
T_{amb}	Temperatures of ambient	^0C
T_{wb} and T_{gi}	Temperatures of water surface and inner glass	^0C

T_{go} *and* T_{sky}	Temperatures of outer glass surface and sky	^{0}C
u	Flow velocity in x direction	m/s
v	Flow velocity in y direction	m/s
V_{out}	Wind speed	m/s
$V_{o,pd}$	Water flow rate	m^3/s
w_elb	Diameter of elbow	m
w	Flow velocity in z direction	m/s
η	Efficiency per hours during day	

ABBREVIATIONS

Symbol	Description
BIPV	Building Integrated Photovoltaics
CSP	Single Slope Solar Still Plant Combined
CSS	Conventional Solar Still
CuO	Copper oxide
DNI	Direct Normal Irradiation
Ds	Double Slope
E	Evaporator [incorporator (absorber plate and pipes)]
FEM	Finite Element Method
FPC	Flat Plate Collector
FVM	Finite Volume Method
GA	Gum Arabic
G.S.S	Glass Solar Still
PV	Photovoltaics
HSC	Heat Sink Condenser
HTF	Heat Transfer Fluid
LTT	louvered Twisted Tape
MCRT	Monte Carlo Ray -Tracing Method
PVT	Photovoltaics Thermal
PTC	parabolic trough collector
PCM	Phase Change Material
PLGB	Packaged Glass Ball Layer
P.SS	Plate Solar Still
R.T	Receiver Tube
SS	single slope
S.S	Solar Still
W.SS	Water Solar Still

CHAPTER ONE: Introduction

1.1. Solar Radiation

Solar radiation is the radiant energy created by the sun as a result of a nuclear fusion process that creates electromagnetic energy. The solar radiation spectrum, which has a temperature of roughly 5800 K, is comparable to that of a black body in the visible short-wave component of the electromagnetic spectrum, which contains nearly half of the energy. The second half of the spectrum, which includes some ultraviolet light, is more in the near-infrared range. Watts per square meter are the measuring units. Solar radiation is becoming more valued owing to its influence on living matter and the potential of using it for practical purposes. It is a never-ending source of natural energy with enormous promise for a wide range of uses, as well as other renewable energy sources, because it is abundant and readily available. [1].

It is categorized into three groups:

1-. The radiation from the sun that reaches the earth without being scattered is known as **direct radiation**.

2- **Diffuse radiation**: is sunlight that travels across the atmosphere and clouds.

3- **Reflected radiation**: Radiation contacting some materials is actually deflected away from the surface rather than being absorbed.

Position, atmospheric conditions, such as cloud cover, aerosol content, and ozone layer state, solar rotation and operation, time of day, and earth/sun distance all affect the amount of solar radiation reaching the earth's surface, as shown in Figure (1.1)[2]-[3].

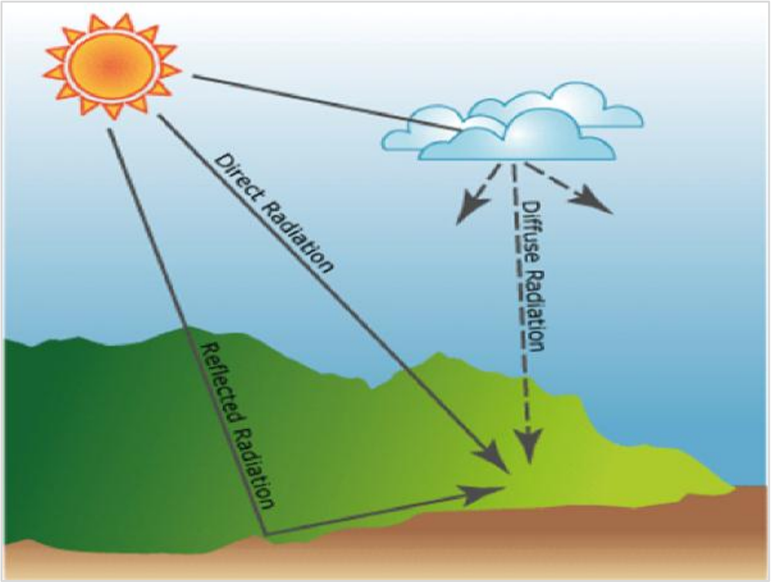


Figure 1.1 The three major solar radiation components [2]

1.2. Radiation Solar Concentrator

A solar concentrator is a device that collects sunlight from a large region and concentrates it onto a smaller receiver a symbolic representation of a solar concentrator, which collects solar energy and converts it into electricity. as shown in Figure (1.2).

The concentrator's material varies depending on its intended function. For solar thermal energy, most concentrators are built of mirrors, but for building integrated photovoltaic (BIPV), the concentrator is made of glass or transparent plastic. These materials are significantly less expensive than PV materials. As a result, the cost of a solar concentrator is significantly lower than the cost of a PV material per unit area.[4]-[5] .

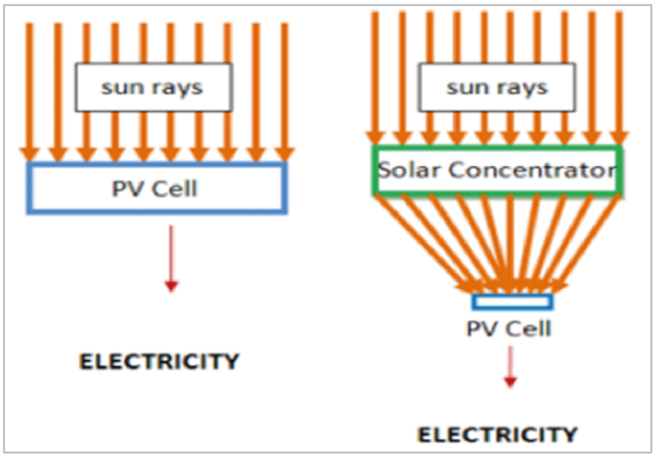


Figure 1.2solar thermal collector[4]

1.3. Solar Thermal Collectors

solar radiation is converted into heat by solar collectors, which then transfers the heat to a medium (solar fluid, air, or water). The heat from the sun can then be utilized to heat water, heat or cool water systems, or heat swimming pools. High temperatures are required for solar energy cooling technologies, which cannot be generated by all types of solar collectors. The necessary collectors are focused on technology that can provide hot water at low temperatures. Temperature ranges from 90°C to 150°C.In general, solar collectors are classified into two groups based on their concentration ratios: concentrators and non-collectors. Concave reflecting surfaces are used in concentrated solar collectors to capture solar energy and focus it on a much smaller receiving area. A non-concentrating collector, on the other hand, has the same intercepting area as its absorption area, resulting in an enhanced heat flow, allowing Carnot to operate the thermodynamic cycle more efficiently at higher temperatures. [6]-[7].

1.3.1. Concentrating Collectors

- Heliostat field collectors: collectors that concentrate have a much higher concentration ratio than collectors that do not concentrate. a set of flat mirrors/heliostats compose of the Heliostat Field Collector, also called the Central Receiver Collector. The whole set of mirrors/heliostats has to have correct alignment to reflect incident solar lights to a typical tower due to the direction shift of the sun during the day. Collectors that concentrate have a much higher concentration ratio than collectors that do not concentrate as shown in Figure (1.3A) [7].

- Parabolic dish collectors are focusing solar collectors that are identical to a large satellite dish in appearance, except at the focal point has mirror-like reflectors. To follow the Sun through the sky, a parabolic dish system uses a device and dual-axis tracking to focus the Sun's rays on the receiver positioned in front of the dish at the focal point. at the receiver, parabolic dish systems can exceed 1000°C and attain the maximum efficiencies in the small-power capability range for converting solar energy to electricity as shown in Figure (1.3B) [8].
- Parabolic trough collectors are based on the scale of the trough. Sunlight can be concentrated in parabolic trough collectors with a concentration rate of about 40, The temperature of the focal line can be as high as 350 °C to 400 °C. A set of parabolic mirrors is the main component of such collectors, each of which the sunlight that is parallel to its symmetrical axis to its typical focal line has the ability to reflect it. A black metal receiver at the focal line (covered by a glass tube to reduce heat loss) Placed to absorb the heat collected. Parabolic trough collectors can be directed in either an east-west direction, from north to south tracking the sun, or a north-south direction, from east to west tracking the sun as shown in Figure (1.3C) [9].

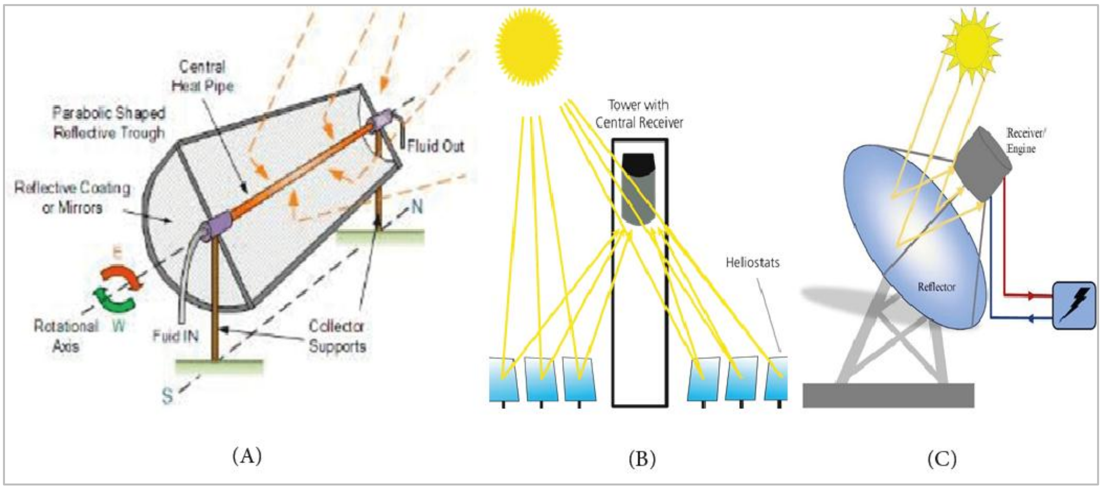


Figure 1.3 Concentrating collectors; (A) Parabolic trough collector, (B) Heliostat field collectors and (C) Parabolic dish collector [10]-[12].

1.3.2. Non-Concentrating Collector

- The flat plate solar collector was developed and many methods and techniques were used to increase its thermal performance and efficiency.

There are different components of a flat plate solar collector, such as aluminum rails, insulation, absorber, glass, back panel, riser and header tubing. for optimum heat transfer to the absorber. The surface is covered with glass. The absorbers are made of aluminum coated with a high absorption content for high performance as shown in Figure (1.4) [13]-[15].

- Hybrid PVT collectors in a PV module. The largest part of the absorbed irradiance is converted to heat (about 60 percent-70 percent). This heat is partially rejected by radiative and convective heat losses and partially increases the solar cell's temperature, decreasing its conversion efficiency. By cooling the solar cells, a PVT device seeks to increase the overall conversion performance of the PV panel [16]-[17].
- Enhanced hybrid PVT collectors. It is possible to categorize hybrid PVT collectors into those that use water as the medium for heat removal and those that use air. Due to its high heat power and excellent optical properties, water is a desirable working fluid in hybrid PVT collectors[7].

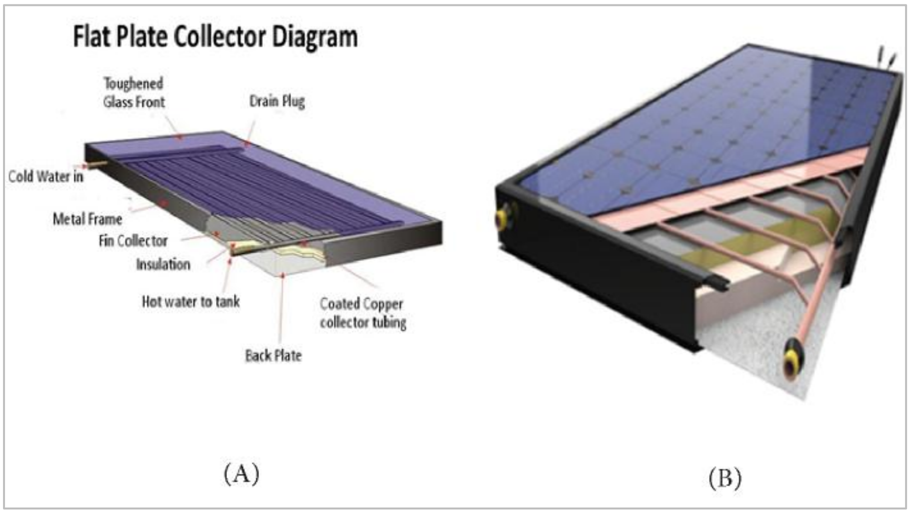


Figure 1.4 (A) Flat-plate collectors, and (B) Hybrid PVT collectors

1.4. Solar Desalination Types

Consumable water demand continues to rise as a result of increased population density and automation. Solar desalination is a process for turning brackish water into drinkable water. Solar desalination is perhaps the earliest technique of water desalination.The sun's radiation evaporates water within a closed glass-covered chamber at a temperature is higher than the ambient temperature. A solar still is the type of desalination technology utilized. Active and passive solar stills are the two major types of solar stills. Passive solar stills produce fresh water without the need of high-grade electricity [18]-[19].

1.4.1. Single basin solar still

The basin liner absorbs the solar energy conveyed by the cover raising the water temperature and vapor pressure. By evaporation, convection, and radiation, as well as conduction to the solar still's base and walls, the water vaporizes and loses heat to the cover. The vaporized water condenses along the cover material, delivering the heat of condensation to the surrounding air, and then runs down to the sloped cover's bottom, where it is collected in the water channel for usage. Water can be delivered constantly or intermittently, but the amount of water in the basin should be double the amount of fresh water generated each day [20].As shown in Figure 1.5.

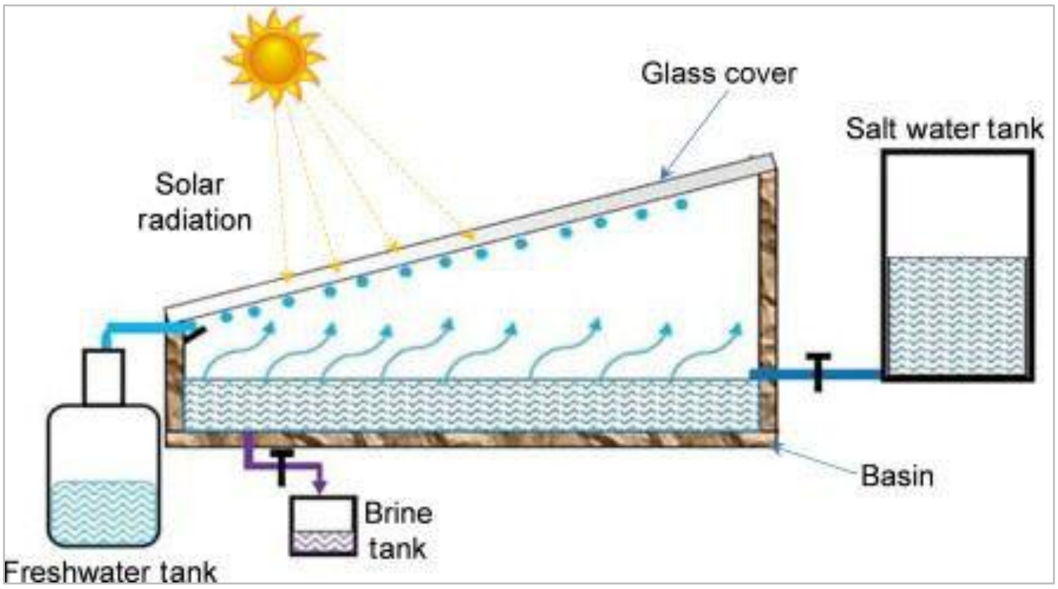


Figure 1.5 Single solar still [21].

1.4.2. Double slope solar still

This type of distiller is based on the slope of the double glass surface and is divided into two parts according to the slope of the surface.

1.4.2.1. Double sloped solar still (symmetrical)

The two symmetrical incline solar still are installed in the south direction for exposure to the longest possible period of sunlight. These distillers depend on the site and the materials available to build the devices as consisting of a basin that is dyed with black paint to increase the absorption of sunlight. The best slope angle for the cover is 15 ^{0} and the daily productivity of this distiller it is 4-7 liter per day.

When sunlight penetrates through the glass cover, it falls on the surface of the water in the distillation basin. When the water temperature rises, it begins to evaporate inside the basin and because the temperature of the surface is lower than the temperature of the steam , it begins to condense and falls in the forms of water droplets that collect in a special channel [22], as shown in Figure 1.6.

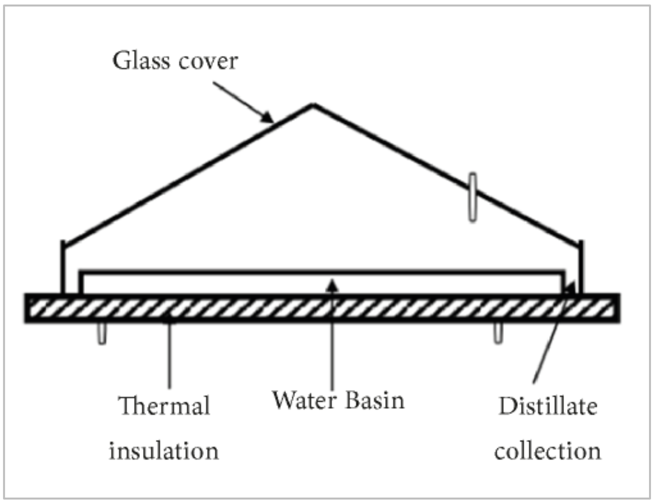


Figure 1.6 Double sloped solar still (symmetrical)

1.4.2.2. Double sloped solar still (Non symmetrical)

The solar asymmetrical double slope stills depend mainly on the location, as the glass cover has a suitable slope for water droplets to fall into the channel designed for it to avoid falling into the basin. The glass must be clean and free of dust and dirt that reduce the penetration of solar rays through it , and that the principle of its work is the same as the principle of the work of identical solar still. as shown in Figure 1.7 [23]-[24].

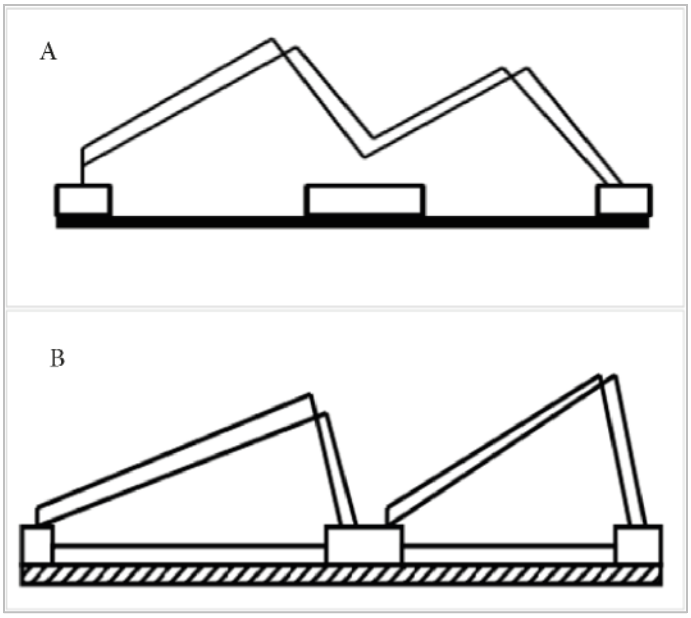


Figure 1.7 (A). Schematic diagram showing the asymmetric double –slope solar non symmetrical that are: A) connected to each other and B) not connected to each other.

1.5. Problem statement

Polluted water is the current problem that requires appropriate measures to improve the productivity of fresh water. Polluted water is not only unhealthy but also poses a threat to the health of the individual. As a result, to reduce this problem and to improve the productivity of fresh water more than the previous researchers, the primary objective of this study was to explore and develop the design for a solar still system with PTC that has a positive effect on the cumulative productivity with the aim of increasing the productivity. As well as water, nanofluids were used as fluids running inside the tubes between the PTC receiver tube and the heat exchanger inside the single slope solar still. A comparison was made between the results of using water and those of the nanofluid. That increases the possibility of thermal improvement inside the solar still.

1.6. Main Scope

The main scope of this study is to increase the productivity of solar water desalination by selecting the best solar still design and using local materials, through experimental measurements combined with PTC to enhance the evaporation process, in different external conditions. The best design for the single solar still is selected by simulating. The other aim is to improve productivity by using nanofluids are used as a fluid that runs inside the tubes.

The objective are:-

1- To develop the numerical simulation for the best design of solar still.

2- To enhence the evaporation process of solar still using the PTC.

3- To evalute performance of solar still system with nanofluid .

1.7. Outlines of Thesis

The outlines of thesis are as follows:-

1. Chapter one consists of a brief background of the solar thermal collectors, followed by problem statement and objectives.
2. Chapter two presents some previous studies of experimental and numerical effects of different solar still types on the freshwater productivity
3. Chapter three reviews the steps of the numerical study of the current study by using COMSOL Multiphysics. It includes the research approach, computational domain, assumptions, boundary conditions and numerical procedure.
4. Chapter four describes the experimental formation of the solar water distillation system, more details of the experimental set-up and the main components of it. It also describes the design of the solar still and structure construction and discusses dimensions such as length, thickness and width in detail. The nanofluid preparation is also described in detail.
5. Chapter five explains the results and discussion of the current study. It includes the effect of nanoparticles volume fraction, the number of heat exchanger pipes on the characteristics of heat transfer and fluid flow and the total freshwater productivity.
6. Chapter six illuminates the main conclusions of the current investigation and highlights some suggested recommendations for future studies.
7. Finally, references which are used in this study are listed.

CHAPTER TWO: Literature Review

2.1. Introduction

Freshwater is an important source of life for all living organisms on the planet. In the community, water supply and management are crucial development. Rapid population growth and industrialization are two examples of rapid population increase and industrialization primary causes of rising freshwater demand and, hence, lower levels of groundwater. Solar energy has the greatest potential to meet future energy requirements among the many alternative energy sources. Sun distillation is thus a very interesting option that may be achieved using solar shots. It is critical to create methods that make optimal use of solar energy for desalination. In this review, the focus was on research that looked at the influence of various variable factors on the solar slope, and to enhance conventional solar distillation, numerical and empirical studies were both conducted. Many of these experiments used different methods to increase evaporation or condensation rates, including the use of a parabolic trough collector. To get the best yield, or use several other techniques with solar still. It is also necessary to understand the many scientific methods of the parabola basin collection system using different distillers.

2.2. Theoretical study of single solar still

Hiroshi Tanaka et al. 2006 [25] they used a basin-type still with internal and external reflectors. When proposing a geometrical method to calculate the solar radiation reflected by the internal and external reflectors and then absorbed on the basin liner when performing a numerical analysis of the mass and heat transfer, it was found that the external and internal reflectors increase the productivity of the distillate, as the average external reflectors 48% for the type of single-slope basin.

A.A. El-Sebaii et al. 2009 [26]numerical simulations were carried out utilizing stearic acid as a PCM on typical summer and winter days in Jeddah (lat. 21 420 N, long. 39 110 E), Saudi Arabia. The still performance has been investigated by computer simulation. The evaporative heat transfer coefficient is increased by 27% when 3.3 cm of stearic acid is used beneath the basin liner. A daily productivity of 9.005 kg/m^2 was achieved on a summer day, with an efficiency of 85.3%, compared to 4.998 kg/m^2 when the still was used without the PCM.

Lovedeep Sahota et al. 2017 [27]photovoltaic thermal flat plate collector integrated double slope solar still (PVT-FPC-DSSS), without operating heat exchanger (System A), with operating helically coiled heat exchanger (System B), as a new method of heat energy collection.including copper oxide (CuO)-water based nanofluid, titanium oxide (TiO2), and aluminium oxide (Al2O3). CuO-water based gives better results (annual performance and economic and environmental) for the systems (A) and (B). Also, the hybrid system (A) gives better annual performance (overall thermal energy and exergy) and productivity) than the system (B).as shown in Figure 2.1.

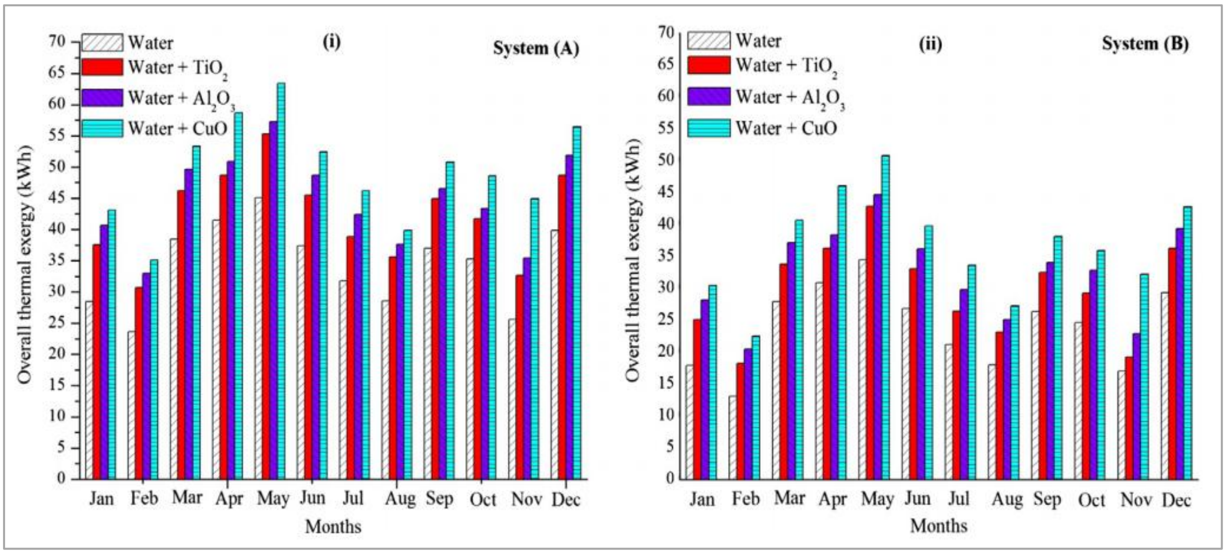


Figure 2.1productivity of system when using different types of nanofluid with water[27]

Muntadher Mohammed et al. 2019 [28]nanoparticles have been used to enhance the thermal conductivity of paraffin wax. The most common wax is paraffin wax (PCM), which contains Al2O3 (nanoparticles). Also, the results showed that the use of 1 kg of PCM represented the optimal amount of enhancement, and thus using a 3 % concentration of Al2O3 nanoparticles dispersed in 1 kg of paraffin wax gives the possibility of improving the traditional single slope solar panel's daily productivity by about 20%. After solar radiation decreases, the PCM or NPCM layer acts as a heat storage layer, extending the operation time of the solar still.

2.3. Experimental study of single solar still

A.S. Abdullah.2013 [29] the experimental performance of a stepped solar still coupled with a solar air-heater was investigated. A single slope passive solar still (conventional still) and a stepped active solar still integrated with a solar air-heater collector were fabricated with an area of 0.5 m^2. He also utilized a substance to store heat from the aluminum filler behind the absorption plate to keep the temperature stable and collect distilled water during the night. The results show that productivity will increase by 112% compared to the traditional system when using a solar air heater. It was also found that the use of aluminum filler inside the solar still under the absorption plate increases the water productivity, as shown in Figure 2.2.

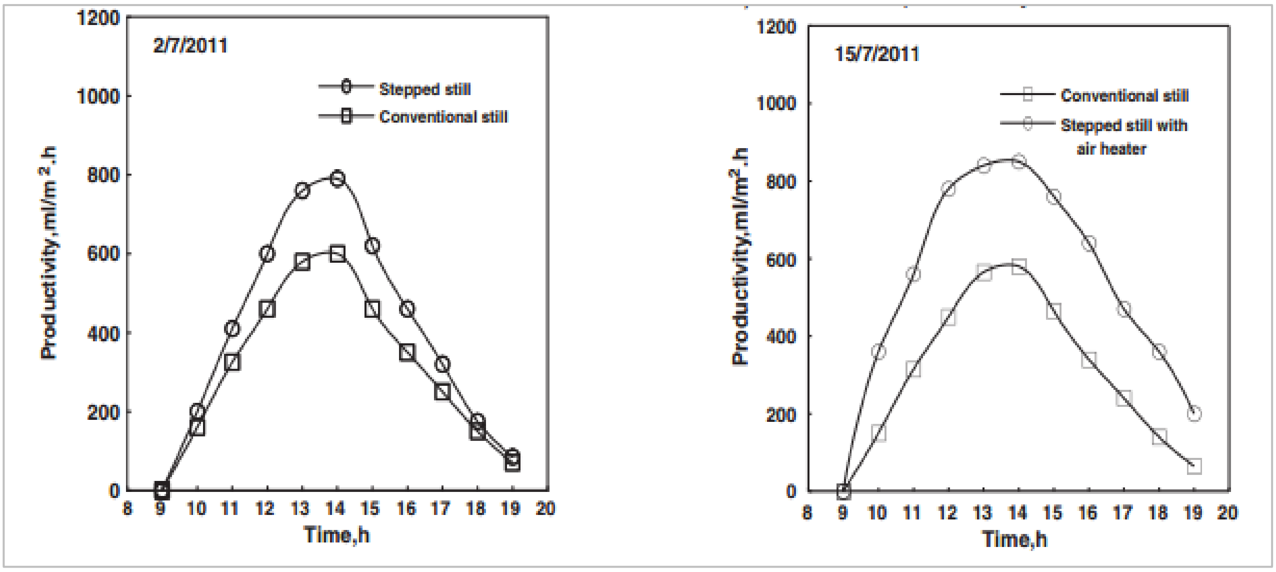
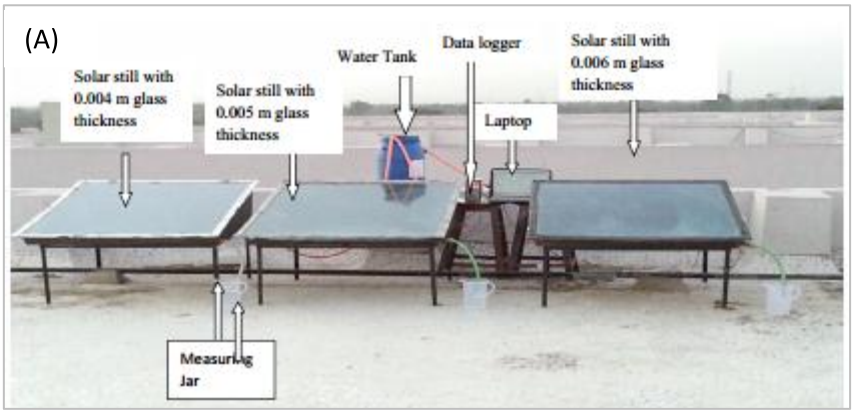


Figure 2.2Hourly variations of fresh water productivity.[29]

Hitesh Pancha.2016[30] investigated the effect of transmittance on glass cover thickness using three different thicknesses of glass cover, such as 4 mm, 5 mm, and 6 mm. After six months of testing, it was determined that a 4 mm and 5 mm glass cover thickness increased average distillate output by 27% and 12%, respectively, as compared to a 6 mm glass cover thickness, as shown in Figure 2.3.



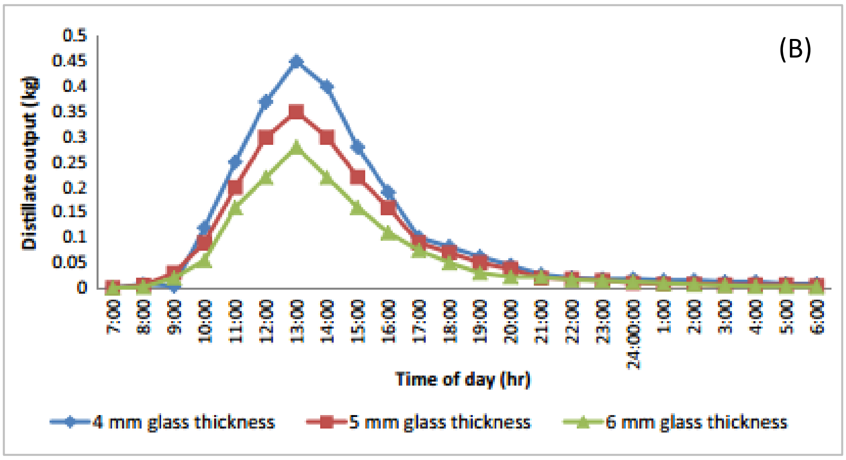


Figure 2.3(A) Shown three models of the system .(B) Distilled water yield for three models of the systems when the thickness of cover glass is 4mm, 5mm and 6 mm.[30]

Ali A. Aljubouri, **et al**. 2017 [31]altered the tilt of the glass covers for five single-sloped solar stills at 20, 31, 45, and 50°. When the tilt angle was reduced from 50 to 20, and the depth of the water in the basin was reduced from 7 cm to 1 cm, the daily volumes generated from fresh water increased. With a tilt angle of 20° and a water depth of 1 cm, the sun still produces the maximum total daily amount of 495 mL (2 L/m^2/day). As shown in Figure 2.4.

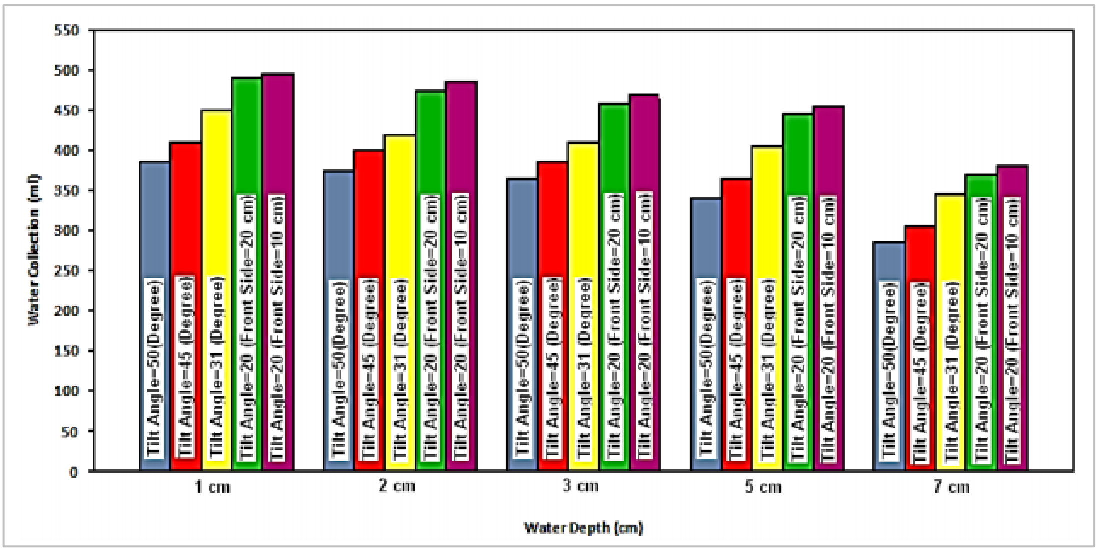
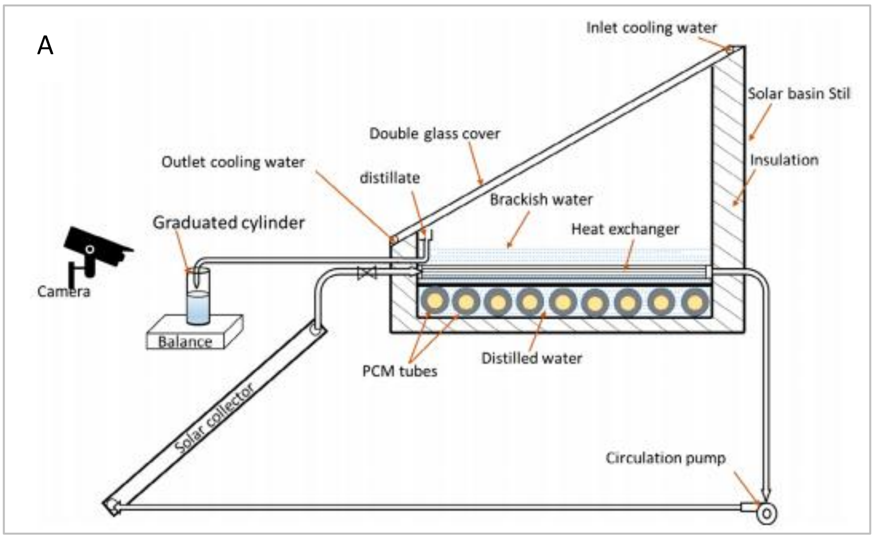


Figure 2.4 Productivity of water when variations water depth and tilt angle.[31]

Mohammad Al-harahsheh, et al. 2018 [32] used single-slope solar stills with a phase change material (PCM) to conduct a water desalination experiment. The rate of desalination was related to the increase in ambient temperature and the rate at which hot water flowed. As the water level rose, the basin's production decreased.The unit has the potential to generate 4300 ml/day. m^2 of water, with about 40% of that arriving after dark, as shown in Figure 2.5.



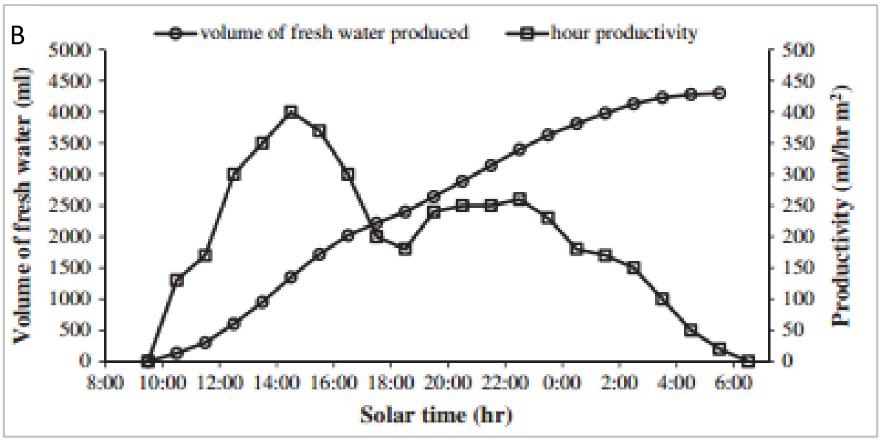


Figure 2.5 (A)Schematic diagram of the system . (B) Productivity variations of water with time.[32]

A. E. Kabeel, et al. 2019 [33] tried two solar parabolic dishes, two conical tanks, a single solar still, and four PV panels in practice, and they are all similar.According to the testing results, the daily distillate productivity of one solar dish was 8.8 and 5.45 kg/day at 10 and 20 mm water depths, respectively. The use of the two solar dishes combined with the solar still boosted daily output to 13.63 and 7.69 kg/day at the two water depths of 10 and 20 mm, respectively. as shown in Figure 2.6.

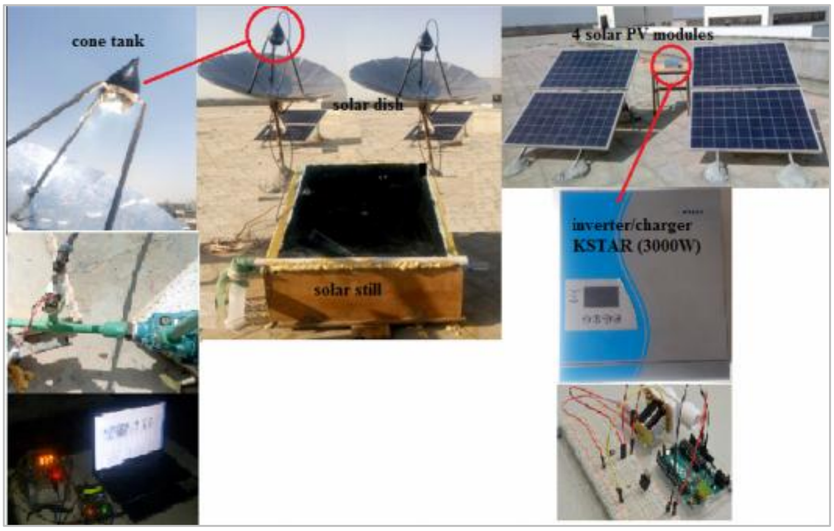


Figure 2.6 Shown the proposed solar water desalination system.[33]

A.E. Kabeel,et al. 2019 [34]they conducted an experiment using the PCM phase change material inside the solar still basin, with internal reflectors and an evacuated tube solar water collection system still used in the stepped solar water collection system. According to the experimental results, the daily distillate productivity varies between 10.43–10.61 L/m^2/day, 11–11.2 L/m^2/day, and 11.98–12.19 L/m^2/day for hot water flow rates of 10, 25, and 35 ml/s, respectively, as shown in Figure 2.7.

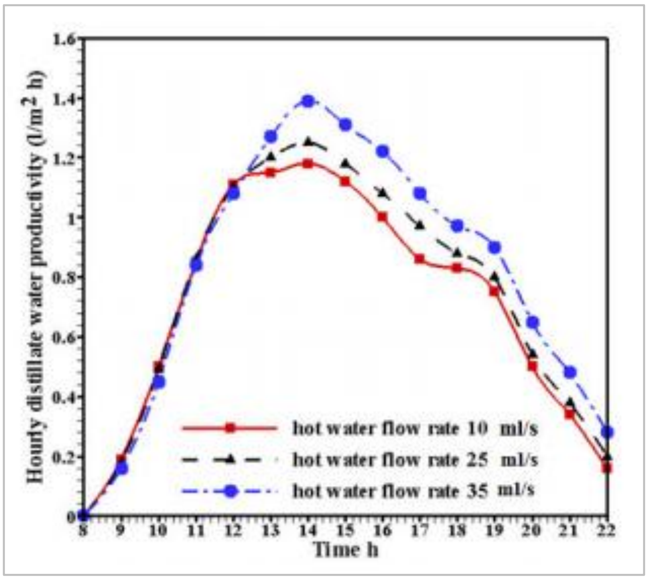


Figure 2.7 Water productivity at the effect of hot water flow rate.[34]

Zahraa Abdulkareem et al. 2020 [35]they used two methods to enhance the fumigation process. One of them was using a solar energy tank with a solar still, which led to an improvement in the productivity of fresh water by 48.83%. The other was using iron wicks of two different sizes to increase the area of solar absorption inside the single slope solar still. The productivity is improved by 86.65% and 72.53%, respectively, as shown in Figure 2.8.

Figure 2.8 (A)Solar energy tank with a solar still.(B) Iron wicks of two different sizes in side solar still.[35]

2.4. Theoretical study of solar still with PTC

A.M.I. Mohamed et al. 2011[36] assessed the performance and productivity of the proposed desalination system for solar humidification and dehumidification, A parabolic trough solar collector is adapted to drive and optimize the considered desalination system. A test setup for the desalination system was designed and a theoretical simulation model was constructed to evaluate the performance and productivity of the proposed sola humidification–dehumidification desalination system. The highest fresh water productivity is found to be in the summer season, when high direct solar radiation and a long solar day are always expected.

The production time reaches its maximum value in the summer season, which is 42% of the day.

Weidong Huang et al. 2012 [37] used a novel analytical model for optical performance and a modified integration technique to predict the performance of a parabolic trough solar collector with vacuum tube receiver.When the distance between the reflection point and the focus point increases, the energy absorbed by the receiver decreases and the angle at which the receiver tube reaches decreases, resulting in an average optical efficiency of Equivalent solar collector when the width of the mirror increases, and the optical efficiency gradually decreases at a far point from the axle.

Sh. Ghadirijafarbeigloo et al. 2014 [38] performed a numerical analysis of a receiver tube with a novel perforated louvered twisted tape (LTT). According to the results, the heat transfer coefficient and pressure drop dramatically increase when a new perforated louvered twisted tape is compared to a standard plain twisted tape in the tube and a plain tube.

C. Ananthsornaraj et al. 2015 [39]three-dimensional numerical modeling of a parabolic trough receiver is performed by coupling the Monte Carlo Ray-Tracing Method (MCRT) with the Finite Volume Method (FVM) to study the non-uniform flux distribution on the receiver's outer surface. For varied HTF intake temperatures and velocity, the temperature distribution of the absorber tube in three dimensions is numerically calculated. The highest solar heat flux reached by the PTC receiver was 9753.3 W/m^2, 19506 W/m^2, 29260 W/m^2, and 39013 W/m^2 when the DNI is 200 W/m^2, 400 W/m^2, 600 W/m^2, and 800 W/m^2.

Z. Huang et al. 2015 [40] investigated heat transfer and flow in the inner tube with and without helical fins and burrs. Dimples were created using numerical simulations of the fully developed turbulent flow in terms of heat transfer enhancement. The results show that receiver tubes with dimples outperform those with protrusions or helical fins. Following that, the effects of dimple shape sizes and combinations on convective heat transfer performance are explored further. It turns out that having more dimples in the direction of the ocean and a deeper depth helps with performance, enhancing heat transmission since the different configurations of the dimples were discovered to have no discernible impact.

Mehmet Canalp Kulahli et al. 2019 [41] theoretically studied new parabolic reflector for a parabolic trough collector (PTC). In the longitudinal direction, the reflector has a changing focal length while maintaining a fixed focal line. As a consequence of the parametric studies, the flow rate optimization researchs resulted in a 0.21 % increase in thermal efficiency and a 0.63% increase in net energy gain.

2.5. Experimental study of solar still with PTC

H. Jafari Mosleh et al. 2015 [42] a combined heat pipe and a twin-glass evacuated tube collector are in a parabolic trough collector. The rate of production and efficiency can reach 0.27 kg/(m^2. h) and 22.1%, respectively, when aluminum conducting foils are used to transport heat from the tube collector to the heat pipe in the area between the heat pipe and the twin-glass evacuated tube collector.

A.E. Kabeel et al. 2017 [43] designed a solar still with an oil heat exchanger, a Phase Change Material (PCM), and a cylindrical parabolic concentrator with a focal pipe.freshwater productivity of the developed solar still was estimated to be 10.77 L/m^2/day, while the value for the traditional solar still was 4.48 L/m^2/day. The improved solar still has a freshwater productivity that is 140.4% higher than the ordinary solar still on average, as shown in Figures (2.9-2.10).

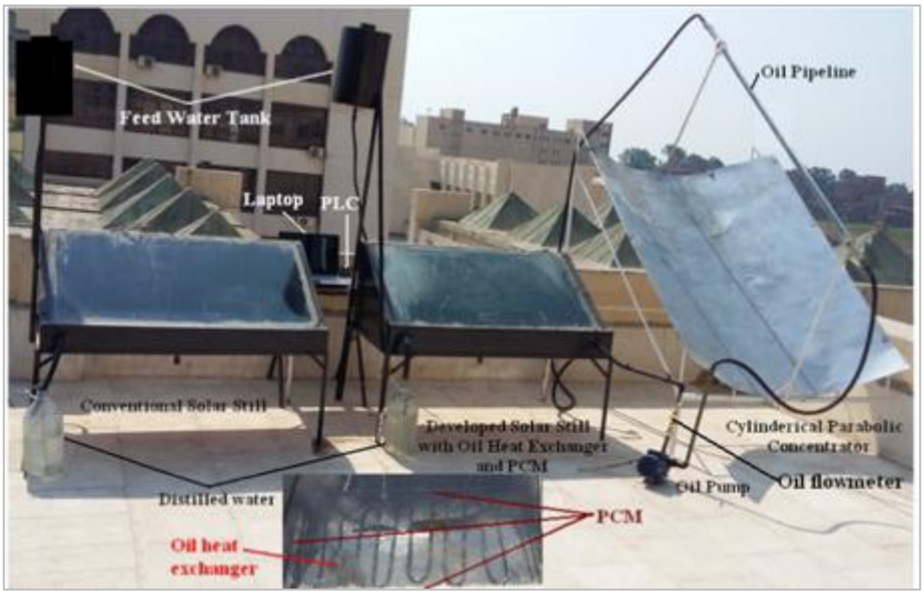


Figure 2.9 the Experimental work.[43]

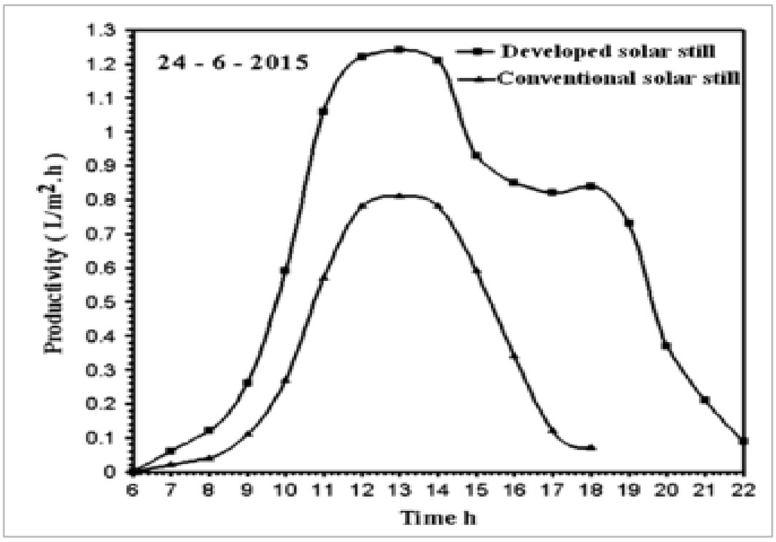


Figure 2.10 variations of productivity per hourly for two systems.[43]

Himanshu Manchanda et al. 2017 [44]used the basin of a distillation unit to dry ginger in a drying chamber built beneath the distillation unit with PTC. Based on the experimental data, heat transfer coefficients are evaluated by using linear regression analysis. Average convective heat transfer coefficients have been observed as 5.75 and 4.8 $W/m^2\ ^oC$ for distillation and 3.64 and 2.9 $W/m^2\ ^oC$ for ginger drying at a water depth of 4 cm and 6 cm. Evaporative and radiative heat transfer coefficients for distillation are observed to increase with the increase of solar radiation and ambient temperature. An average of 2 L/m^2 of distillate and 1 kg/m^2 of dried ginger is obtained from the system at 4 cm of water depth with an estimated cost of Rs. 2.55 per litre of distillate and per kg of dried ginger. As shown in Figure 2.11.

Figure 2.11 Shown exprimental work for PTC with single slope solar still.[44]

Mohamed Fathy and et al. 2018 [45] investigated the performance of a double-slope solar still with a parabolic trough collector (PTC) connection. The incident solar energy on the PTC is transferred to the solar still by oil pipes connected to a finned-piped loop heat exchanger imbedded in the solar still. The results illustrate that the solar still with PTC has higher sill temperature and productivity compared with conventional solar stills. The freshwater productivity of solar stills with tracked PTC is higher than that of fixed PTC by about 28.1%. Freshwater productivity is about 8.53 $kg/m^2/day$ and 4.03 $kg/m^2/day$ for solar stills coupled with fixed PTC in the summer and winter, respectively, as shown in Figures (2.12- 2.13).

Figure 2.12Shown components of the systems.[45]

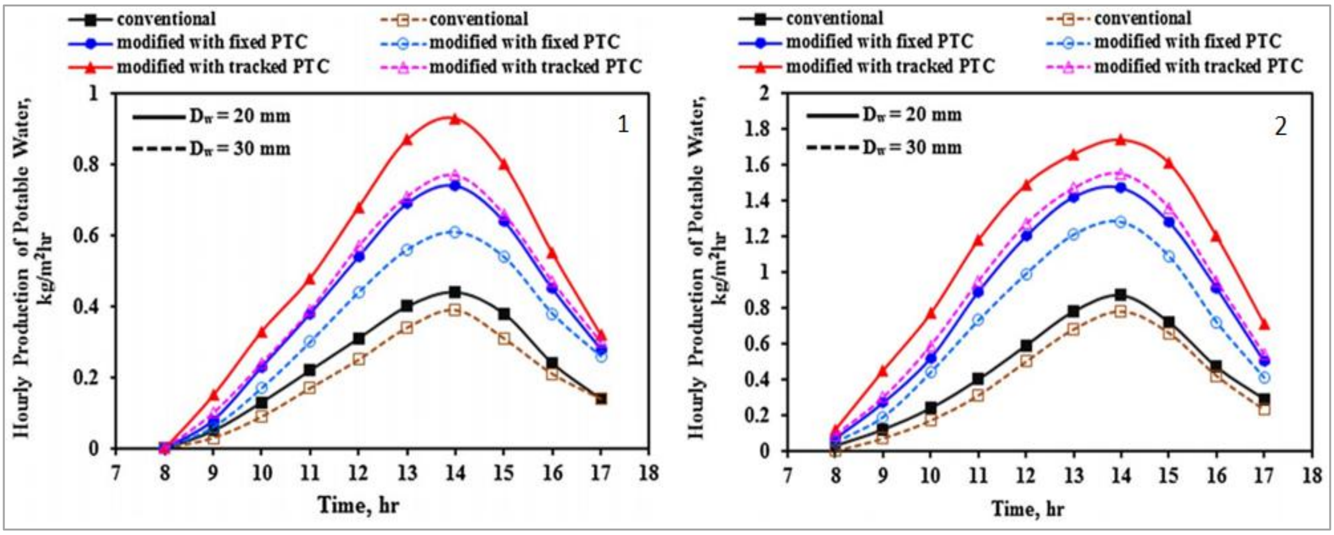


Figure 2.13(1)Productivity of water in winter. (2) productivity of water in summer time.[45]

Hamdi Hassan et al. 2019 [46]the impact of a salt water middle on the work of dual-action solar energy was examined experimentally using a parabolic trough collector. In the bowl, salt water media included steel wire mesh, clear salt water, and salt water-impregnated sand. Wire nets and sand boosted daily fresh water flow by roughly 3.1% in the winter and 13.7% in the summer, respectively.

Arun C A et al. 2018 [47]aided desalination is accomplished by a parabolic trough collector, which employs a variety of stainless steel and glass-covered copper receiving tubes. The performance of a parabolic trough solar collector is found to be highly dependent on solar light tracking and focal receiver. Physical and chemical analyses of both saline and desalinated water inputs were also performed. The yield of the desalination system is 2 L/m^2.

Jamel Madiouli et al. 2019 [48] have examined experimentally the effect of combining a flat plate collector and running a standard sloped solar still, in addition to the parabolic trough complex supported by a spherical layer filled with glass, which acts as a thermal storage medium for devices. The results indicate that solar energy combined with a parabolic trough collector can lead to excellent results, as shown in Figures (2.14–2.15).

Figure 2.14 Exprimental systems components.[48]

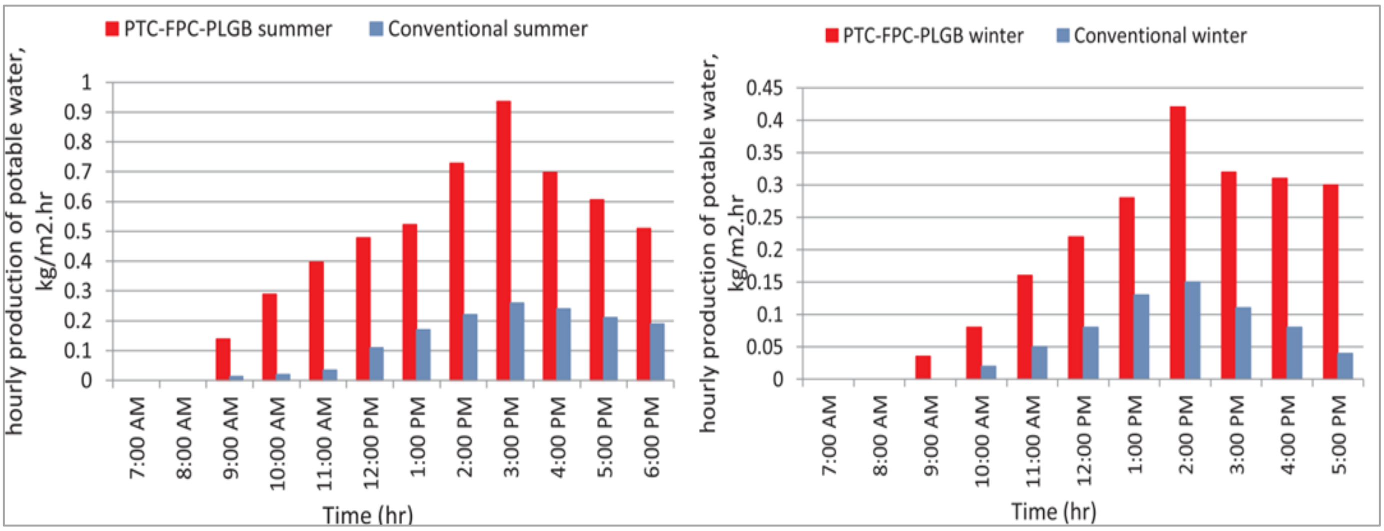


Figure 2.15 Hourly productivity of water at winter and summer .[48]

Qahtan A Abed et al 2020 [49] investigated the pre-designed and produced water systems in an experimental study. For the first time, a wastewater desalination project was implemented at Najaf, Iraq (32° 1'N, 44° 19'E). The proposed design attempts to increase distilled water output by including a parabolic solar basin. The first outcomes, the primary results, show an 11% increase in system efficiency, and the results also show that orienting the PTC to the north or south is optimum for preserving system efficiency, as shown in Figure 2.16.

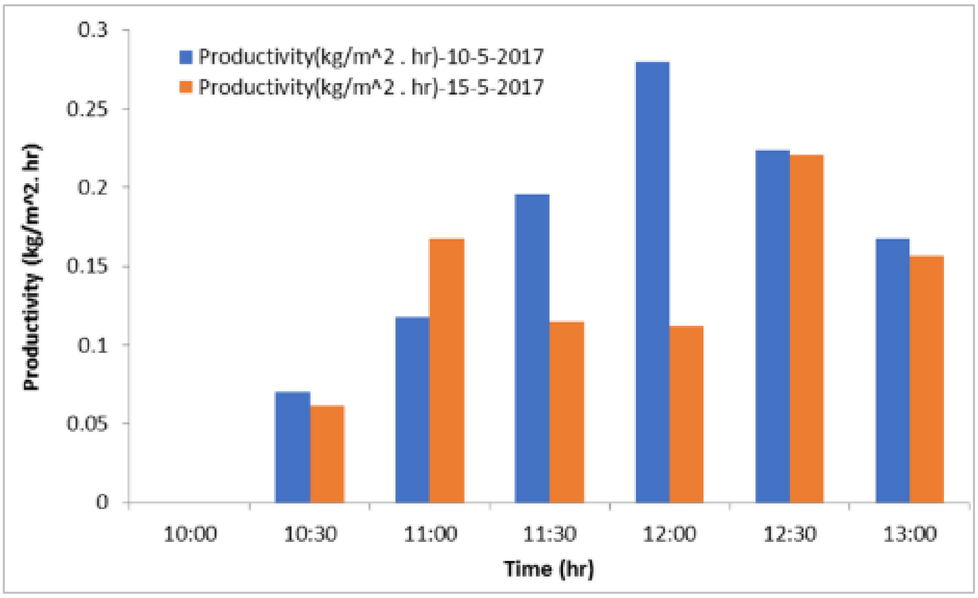


Figure 2.16 productivity of water for two different days.[49]

Anil Kumar et al. 2020 [50]conducted an experiment on the energy analysis of a single slope solar still connected to a parabolic trough collector for three different brine depths (5 cm, 10 cm, and 15 cm) and the results are presented. The yield obtained at 5 cm, 10 cm and 15 cm water level was 4.1 L/m^2, 3.645 L/m^2, and 3.2 L/m^2, respectively. It was observed that the annual energy output, energy payback time, and CO2 mitigation decreased with increasing water depth, while a reduction in water level from 15 cm to 5 cm showed an increase in daily energy yield of 22%.

Mohamed M. Khairat Dawood et al. 2020 [51]used a heat exchanger serpentine with an under-basin phase change material (PCM) and an evacuated tube on the focusing axis of a parabolic trough (PTC). They studied the effect of two variable salt water thicknesses, 3 cm and 1.5 cm, inside the single slope solar still. The daily productivity for the conventional solar still and oil as a working fluid at flow rates of 1.5, 1.0, and 0.5 L/min, and nano-oil as a working fluid at a flow rate of 0.5 L/min, respectively, was 3.182, 4.67, 6.21, 8.79, and 11.14 L/m^2/day when at 1.5 cm and 3 cm thickness for salt water, as shown in Figure 2.17.

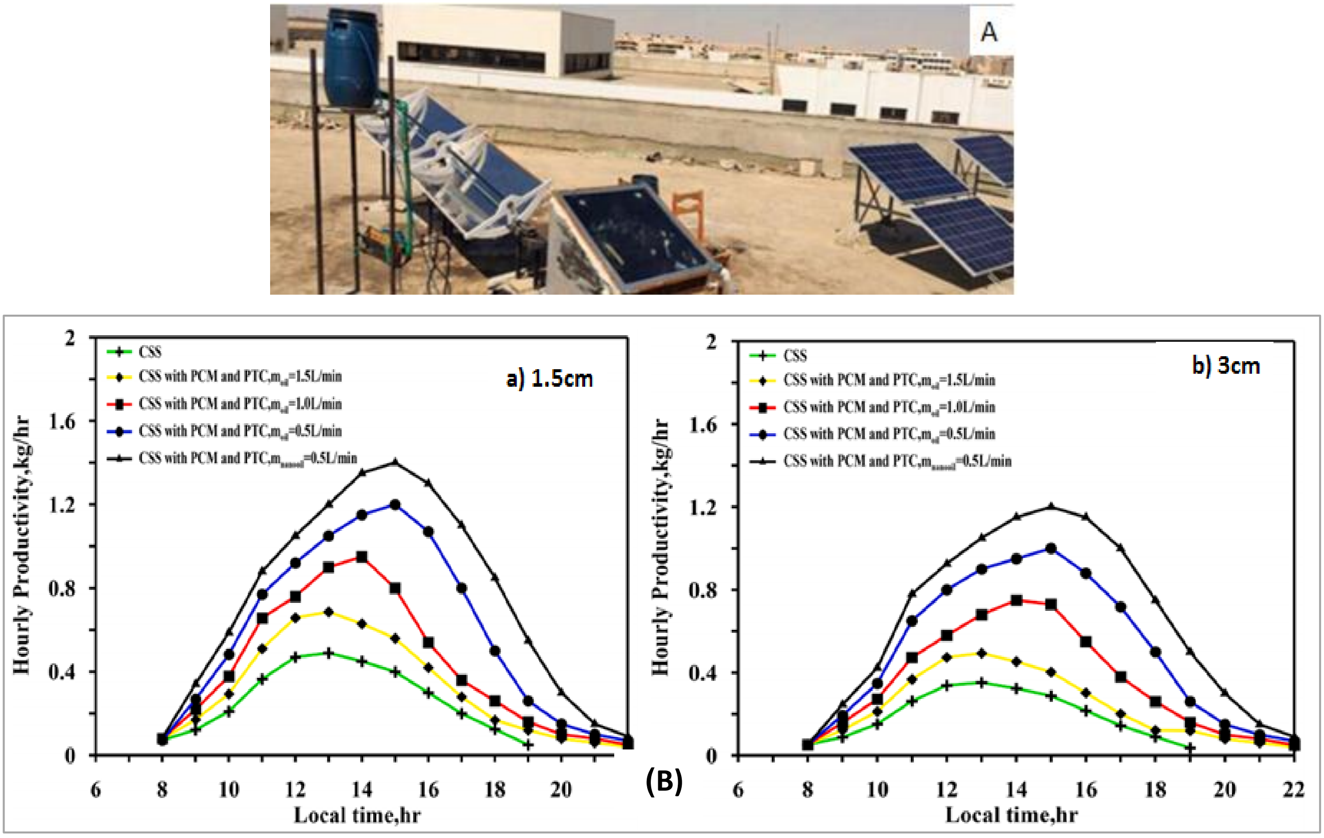


Figure 2.17 (A) Exprimental work systems .(B) Variation of productivity for two water depth for different cases system.[51]

Hamdy Hassan et al. 2020 [52]both the standard solar still with a glass condenser (CSS) and the solar still with a plated finned heat sink condenser are investigated. The use of wire mesh, sand, and a heat sink condenser (HSC) increases the still freshwater yield and efficiency, according to the findings. When compared to CSS, the maximum freshwater yield rising in summer is 67%, 7.3%, and 6% due to using PTC, HSC, and sand, respectively, compared to CSS. The efficiency of all still systems in summer is found to be greater than in winter. Moreover, utilizing HSC raises the efficiency by 11.6% in summer and 8% in winter compared to CSS. With an efficiency of 41.95% in summer and 31.96% in winter, MSS+sand+PTC accomplishes the minimum freshwater cost with a decrease of 25.2% compared to CSS.

Hossein Amiri et al. 2020 [53] worked on a novel independent desalination system that consists of a parabolic trough collector with a solar still. The solar still system generates 0.961 L of fresh water per day in the summer, which is 55% more than the yield of the fixed parabolic trough collector in the winter. In the summer, the parabolic trough collector with tracking systems would yield 1.266 L/day.

2.6. experimental study of solar Concentrating with nanofluid.

K. S. Chaudhari et al. 2015 [54] studied experimentally the effect of nanofluid (Al2O3 + water nanofluid) on the efficiency of the parabolic trough collector. Experiments were conducted using nano liquid or using water as a fluid that runs inside the tubes. A comparison in terms of thermal efficiency was made. The results showed that the parabolic trough collector that works with nano-liquid is more efficient than the water-based parabolic trough collector by 7%, and an increase in the heat transfer coefficient was found by 32%, as shown in Figure 2.18.

Figure 2.18 Exprimrntal setup.[54]

Alibakhsh Kasaeian et al. 2015 [55]have manufactured and designed a small parabolic trough collector with a width of 70 cm and a reflector height of 2 m, made of mirror steel. Several experiments were conducted using different designs of receiver tubes. The nanofluid was used as a working fluid that runs inside the receiving tube. The results show that the vacuum tube is more efficient than others by 11%. It was found that the use of nanofluid gives a high thermal potential for many experiments, improving the performance of PTC.

Madhu.B.et al. 2017 [56] studied experimentally the effects of different types of nanofluid on the productivity of the solar still and compared it with the traditional system. They used CuO, TiO2, and Al3O2 at different concentrations. The results showed that the use of nanofluid would improve the productivity of distilled water and the efficiency. Also, an improvement in temperatures was also obtained. As shown in Figure 2.19.

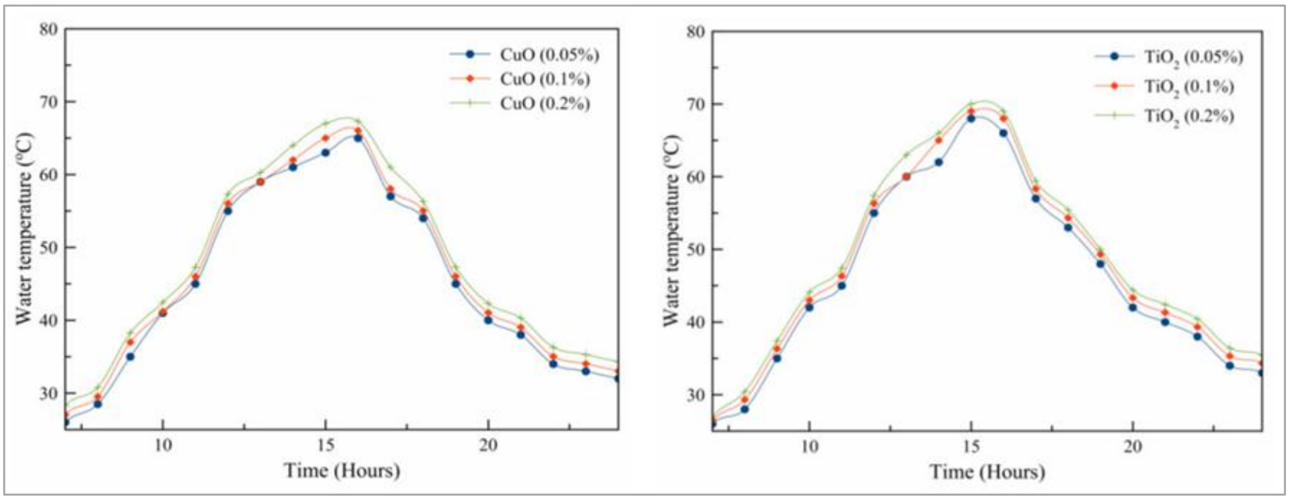


Figure 2.19 (A) Effect of CuO nanofluids on water temperature at different concentration, (B) Effect of TiO2 nanofluids on water temperature at different concentration.[56]

Ananda Gowda et al. 2019 [57] conducted research on the PTC system's thermal examination. A method was developed for the reduction of graphene oxide as a nanofluid with a base liquid. There is a differentiation established between evacuated and non-evacuated circumstances in order to improve the thermal performance of PTC. Reynolds number (Re), friction factor, and average Nusselt number with a consistent amount of heat flux were chosen as physical characteristics.They discovered that utilizing nanoparticles as a water exchanger in an evacuated receiver tube improves heat transfer performance owing to the thin layer of the thermal boundary layer of nanoparticles positioned in the tube's wall.

Dattatraya G. Subhedar et al. 2020 [58]worked experimental for a single-slope solar still plant (CSP) with a parabolic trough collector (PTC) using Nanofluid. With 0.1 % volume fraction Al_2O_3/Water nanofluid as working fluid, the highest yield was determined to be 1741 mL for a 2.5 cm saline water depth in a 1 m^2 basin. The Al_2O_3/Water nanofluid integrated solar still system's yield, as shown in Figure 2.20.

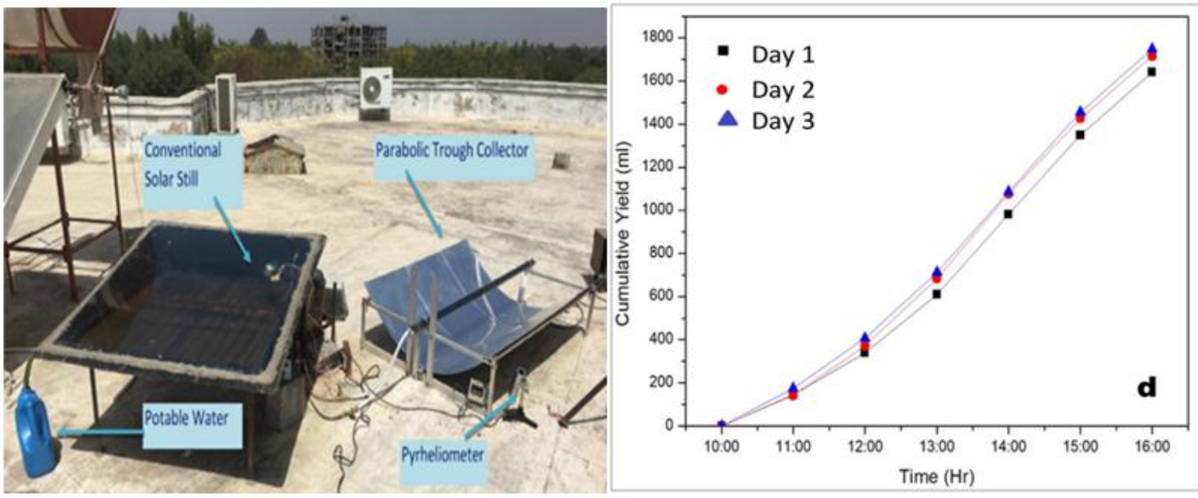


Figure 2.20(A)Exprimental setup, (B)CSP integrated with 1% Volume fraction Al2O3-Water Nanofluid based PTC.[58]

2.7. Summary

The following are the most important conclusions drawn from the literature review**:**

1. Through research, it was discovered that using solar energy to distill water is one of the most important ways to provide drinking water because it depends on free energy

and that solar distillation is easy to build and at a cheap cost, whether in terms of using solar distillers or solar collectors. Therefore, there is an urgent need to continue many research and development in improving the work of solar collectors or solar still.

2. Analytically and experimentally, the majority of researchers have sought to improve the processes of evaporation and condensation.
3. Some researchers did not give the desired results with a higher difference in yield when compared to conventional distillates, while others produced the opposite effects, resulting in lower yields. Some researchers have used external catalysts as solar collectors to help speed up the heating process.
4. Some researchers have used different nanofluids with different concentrations to improve the performance of solar concentrators, whether with monoclinic solar still or with PTC or both or with other concentrators. It is used as a liquid that flows inside the pipes. The improvement is done in terms of distilled water productivity and efficiency. They also concluded that nanofluids increase the thermal potential, and it is a very useful liquid for heat transfer fluids to enhance the thermal properties.

Table 2.1. Summary of Theoretical and Experimental of the literature Review

No.	Researcher	Type of study	Work	Results
1	Hiroshi Tanak . et al (2006)[25]	Theoretical	used a basin type still with internal and external reflectors	the external and internal reflectors increase the productivity of the distillate 48%
2	A.A. El-Sebaii, et al (2009)[26]	Theoretical	Numerical simulations were performed using stearic acid as a PCM.	The use of PCM increases the productivity improvement by 85% compared to the traditional system
3	Lovedeep Sahota,	Theoretical	nanotechnology has	It is determined to

	et al (2017)[27]		been used into solar distillation systems to create drinking water.	be 24.61 tones and 2.36 tones, respectively, for the hybrid system mixing copper oxide and water based nanofluid.
4	Muntadher Mohammed ,et al (2019) [28]	Theoretical	Thermal conductivity of paraffin wax has been improved using nanoparticles. Al_2O_3	The results showed that 1 kg of PCM provides the most degree of increase, and that employing 3%Al_2O_3 nanoparticles dispersed in 1 kg of paraffin wax can boost typical single slope solar still daily productivity by about 20%.
5	A.S. Abdullah, (2013)[29]	Experimental	Use a substance to store heat from the aluminum filler behind the absorption plate inside solar still	utilized a substance to store heat from the aluminum filler behind the absorption plate to keep the temperature stable and .Results showed that, water productivity increased by 112%

				over conventional still, when the system was coupled with a solar air-heater and glass cover cooling, for stepped solar still.
6	Hitesh Pancha ,(2016)[30]	Experimental	Use three various thicknesses of glass cover, such as 4 mm, 5 mm, and 6 mm	The highest rate of productivity increase was obtained at the lowest thickness of 4 mm glass by 27%
7	Ali A. Aljubouri, et al (2017).[31]	Experimental	Using glass covers with different tilt angles of 20^0 , 31^0 , 45^0 and 50^0	The solar still with a tilt angle of 20°C and a water depth of 1 cm produced the highest total daily quantity of 495 ml (2 L/m^2 /day).
8	Mohammad Al-harahsheh, et al (2018)[32]	Experimental	used single slope solar stills with a phase change material (PCM)	The rate at which desalinated water was produced was proportional to the rise in ambient temperature and the pace at which hot water circulated.
9	A. E. Kabeel, et al(2019) [33]	Experimental	using the PCM phase change material inside	the daily distillate productivity varies

			the solar still basin, with internal reflectors and an evacuated tube solar water collection system	between 10.43-10.61 L/m^2 day, 11-11.2 L/m^2 day, and 11.98-12.19 L/m^2 day
10	A. E. Kabeel, et al(2019)[34]	Experimental	Two identical solar parabolic dishes with two conical tanks, a single solar still, and four PV	the use of the two solar dishes combined with the solar still increased daily productivity to 13.63 and 7.69 kg/day.
11	ZahraaAbdulkareem et al(2020)[35]	Experimental	use a solar energy tank with solar still. and use iron wicks of two different sizes	The productivity is improved by 86.65%. and 72.53%.
12	A.M.I. Mohamed. et al (2011)[36]	Theoretical	A theoretical simulation model was developed to evaluate the performance and productivity of the proposed desalination system	Summer yields the biggest amount of fresh water; production time is at its peak in the summer, accounting for 42 % .
13	Weidong Huang et al,(2012)[37]	Theoretical	The performance of a parabolic trough solar collector with vacuum tube receiver is simulated	The results also showed that the tracking error leads to a decrease in the optical efficiency, as it decreases by from 71% to 53% with tracking error

				increasing from 0to 12 m rad.
14	Sh. Ghadirijafarbeiglo o et al(2013)[38]	Theoretical	Making a numerical study of the receiver tube equipped with a new perforated louvered twisted tape (LTT).	the heat transfer coefficient and pressure drop rise dramatically when use a new perforated louvered twisted tape inside of pipe
15	C. Ananthsornaraj et al ,(2015)[39]	Theoretical	By coupling the Monte Carlo Ray-Tracing Method (MCRT) with the Finite Volume Method (FVM), three-dimensional numerical modeling of a parabolic trough receiver is performed to study the non-uniform flux distribution on the outer surface of the receiver,	When the DNI is 200 W/m^2, 400 W/m^2, 600 W/m2, and 800 W/m^2, the highest solar heat flux reached by the PTC receiver is 9753.3 W/m^2, 19506 W/m^2, 29260 W/m^2, and 39013 W/m^2.
16	Z. Huang, et al (2015)[40]	Theoretical	Numerical simulations were performed on the fully developed turbulent and the heat transfer and flow in the inner tube with and without helical	The results demonstrate that receiver tubes with dimples outperform those with protrusions or helical fins in terms

			fins, burrs and dimples were examined.	of heat transfer augmentation
17	Mehmet Canalp Kulahli et al,(2019)[41]	Theoretical	introduce a new parabolic reflector for a Parabolic Trough Collector (PTC). The reflector has a variable focal length in the longitudinal direction while keeping a fixed focal line.	The flow rate optimization study results in a 0.21 % increase in thermal efficiency and a 0.63 %increase in net energy gain as a result of the parametric studies.
18	H. Jafari Mosleh, et al (2015)[42]	Experimental	Use with PTC a combination of a heat pipe and a twin-glass evacuated tube collector is used.	When aluminum conducting foils are employed in the area between the heat pipe and the twin-glass evacuated tube collector . the rate of production and efficiency can reach 0.27 kg/($m^{2.}$ h) and 22.1 %, respectively.
19	A.E. Kabeel , et al (2017)[43]	Experimental	A designed solar still with (PCM) and a cylindrical parabolic concentrator with focal pipe	The freshwater productivity of the developed solar still was estimated to be 10.77 L/m^2 /day,

				while the value for the traditional solar still was 4.48 L/m^2 /day,
20	Himanshu Manchanda, et al (2017)[44]	Experimental	used the basin of a distillation unit was to dry ginger in a drying chamber built beneath the distillation unit. With parabolic reflector.	The system produces 2 kg/m^2 dried ginger at a 4 cm water depth, at a cost of Rs. 2.55 per liter of distillate and each kg of dried ginger
21	Mohamed Fathy, etal (2018)[45]	Experimental	three systems were used: conventional solar still, solar still with fixed PTC and with tracked PTC.	At a salty water level of 20 mm in summer, the freshwater productivity of solar stills with tracked PTC is about 28.1% greater than that of fixed PTC and about 142.3%higher than that of conventional solar stills.
22	Hamdy Hassan, et al (2018) [46]	Experimental	use pure saline water, steel wire mesh, and sand soaked with saline water	increases the daily yield freshwater by about 3.1 % and 13.7 %in the winter and around 3.4 % and 14.1 % in the summer.

23	Arun C A, et al (2018)[47]	Experimental	PTC, which employs a variety of stainless steel and glass-covered copper receiving tubes.	The yield of the desalination system is 2 L/m^2.
24	Jamel Madiouli, et al (2020)[48]	Experimental	integrating (FPC) and (PTC) supported by a packed glass ball layer on the performance of a typical single slope solar still	The results indicated that solar, when combined with PTC, FPC, and PLGB, produces more freshwater at a rate of 6.036 kg/m^2 in the summer and 2.775 kg/m^2 in the winter
25	Qahtan A Abed et al,(2020)[49]	Experimental	Use PTC with single slope solar still	the results show an 11% increase in system efficiency
26	Anil Kumar,et al, (2020)[50]	Experimental	with three different brine depths, have been use single slope solar still linked with PTC	lowering the water level from 15 cm to 5 cm resulted in a 22 % increase in daily energy yield.
27	Mohamed M. Khairat Dawood, et al (2020)[51]	Experimental	A heat exchanger serpentine with an under basin inside it (PCM) with (PTC)	The daily productivity for the conventional solar still and oil as a working fluid 6.21 L/m^2 /day and nano-oil as a working fluid was 11.14

				L/m^2 /day
28	Hamdy Hassan, et al (2020)[52]	Experimental	The standard solar still with glass condenser (CSS) and the solar still with plated finned heat sink condenser are both investigated.	the maximum freshwater yield growing in summer is 67%, 7.3 %, and 6 % due to the use of PTC, HSC, and sand, respectively.
29	Hossein Amiri, et al (2021)[53]	Experimental	The work on a novel independent desalination system that consists of a PTC with SS	The solar still system generates 0.961 L of freshwater per day in the summer, the parabolic trough collector with tracking systems would yield 1.266 L
30	K. S. Chaudhari, et al ,(2015)[55]	Experimental	The working fluid (Al_2O_3 + water nanofluid) was used.	The results reveal that a nanofluid-based parabolic trough collector outperforms a water-based parabolic trough collector in terms of efficiency.
31	Alibakhsh Kasaeian et al.(2015)[56]	Experimental	manufactured and designed a small parabolic trough collector with a width of 70 cm and a	The results show that the vacuum tube is more efficient than others by 11%. Where it

			reflector height of 2 m .with use nanofluid	was found that the use of nanofluid gives a high thermal potential
32	Madhu.B.et al,(2017)[56]	Experimental	They used CuO, TiO_2, Al3O2 at different concentrations	The results showed that the use of nanofluid would improve the productivity of distilled water and the efficiency
33	Ananda Gowda et al,(2019)[57]	Experimental	Thermal examination of the PTC system with the use of nanofluid	utilizing nanoparticles as a water exchanger in an evacuated receiver tube improves heat transfer performance
34	Dattatraya G. Subhedar et al,(2020)[58]	Experimental	use single-slope solar still plant (CSP) with a parabolic trough collector (PTC) using Nanofluid	The Al_2O_3/Water nanofluid integrated solar still system's yield and thermal efficiency are around 66 % and 70 % greater than CSP

CHAPTER THREE: Numerical simulation

3.1. Introduction

This chapter deals with the numerical simulation of the receiver tube of a parabolic trough collector with solar distillation using a heat exchanger with two designs, one of which winding consists of 8 pipes and the other is an incorporator (absorber plate and pipes) inside single slope solar still by using COMSOL 5.5 software. theoretically tested temperatures when using these heat exchanger designs.

3.2. COMSOL Program

COMSOL is a Program platform finite element analysis tool. It's a simulation program for multi-physics solutions. It is possible to create numerous designs and compare them to find the best design without having to do any experimental effort. It is built on the basis of partial differential equations (PDE_S). The equation of conservation of energy, momentum, and mass is one of these equations. There are various nodes in the COMSOL. These equations are solved for a set duration for each node. The numerical simulations based on the FEM were achieved by employing COMSOL Multiphysics. The flow chart illustrating different steps of modelling is shown in figure 3.1. As a result, the boundary conditions must be defined in order for those equations to determine the physics of the instance in question. The solution contains all of the data for the investigated model, including pressure gradient, flow velocity, and temperature. The steps to conduct an analysis of every given study have been presented below.

1- Global Definitions (Parameters and Variables)
2- Materials
3- Geometry (3D Geometry modeling)
4- Define the model's governing physics and bounds
5- Generating Mesh
6- Computational Solution
7- Acceptable Solution

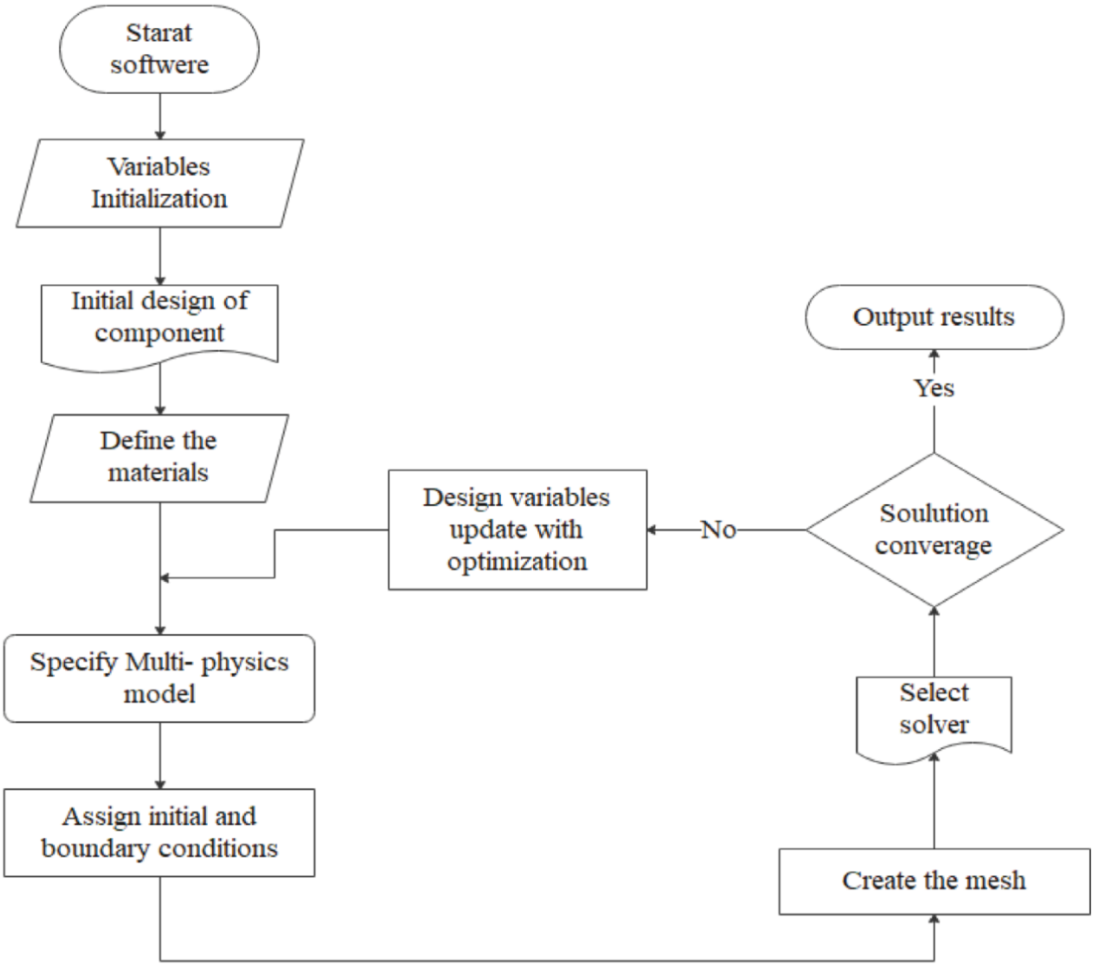


Figure 3.1. flow chart of the simulation steps and parameters

Assumptions that were adopted in the COMSOL 5.5 program.

1- 3D flow
2- unsteady state flow
3- single phase flow (laminar flow)
4- heat transfer fluid

3.2.1. Physical method used

In order to investigate the performance of the solar still technology, a three-dimensional simulation model is design using COMSOL Multiphysics. A numerical simulation was performed in the COMSOL Version 5.5 program. The complete three-dimensional solar system consisting of a receiving tube for a parabolic trough collector with an inner diameter of 16 mm and a length of 140 cm of copper material has been implemented by this simulation. The receiving tube is connected via connections to the heat exchanger inside the solar still. The solar still is of polystyrene rectangular shape. The length of the solar still is 61cm, and its width is 38cm with an angle of inclination of 32.1. It is covered from the top with 4 mm thick glass. the angle of inclination (32.1° north latitude and 44.32° east longitude) was chosen based on the latitude of the city of Najaf. Inside it is a heat exchanger where two models were used, one of which winding consists of 8 pipes each pipe is 1 cm in diameter and the other is an incorporator (absorber plate and pipes) that has been painted with a black thermal color to enhance absorption and reduce reflection. The thickness of the water inside the solar still is 1.5 cm. As shown in figure 3.2. The geometrical properties of the solar parabolic trough and single solar still are presented in Table 3.1. Water was used as a working fluid. The properties are shown in Table.3.2.

Table 3.1 Real dimensions of the parabolic trough collector & single solar still

Parameter	Value	Unit
Aperture width for parabolic trough collector	80	[cm]
Trough length	140	[cm]
Aperture area	1.12	[m^2]
Concentration ratio	13.091	[-]
Inner diameter of receiver tube	16	[mm]
Outer diameter of receiver tube	19	[mm]
Width of single solar still	38	[cm]
Length of single solar still	61	[cm]
Rim angle	90°	[°]
Diameter of pipe for heat exchanger	1	cm

Table 3.2 Properties of fluid (water) at 20°C

Properties	Value	Unit
Specific heat $(C_P)_w$	4182	[J/kg. k]
Thermal conductivity$(K)_w$	0.6	[W/m. K]
Density$(\rho)_w$	998.3	[kg/m^3]
Prandtl $(P_r)_w$	7	[-]

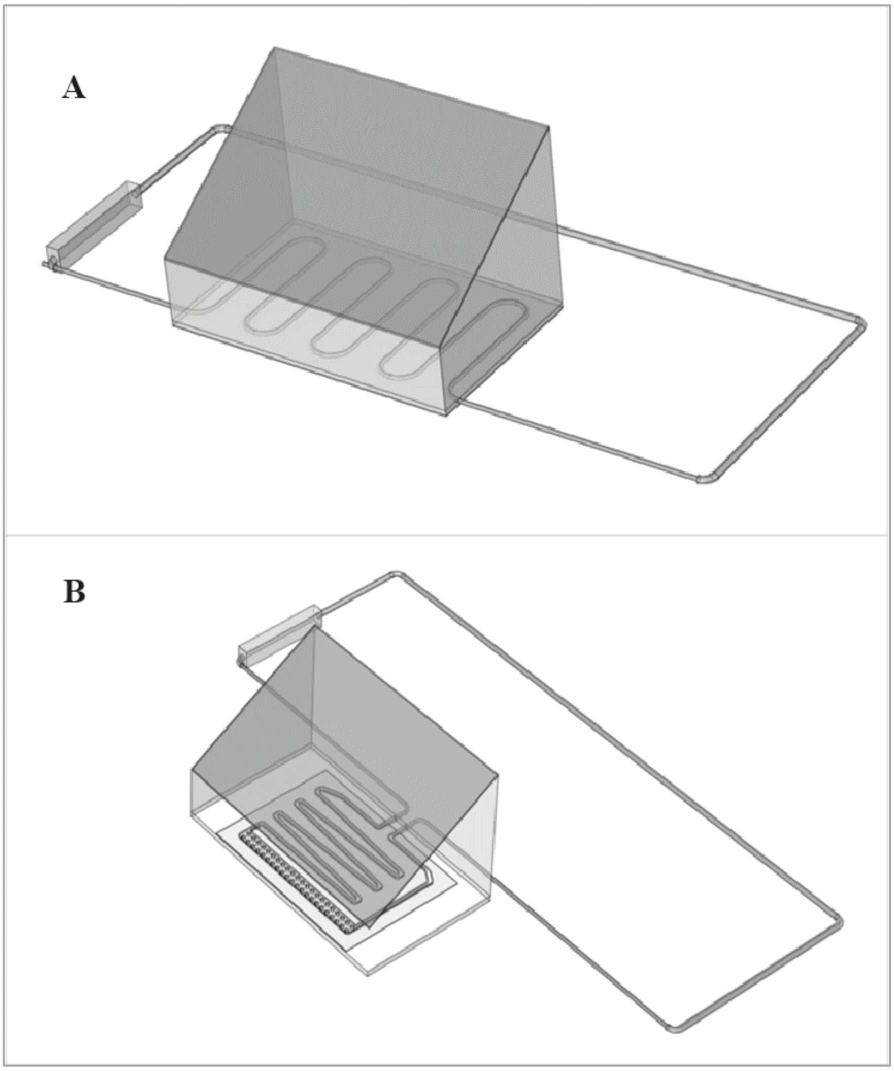


Figure 3.2. System geometry, (A)heat exchanger winding (b) heat exchanger incorporator (absorber plate and pipes).

3.2.2. Mesh implementation

The mesh resolution of the parabolic trough collector with single solar still is presented in figure 3.3 In the second stage of the COMSOL numerical simulation. A 3-D mesh type has been created for this simulation. The mesh quality immediately influences the simulation result. Therefore, a number of networks are examined to find accurate solutions. This grid is improved near the walls and heat exchanger and salt water. The mesh type was uniform over the water pipe domain but near solar still walls were network mesh extremely bigger, while the element size use is normal mesh. Mesh consists of 794654 element

Minimum Quality : $6.876*10^{-4}$, average quality : 0.6 .where the closer the average quality is to one the more the mesh is perfect, as shown in Figure 3.3B.

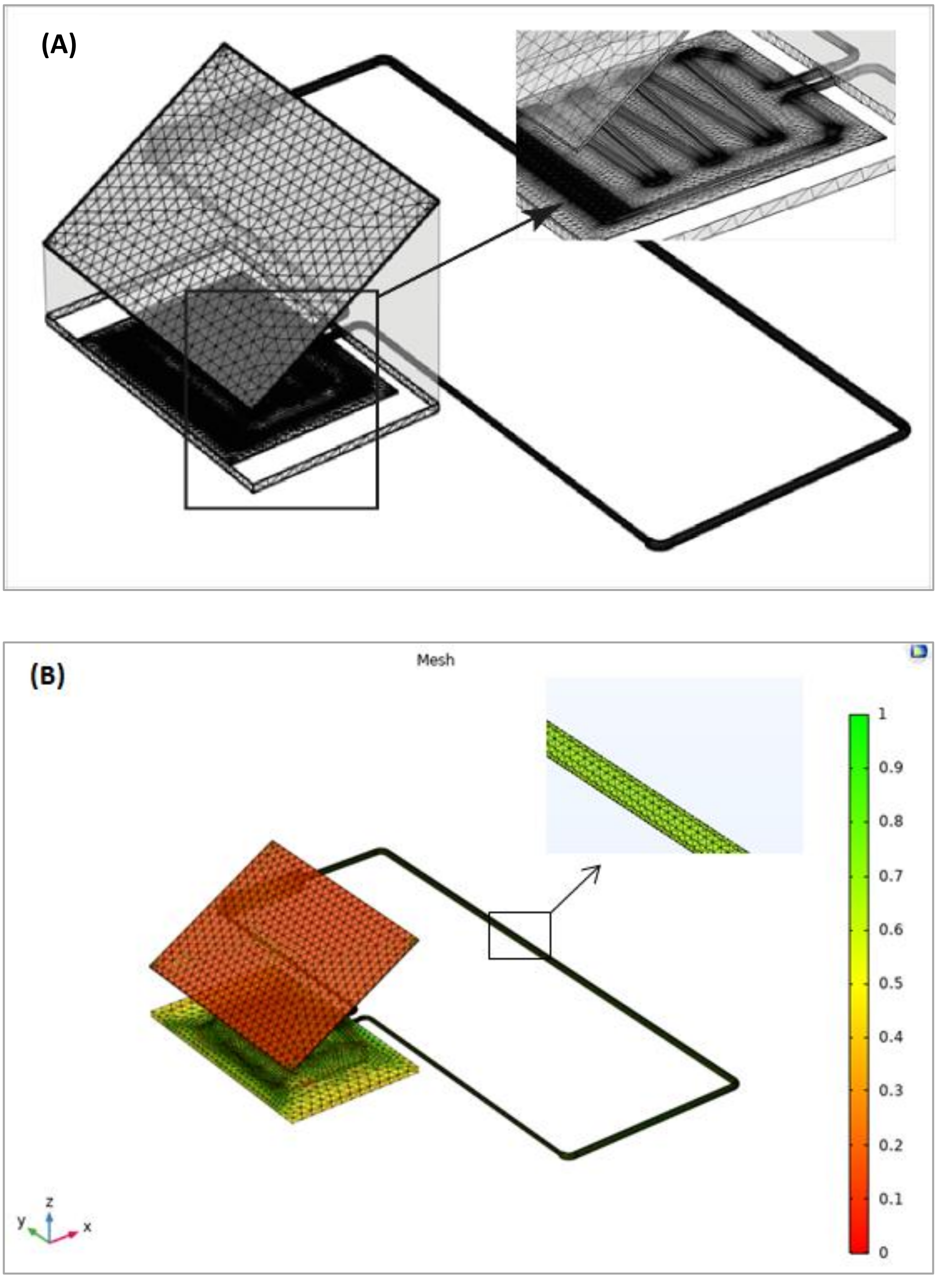


Figure 3.3 (A)and (B)Mesh distribution in the system with different numbers of elements

3.2.3. Mathematical model

The model consists of the following sets of equations Continuity, three dimensional flow unsteady[60]-[61]

$$\frac{\partial \rho}{\partial t} + \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \qquad 3.1$$

where u flow velocity in x direction (m/s), v flow velocity in y direction (m/s), w flow velocity in z direction (m/s), and ρ the density of steam (kg/m^3).

The Momentum Equations of water flow in three dimensional unsteady as flowing:[61]

In x-direction.

$$\rho\left(\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z}\right) = \rho g_x - \frac{\partial p}{\partial x} + \mu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right) \qquad 3.2$$

In y-direction

$$\rho\left(\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z}\right) = \rho g_y - \frac{\partial p}{\partial y} + \mu\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2}\right) \qquad 3.3$$

In z-direction

$$\rho\left(\frac{\partial w}{\partial t} + u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z}\right) = \rho g_z - \frac{\partial p}{\partial z} + \mu\left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2}\right) \qquad 3.4$$

The energy equation for the water flow in three dimensional unsteady as flowing:

$$\rho . C_p . \left(\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial y} + v\frac{\partial T}{\partial y} + w\frac{\partial T}{\partial z}\right) = k . \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right) \qquad 3.5$$

Where **p** the pressure of water flow and **k** the thermal diffusivity.

3.3. Initial and Boundary Conditions

3.3.1. Initial Conditions (I.C)

At time t = 0

$$u(x, y, z, 0) = v(x, y, z, 0) = w(x, y, z, 0) = 0$$

$$P(x, y, z, 0) = 0$$

$$T(x, y, z, 0) = 22.8°C$$

3.3.2. Boundary Conditions (B.C):

1- Concentration tube.

The wall of concentration tube, has from one halve of tube to concentration solar irradiation as following: -

$$Q_b = G \times C.R. \times \alpha \qquad 3.6$$

Where α is Absorption coefficient.

While the other halve of concentration tube subjected to convection to ambient as following equation:

$$Q_{out} = h_{out}\left(T_{tube} - T_{amb}\right) \quad 3.7$$

$$h_{out} = 5.7 + 3.8V_{out} \quad 3.8$$

where Q_b and Q_{out} are the rate of heat transfer to the receiver tube and the ambient, G is the solar irradiation (W/m^2), $C.R.$ is a concentration ratio, T_{tube} and T_{amb} are temperatures of receiver tube and ambient (ºC), V_{out} is wind speed (m/s) and h_{out} is the convective heat transfer coefficient (W/m^2.ºC) .

2- Water domine of solar still

i- Heat absorbed by water

$$R_w = G \times \tau_w \times A_b \quad 3.9$$

ii- Evaporation from water surface

$$Q_{ew} = h_{ew}\left(T_{wb} - T_{gi}\right) \quad 3.10$$

iii- Heat convection from water surface

$$Q_{wc} = h_{cwb}\left(T_{wb} - T_i\right) \quad 3.11$$

iv- Heat radiation from water surface

$$Q_{wr} = h_{rw}\left(T_{wb} - T_{gi}\right) \quad 3.12$$

where R_w and Q_{ew} are the rate of heat absorbed and evaporated from water (W/m^2), Q_{wc} and Q_{wr} are the rate of heat transfer from water surface by convection and radiation (W/m^2), G is the solar irradiation (W/m^2), h_{ew}, h_{cwb} and h_{rw} are Evaporative, convective and radiative heat transfer coefficients from the water surface (W/m^2.ºC), T_{wb} and T_{gi} are temperatures of water surface and inner glass (ºC). τ_w is Transmissivity of water

3- Trough domine of solar still

i- Heat absorbed by trough

$$R_T = G \times \tau_t \times A_b \quad 3.13$$

Where τ_t is Transmissivity of trough

ii- Heat loss to ambient by convection

$$Q_{tha} = \left(\frac{k_{ins}}{t_{ins}}\right)\left(T_b - T_{amb}\right) \quad 3.14$$

Where k_{ins} Thermal conductivity of insulation, t_{ins} the thickness of insulation materal

4- Glass domine of solar still

i- Heat absorbed by glass

$$R_g = G \times \tau_g \times A_g \quad 3.15$$

Where τ_g is Transmissivity of glass , A_g area of glass

ii- Condensation in inner glass.

$$Q_{cdha} = h_{ew}\left(T_{wb} - T_{gi}\right) \quad 3.16$$

iii- Heat convection between inner glass and moisture air

$$Q_{cha} = h_{cwb}\left(T_i - T_{gi}\right) \quad 3.17$$

iv- Heat radiation between inner glass and water surface.

$$Q_{rw} = h_{rw}\left(T_{wb} - T_{gi}\right) \quad 3.18$$

v- Heat convection between outer glass surface and ambient

$$Q_{cc} = h_{cga}\left(T_{go} - T_{amb}\right) \quad 3.19$$

vi- Heat radiation between outer glass surface and ambient

$$Q_{rgs} = 0.9 \times \sigma \times A_g\left(T_{go}^4 - T_{sky}^4\right) \quad 3.20$$

$$T_{sky} = 0.0552 \times T_{amb} \quad 3.21$$

where R_g and Q_{cdha} are the rate of heat absorbed and condensate by glass (W/m^2), Q_{cha} and Q_{rw} are the rate of heat transfer from inner glass surface by convection and radiation (W/m^2), Q_{cc} and Q_{rgs} are the rate of heat transfer from outer glass surface by convection and radiation (W/m^2), T_{go} and T_{sky} are temperatures of outer glass surface and sky (ºC). σ is Stefan-Boltizmann's constant= 5.6703* 10^{-8} watt/m^2.K^4.

The boundary condition for fluid flow in the closed loop system using pump to circulation the water between the concentration tube of parabolic trough collector and the coil tube inside the solar still, where the governing equation used for pump in the system, is as following: [62]

$$\left[\rho u.n\right]_{-}^{+} = 0 \quad 3.22$$

$$\left[\rho - n^T\ kn + \rho\left(u.n\right)^2\right]_-^+ = \Delta p_{pc} \qquad 3.23$$

$$\Delta p_{pc} = f\left(P_{np}, V_{o,pd}\right) \qquad 3.24$$

where u is velocity field, n is normal component of flow field P_{np} is static pressure of pump as function of the volumetric flow rate pump, $V_{o,pd}$ is water flow rate, P_{pc} is pressure difference between inlet and outlet of pump.

In our study have been implemented the following values; $P_{np} = 100\,Pa$ and $V_{o,pd} = 2.01\times10^{-7}\ m^3/s$.

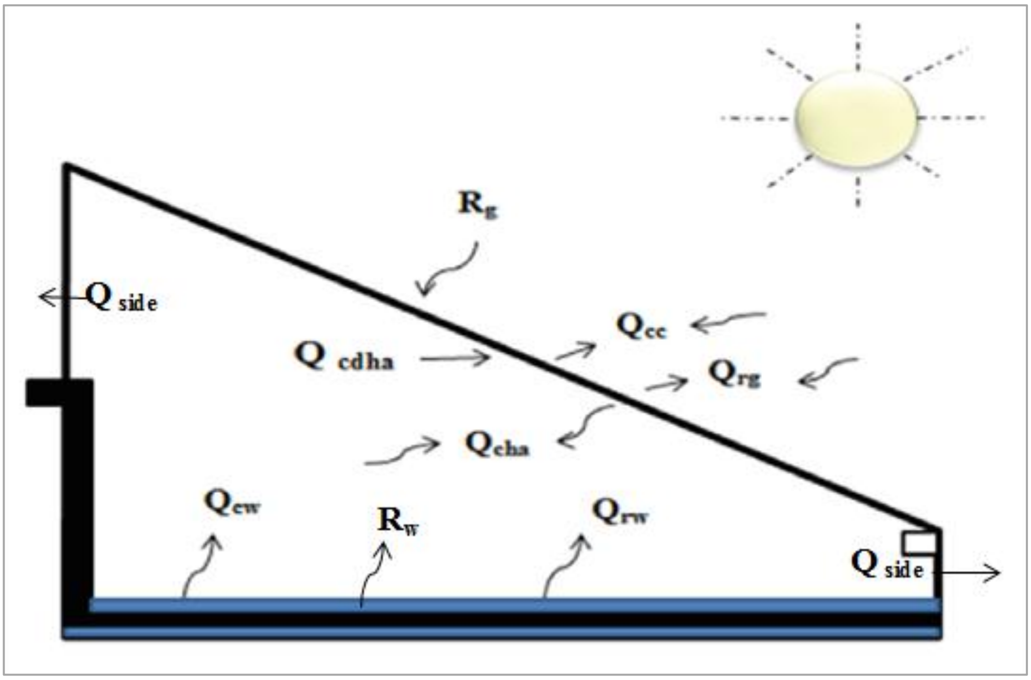


Figure 3.4 Energy distribution of the Single Slope Solar Still

3.3.3. Efficiency calculation

Through the recorded data of temperatures, solar radiation, productivity of distilled water and other data for a sunny day in March, April, May and June during the time period from 7:00 am to 5:00 or 6:00 pm. Efficiency was calculated. The efficiency calculation appears with fluctuating variable values during the day as a result of the impact of many factors on the efficiency. However , efficiency can be calculation from the following relationships [43], [50].

$$\eta = \frac{Q_{usf}}{A_s * I} \qquad 3.25$$

$$\mathrm{Q_{usf}} = \mathrm{P_w} * \mathrm{L_{he}} \tag{3.26}$$

$$\mathrm{L_{he}} = 10^3[2501.9 - 2.40706\mathrm{T_w} + 1.192217 * 10^{-3}\mathrm{T_w^2} - 1.5863 * 10^{-5}\mathrm{T_w^3}] \tag{3.27}$$

where **η** efficiency per hours during day, Q_{usf} useful energy (W), A_s projected area (m^2), I incident solar radiation (W/m^2), P_w output of pure water (kg/s). L_{he} latent heat of evaporation (kJ/kg).

3.4. Numerical Validation

The performance of the developed 3-D model was compared with the work of other researchers. This is to validate the presented novel 3-D COMSOL model. It is vital to adopt the climatic and parametric conditions of the work to be compared with.This is to ensure a similar environment and circumstances influencing the developed model.

To validate the COMSOL simulation model have been applied the same real boundary conditions were implemented in expremental of [63]. The temperature at the water surface during four periods of the day has been compared. The validation is presented in Figure 3.5. It can be comprehended that the COMSOL simulation results are in agreement with the experimental measured result. The relative main errors were 3.7 %. Therefore, the simulation model can be employed to analyses the impacts of different parameters.

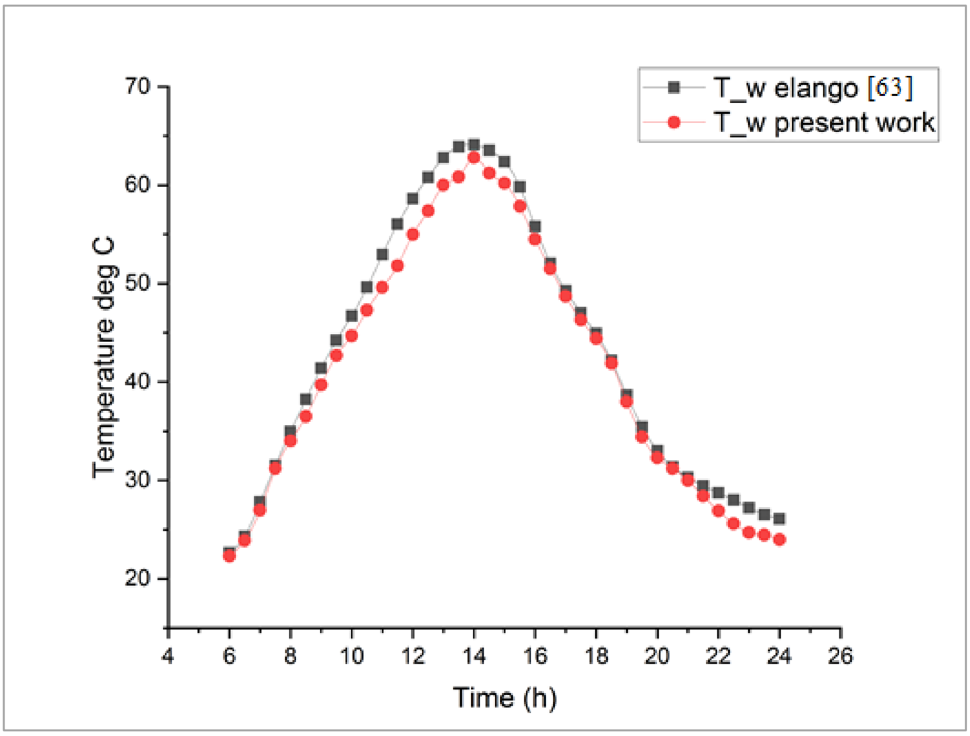


Figure 3.5Comparison of COMSOL simulation water temperature with real experimental test

3.5. Numerical analysis results

A numerical study of the receiving tube of PTC with a two-stage heat exchanger was conducted. The first stage is the design of a winding heat exchanger inside the solar still. The second stage was a design of the heat exchanger, which is an incorporator (absorber plate and pipes). These stages were implemented in COMSOL 5.5 simulation program to obtain the best design between them, through which the best temperatures are obtained to improve the yield of distilled water.

3.5.1. Temperature numerical results

A comparison was made in terms of water temperatures inside the solar still (T_w): the temperature of the glass surface of the solar still (T_{gi}) for the two models of the heat exchanger. The results show that using the heat exchanger, which is an incorporator (absorber plate and pipes), the highest temperatures are obtained from the winding heat exchanger; whereas the highest water temperatures inside the solar still and the highest temperature of the inner glass surface of the solar still are obtained when using the incorporator (absorber plate and pipes) design are 92.53^{o}C and 79.651^{o}C at 2 Pm, respectively. As for the temperatures of the water inside the solar still and the surface of the inner glass produced when using a winding heat exchanger, they are 86.78ºC, 72.472ºC, respectively, as shown in Figure. (3.6, 3.7, 3.8). where the weather condition were adopted at 7th may, as shown in the Table 3.3.

Table 3.3 weather condition that were adopted in numerical calculations at 7th may

Time (hr)	Solar Radiation	T_{amb}	Wind speed
7	395	33	0.85
7.15	444	33.4	0.81
7.3	534	33.7	0.75
7.45	594	34.2	0.41
8	654	35.3	0.38
8.15	694	36.7	1.1
8.3	769	36.4	0.69
8.45	845	37.1	0.52
9	896	37.5	0.13
9.15	935	38.3	0
9.3	990	38.7	0
9.45	1021	38.6	0.14
10	1085	39.2	0
10.15	1110	40	0.89
10.3	1132	41.5	0.02
10.45	1145	42.5	0.01
11	1155	42.2	0
11.15	1170	43	0.04
11.3	1184	43.5	0.14
11.45	1195	44.1	0
12	1210	44.7	0.2
12.15	1192	44.6	0.09
12.3	1178	44.5	0
12.45	1152	44.3	0.4
13	1132	44.7	0.02
13.15	1104	45.2	0.16
13.3	1089	45.6	0.32
13.45	1077	45.9	0.22
14	993	45.8	0.18
14.15	980	46.1	0.23

14.3	961	46.4	0.12
14.45	904	46.3	0.04
15	856	46.7	0.32
15.15	811	46.5	0.47
15.3	750	46.3	0.61
15.45	725	46.7	0.53
16	655	46.1	0.67
16.15	590	46.6	0.21
16.3	565	46.3	0.83
16.45	464	45.7	0.55
17	300	45.3	0.41

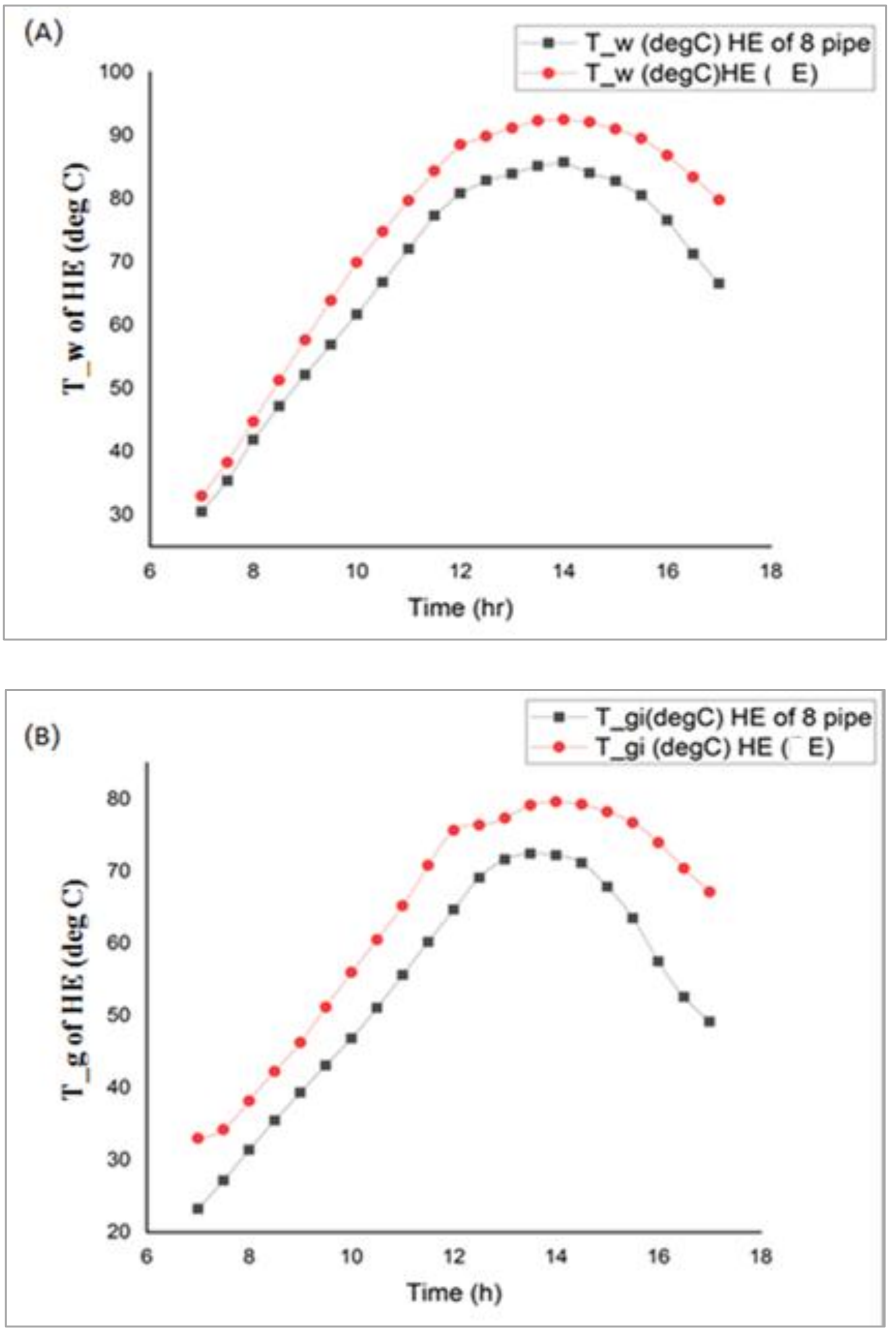


Figure 3.6. Variations of water and glass temperatures for different Heat exchanger: (A) water, (B) glass

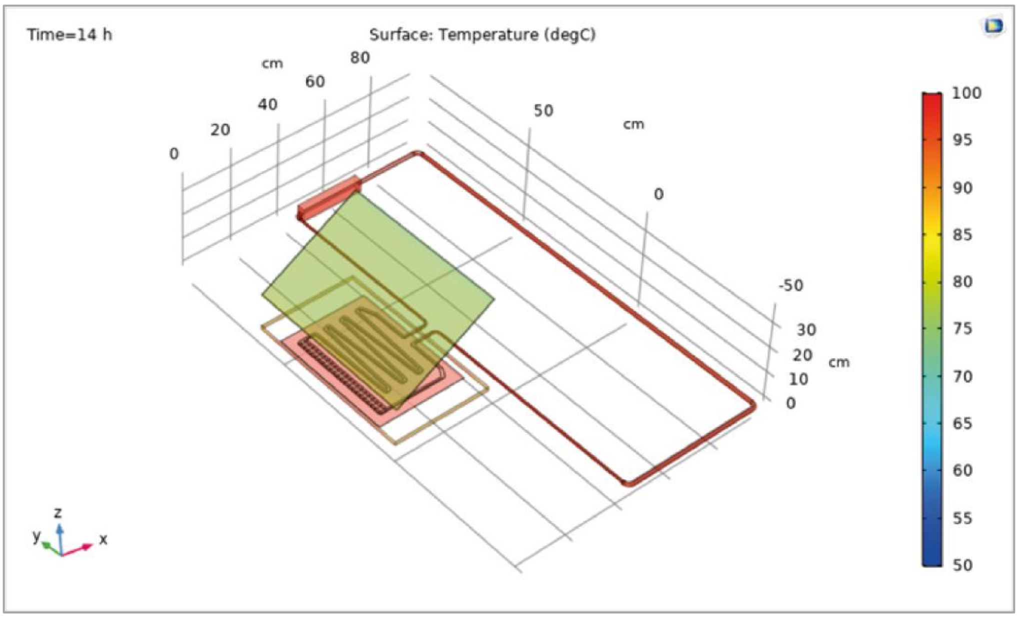


Figure 3.7. Temperature distribution of the single-slope solar still integrate with parabolic trough collector when the heat exchanger is incorporator (absorber plate and pipes).

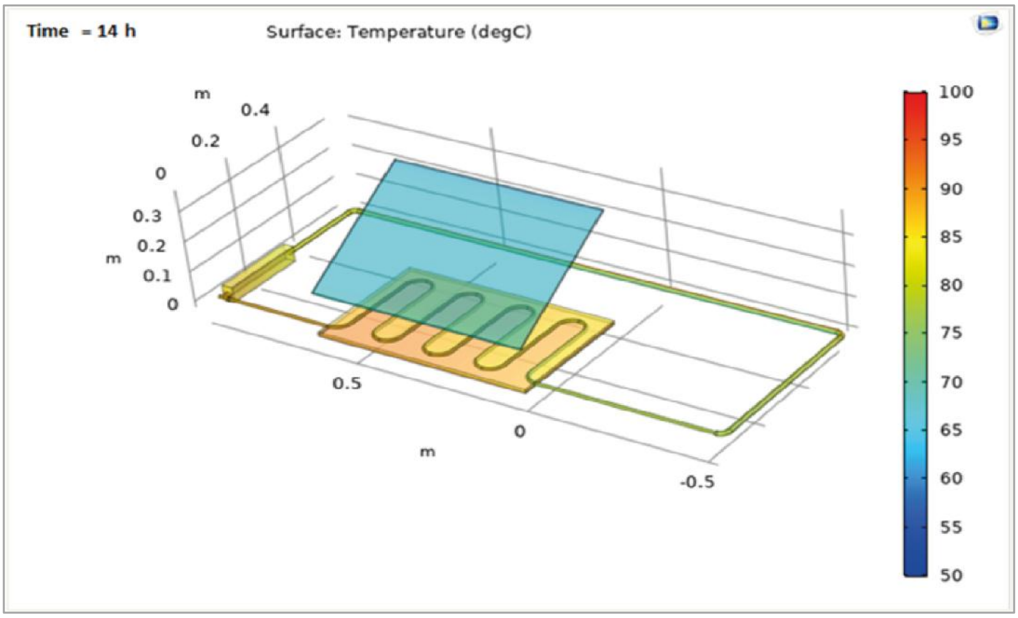


Figure 3.8. Temperature distribution of the single-slope solar still integrate with parabolic trough collector when the number of heat exchanger winding

A comparison was made in terms of the productivity of distilled water when designing a winding heat exchanger and an incorporator (absorber plate and pipes) type heat exchanger. It was found through the results that when using the heat exchanger, which is an incorporator (absorber plate and pipes), the productivity of distilled water is obtained during the day 5.35017 Kg/m^2 is higher than the throughput of a winding heat exchanger of 4.5 Kg/m^2. As shown in Figure 3.9. At 8 am, it was found through the results that the productivity when using a winding heat exchanger is higher than the second type incorporater(absorper plate and pipes), because at the beginning of operation the winding heat exchanger heats up faster due to its small area, unlike the second type, which is pipes and an absorbent plate.Then the productivity begine to increase when using the second type heat exchanger in order to increase the heat exchange due to the increase in the surface area ,which leads to an increase in temperature and then increase the productivity .

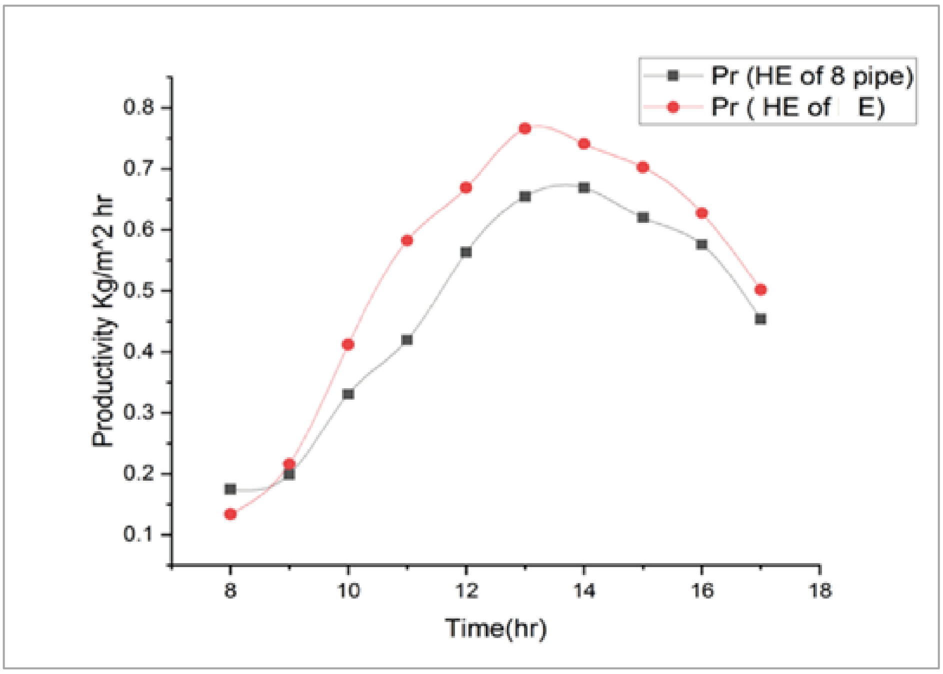


Figure 3.9. Variations of productivity HE of winding and Productivity HE of E

In Figure 3.10A, the temperature distributions inside of the single slope solar still ,where at 10 Am the water temperature inside the solar still basin reach approximately 88°C , while at 2 Pm the water temperature inside the basin rises to 92°C ,as a result of the increase in solar radiation falling on the system , which leads to temperature increase, as shown in Figure 3.10B

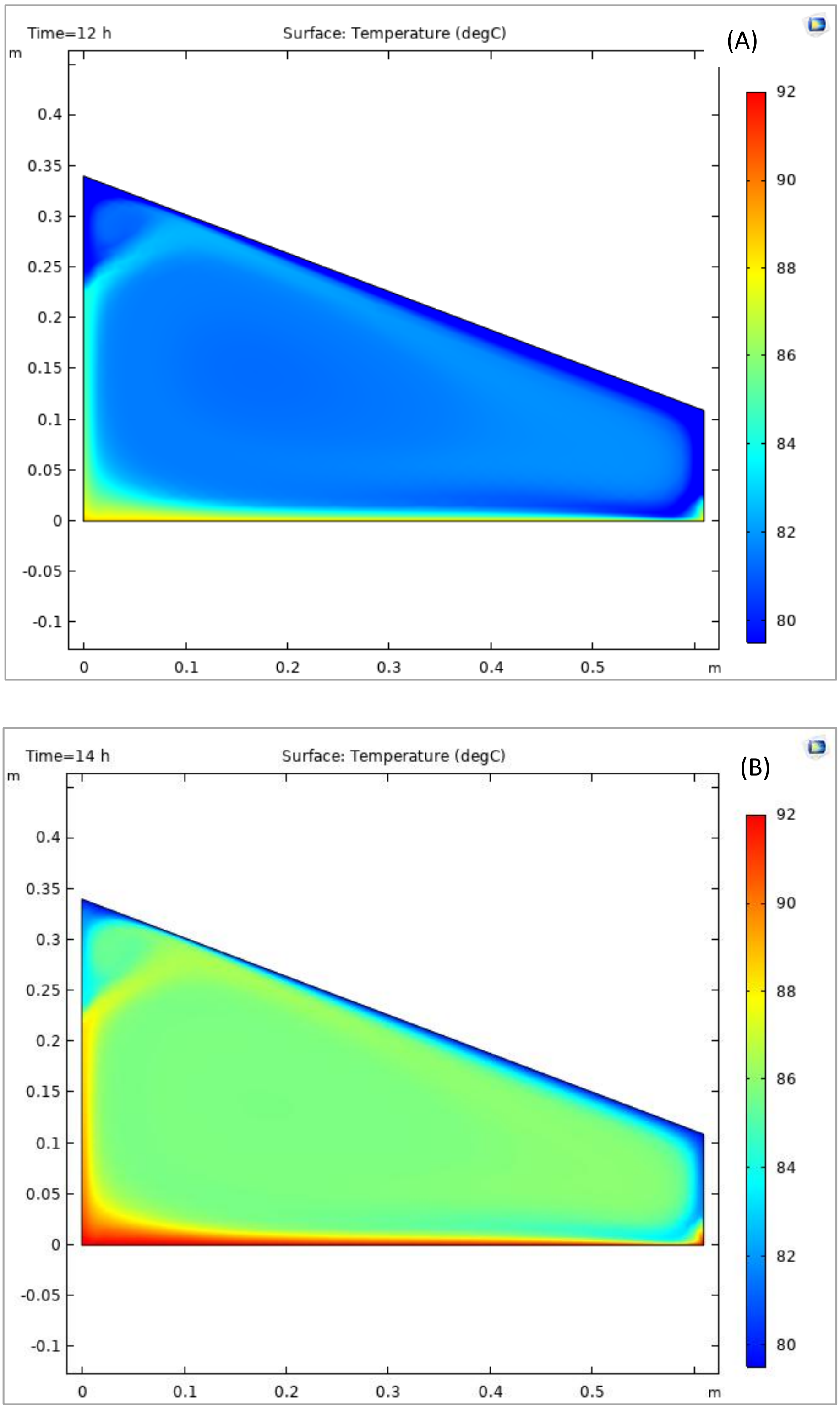


Figure 3.10 Temperature distributions of single slope solar still

In Figure 3.11 shown the velocity distributions of the moist air inside the solar still basin for two different hours. As the speed increases the temperature degreases as a result of the presure drop ,as shown in Figure 3.12. irregular pressure distribution of moist air inside the single slope solar still that were examined for two different hours. The results showed that the water vaper presure increases as the temperature increases as a result of the increase in solar radiation .

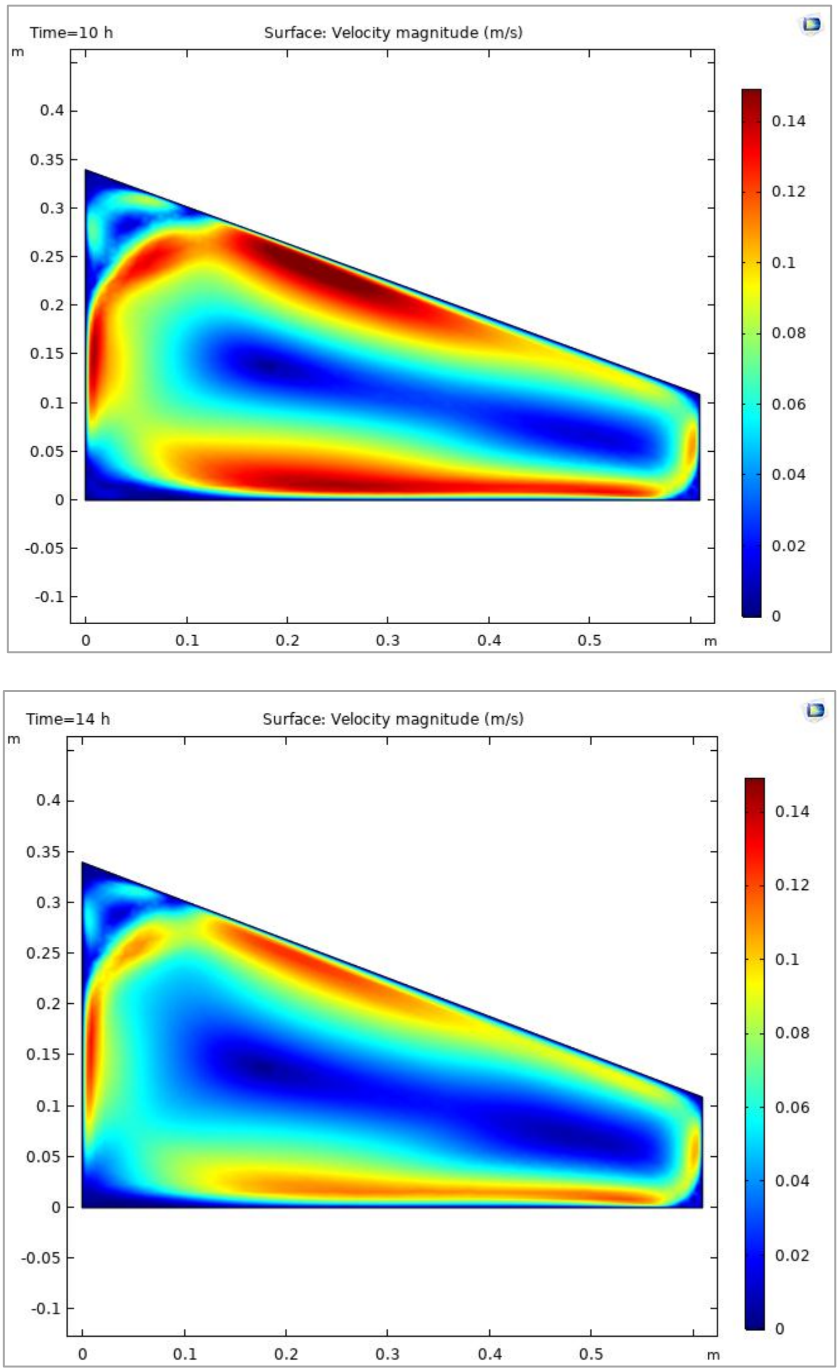


Figure 3.11 velocity distributions of single slope solar still

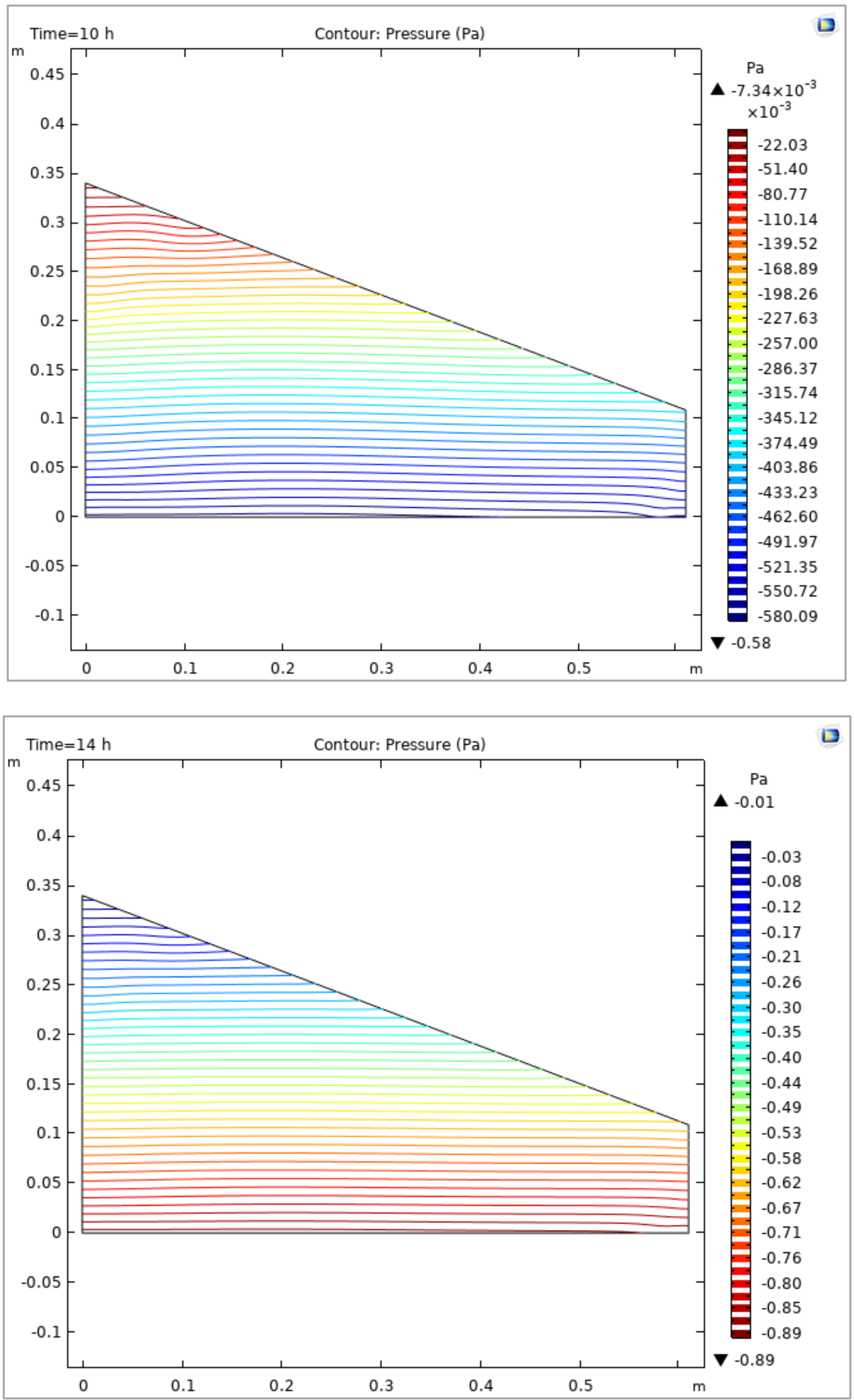


Figure 3.12 pressure distribution of moist air inside the single slope solar still for two different hours.

CHAPTER FOUR: Experimental Setup

4.1. Introduction

The experimental study's main goal is to assess the impact of Solar radiation, wind speed, and ambient temperature, as well as the effect of some ideas Parameters that affect the evaporation process, including as (parabolic trough collector and nanofluid use). The experimental study was carried out in Najaf, Iraq(32^{o} 1′ N 44^{o} 19′E). The project lasted from November 2020 to June 2021. The device construction and experimental measurements are covered at this time. And for reliable findings, all of the studies were carried out during the daytime sunny.

4.2. Materials and Building

The single slope solar still with parabolic trough collector are designed for experiments using the most practical and low-cost materials. The structure of the device and the materials used to build the device, whether for the parabolic trough collector or the monoclinic solar still, are from the local market and have specific characteristics. Figure 4.1 depicts the schematic representation and image of the experimental setup.

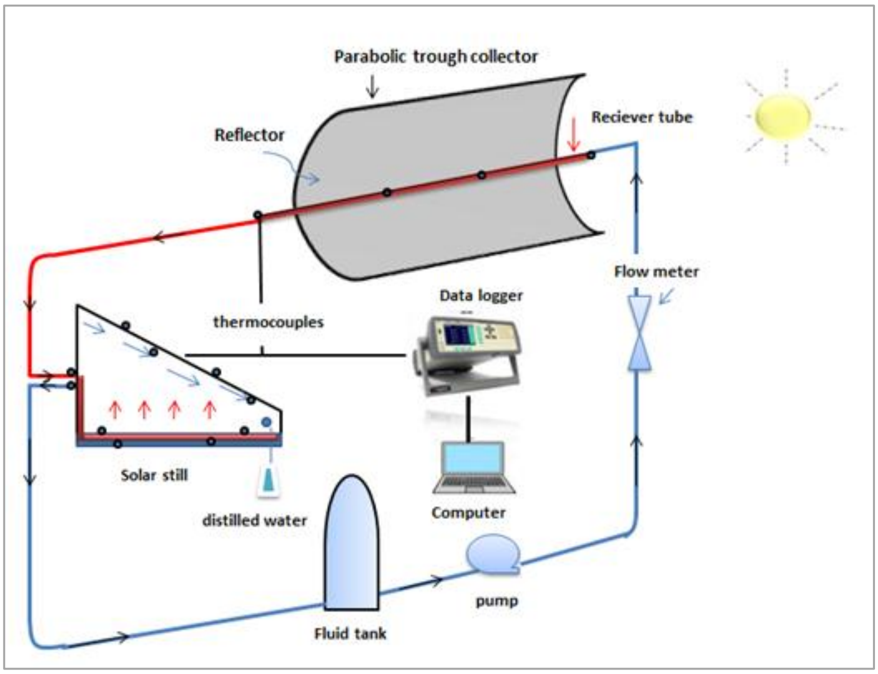


Figure 4.1 The schematic diagram represents the device with complete equipment

4.2.1. Parabolic Trough Collector Structure

The frame is made of iron with dimensions of length 140 cm and width 80 cm, parabolic collector bracket defined by CNC machining and rim angle is 90^{o}, and the focal distance was determined from the middle of the parabolic collector arc to know the radiation reflected on the receiving tube , where the focal point was calculated from the equation 4.1, [64].As shown in Figure 4.2.

Figure 4.3 represents the experimental setup system of each part are shown below.

$$y = \frac{x^2}{4f} \qquad 4.1$$

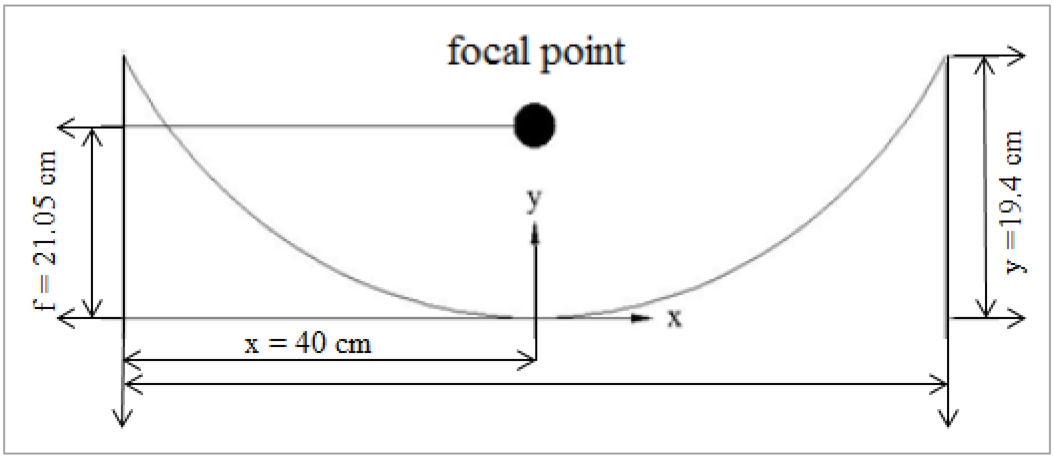


Figure 4.2Concentrator dimensions and focal point.

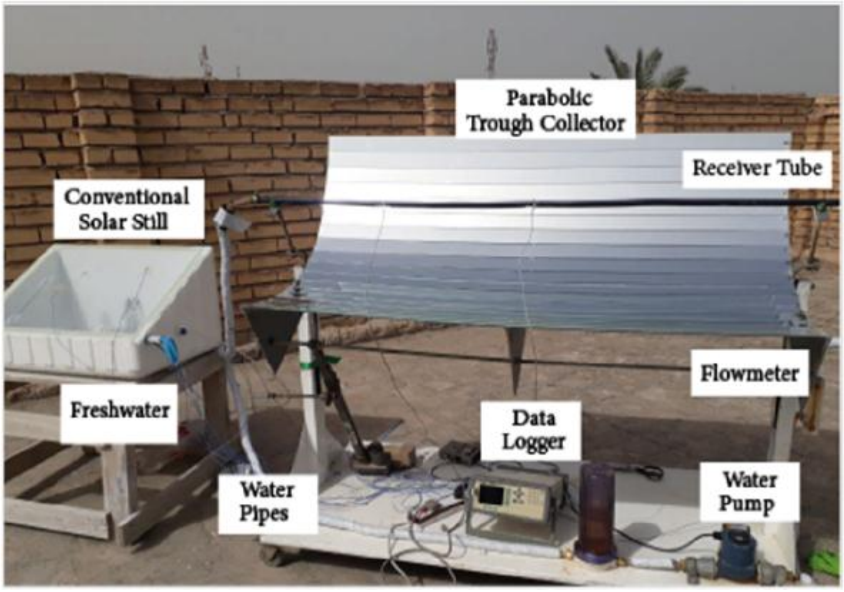


Figure 4.3 the experimental setup for parabolic trough collector with solar still

4.2.1.1. Receiver Tube

Receiver tube Is a high temperature-resistant black-coated copper tube. it's painted black to obtain the best absorption of solar energy. The length of the tube is 160 cm, its outer diameter is 19 mm, and its inner diameter is 16 mm. The receiver tube is fixed at the focal point.as shwon in Figure 4.4

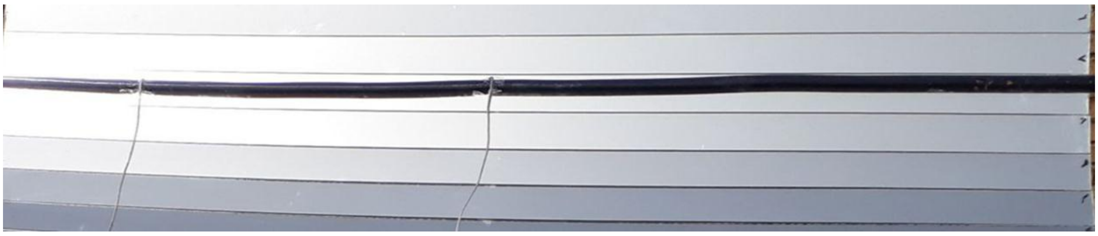


Figure 4.4 Receiver Tube

4.2.1.2. Reflector

The reflector is a set of mirrors with good reflectivity installed on the structure of the parabolic trough. The length of one piece of the mirror is 140 cm and its width is 5 cm. They were combined together to form a parabolic trough collector, as shown in Figure 4.5.

Figure 4.5 Reflector

4.2.1.3. Delivery Tubes

A set of transparent tubes made of plastic is used to deliver the fluid from the tank to enter the receiver tube and then connect from the outlet of the receiving tube to the inlet of the single solar still, and another connecting tube from the outlet of the solar still to return to the tank to become a closed cycle between the parabolic trough collector and the single solar still.

4.2.2. Solar still basin

The solar still basin used has standard dimensions of 61 cm length, 38 cm width, 36 cm height, and 4 cm thickness, where the slope is created by cutting it with an angle of 32.1° using a CNC machine to maintain a smooth finishing, the single slope solar still basin made of polystyrene material that is highly resistant to moisture and polystyrene material has the advantage of adapting to changes in temperature and pressure without compromising its safety and it is practically impermeable to liquids. It is also an excellent heat insulator, as shown in Figure 4.6.

Figure 4.6 photographs and schematic diagram of single solar still

4.2.2.1. Glass cover for single slope solar still

The cover of the solar still basin is transparent of glass with a thickness of 4 mm to allow the entry of the largest amount of solar energy. The cover is tilted at an angle of 32.1°. An adhesive material is used to securely attach the glass cover to the basin to prevent steam from escaping from the solar still basin.

4.2.2.2. Distillation channel of the solar still basin

To collect the condensed distilled water from the basin, the end of the glass cover is placed, and along the inside of the cover is a stream of plastic in the form of a rectangle, 66 cm long, 2.5 cm wide, and 1.5 cm high on both sides as shown in Figure 4.7. At its end, a balloon is tied to collect the distilled water, then the weight of the distilled water inside the balloon is taken in g/h.

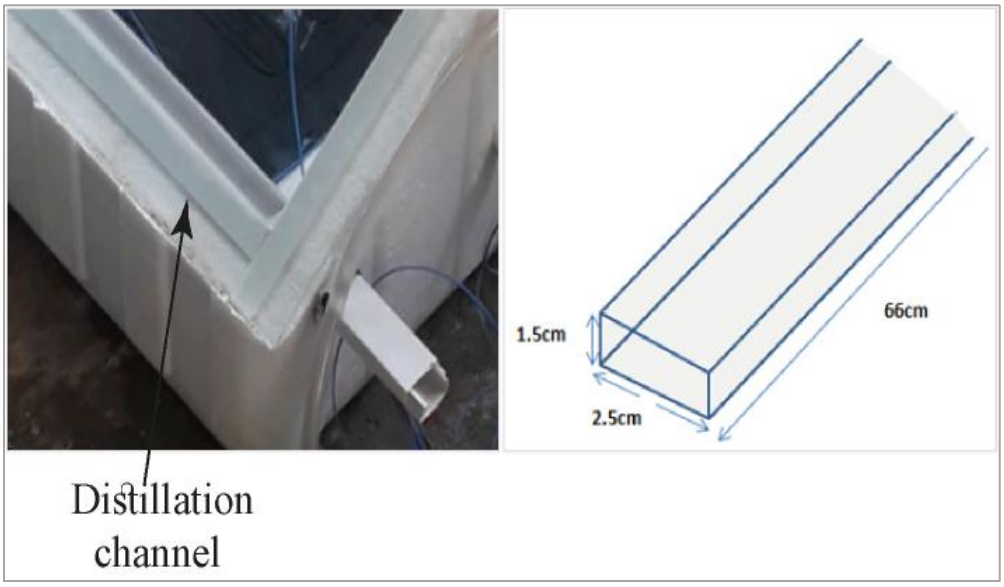


Figure 4.7 Photograph and schematic diagram of yhe distillation channel

4.2.3. Heat exchanger inside the solar still

The incorporator (absorber plate and pipes), which is one of the types of heat exchangers, was used. It is placed inside the solar still basin, so that it is immersed in water whose height inside the basin is 1 cm. The length of the heat exchanger is 44 cm and its width is 36 cm. Its type is coiled from tubes embedded in the board, as shown in Figure 4.8. It has been dyed black to absorb the greatest amount of heat.

Figure 4.8 Photograph of the heat exchanger

4.2.4. Working fluid

There are two types of fluid were used to transfer heat between the parabolic trough collector and the solar still during a closed cycle, the first type was using water as a heat transfer fluid and the second type was using a solution of nanofluid particles with water. Experiments were conducted using both types to see which one gives the most productivity when used.

Water was used to transfer heat, where the water was placed inside a tank of 1.5 liters and it is transferred through a pump that operates at the lowest speed to transfer the water to the receiving tube and then pass through the delivery tubes to the solar still. From the solar still, it returns to the tank and then the cycle begins again. Where the water volume flow rate was determined by a flow meter, which will be explained below. The second type of working fluid (Nanofluid). The Nano-particles solution with water was used as a fluid that flows inside the tubes instead of water. Its type is copper oxide (CuO). After mixing, it was placed in a tank of 1.5 liters. It was prepared as shown in the explanation below.

4.2.5. Preparation of Nanofluid

Because of the unique physical and chemical properties involved, nanotechnology has lately emerged as the most sophisticated technology of this century. Researchers have taken a novel approach to using nanomaterials to improve heat transmission by developing homogenous, stable, and high-conductivity heat exchange mediums [65]-[67]. CuO nanoparticles were used. The nanoparticles were suspended with 1% pure water (PH 6.6). For the production of nanofluids, the preparation vessel containing pure water and nanoparticles was placed inside the ultrasonic device for one hours at a frequency of 37 Hz and a power of 100 W, as shown in Figure 4.9. Gum Arabic (GA) was added in a small percentage to the solution after mixing it with water to prevent clumping when added to the nano solution.

Figure 4.9 Preparation of nanofluid

GUM Arabic is a heterogeneous substance because it is a nonionic surfactant. The natural gum produced by acacia species such as acacia Senegal and acacia seyal is known as GUM Arabic. They dissolve quickly in water, yielding a transparent solution ranging in hue from pale yellow to orange-brown. It also has a pH of about 4.5 and a viscosity of extremely low [68]-[70], as shown in Figure 4.10 .The stability of nanoparticles was monitored for 15 days, and no nanoparticle deposits were found during this period. As for the particles that were exposed only to ultrasound without adding GUM Arabic, they were deposited during a short period.

Figure 4.10 Photograph of the GUM Arabic

The properties of nanoparticles (copper oxide CuO) and the Scanning electron microscopy as shown in Appendix B.

4.3. Measurement's devices

All experiments in this work are carried out at the Technical enginering collage of Najaf / Iraq (32.1°N and 44.19°E). These experiments were carried out in March, April, May and June with the help of four main devices. Each of these devices will be explained as follows. When pure water flows from the solar distillation basin, it will fall from the distillation channel and be collected in a balloon. Every hour, the weight of the distilled water inside the balloon is measured by a balance after the balloon is weighed while it is empty.

4.3.1. Measuring the amount of solar irradiance

To measure the amount of direct radiation falling on the parabolic trough collector, the TENMARS (TM-207) solar radiation meter is placed with the same tilt angle of the parabolic trough collector. The accuracy of the device is (± 5%, ± 10) W / m^2, where the maximum radiation power reads about 2000w/m^2, as shown in Figure 4.11.

Figure 4.11 Solar radiation meter

4.3.2. Temperature measuring device

water inside the solar still. The surface temperature of the inner and outer glass of the solar still basin, etc. All of these thermocouples are connected to a 32-channel

Applent (AT-4532x) data logger device, to display the temperature reading. As shown in Figure 4.12. The accuracy (0.2% ∓2 digit), and calibration was made for these thermocouples as shown in Appendix A.

Figure 4.12 Data logger (AT-4532)

4.3.3. Wind speed measurement

The air that passes on the device, especially when it passes on the glass cover of the solar still has a good effect on the condensation process. Therefore, the wind speed is measured by the Anemometer (AM-4206M). The range of velocity (0.5 to 35.0 m/s), and power supply 9V, the accuracy of the device is from ± (2 % +0.2 m/s). As shown in Figure 4.13.

Figure 4.13 Anemometer device

4.3.4. Flow meter device

The volume of water flow inside the pipes was determined by means of a flow meter of 0.5 LPM. The accuracy of the device is ∓4%, model (LZM – Z), as shown in the Figure 4.14.

Figure 4.14 Flow meter device

4.3.5. Circulation pump

The pump used to pump the fluid into the pipes between the solar collector and the solar still within a closed cycle is model (XP S25-6-130) with three speeds; the lowest speed is used with a current of 0.2 amps of 45 watts, with a level of protection IP 44. mains connection (220V/50Hz), and the rate of performance, the highest performance of the flow 10 cubic meters per hour and the highest head 12 m. The highest ambient temperature is 40 degrees and the highest pressure is 10 bar. The pH of the pump ranged from 6.5 to 8.5, as shown in figure 4.15.

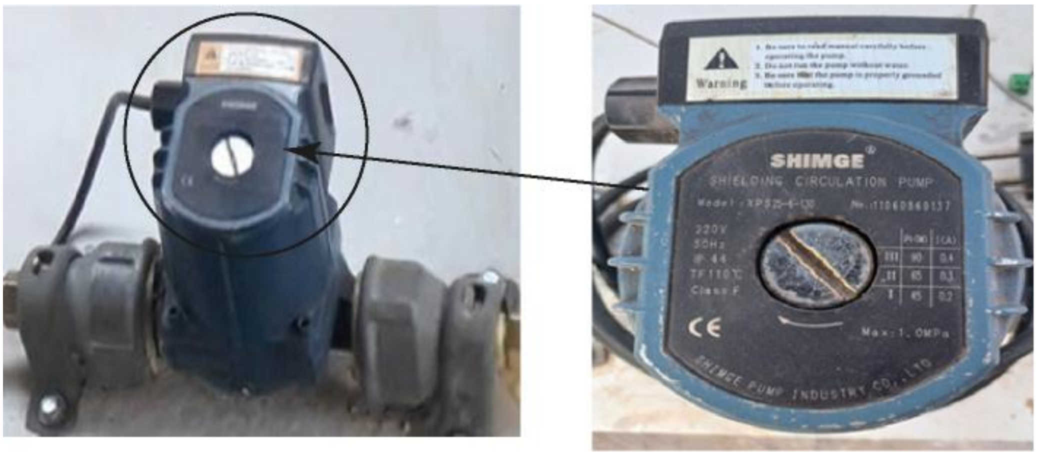


Figure 4.15 Circulation pump

4.4. Experiment Procedure

1- The measurement devices must be placed and secured in place after all of the device elements have been assembled. The measurement devices that were utilized can be explained as follows

a- Solar radiation measuring: The solar radiation meter is positioned at the same tilt angle of the bounty collector. Direct incident radiation is measured every 15 minutes. The work starts from 7 am to 5 or 6 pm.

b- The T-type thermocouples are used to measure temperatures in 14 locations in the device, inside and outside the receiving tube, as well as inside and outside the solar still. Two thermocouples are used outside the receiver tube; one thermocouple at the fluid inlet to the receiving tube and another at the fluid exit. Other two are used when the fluid enters the single solar still, and another when it leaves the single solar still. Two thermocouples were on the outer glass surface of the single solar still and two on the inner glass surface. Also, two thermocouples were used to measure the water temperature inside the solar still and two to measure the temperature of the heat exchanger. These thermocouples were connected to a 32-channel data logger to record all temperature data. A calibration of all these thermocouples was done in comparison with a mercury thermometer to obtain the best measurement accuracy.

c- Wind speed and ambient temperature measuring: An anemometer probe is placed near the receiver tube of the parabolic trough collector to measure wind speed every 15 minutes. The ambient temperature is also measured by placing an anemometer probe in the shade every 15 minutes.

d- Distilled water measuring container: To collect and measure the distilled water, a balloon is placed at the end of the collection tube, then the weight of the distilled water inside the balloon is taken using the scale.

2- The measuring devices work from the time the experiment began from 7:00 in the morning until 5:00 or 6:00 in the evening.

3- Readings are recorded either manually (such as recording data of solar radiation, ambient temperature, and wind speed) every 15 minutes. The production of distilled water is recorded every hour. or automatic recording (temperatures).

4- Experiments were conducted on the surface Technical Engineering college of Najaf/Iraq. The work was carried out from March 2021 to June 2021.

CHAPTER FIVE: Results and Discussion

5.1. Introduction

All results were performed at the Technical Engineering college of Najaf - Iraq (32.1 N 44.19 E). Where the experiment period was from 7:00 am to 5:00 or 6:00 pm and lasted for several months on different climatic days. A Comparison was made between the results of the solar still alone and the solar still with the equivalent collector basin. Also, the results were compared between using water as a fluid running inside the tubes or using nanofluid as a fluid running inside the tubes (between the receiver tube and the heat exchanger of the solar distiller). The productivity of the system depends on whether variables in terms of ambient temperature, wind speed and solar radiation. The purpose of this study is to make the best design of the solar still through the COMSOL 5.5 program to obtain the best temperatures to improve the productivity. The effect of nanofluid on the productivity of distilled water is also being studied.

5.2. Experimental results

5.2.1. Result of single solar still

The experiment was conducted at 25th March, 2021, for a single-slope solar still. As shown in Figure 5.1, the solar radiation starts from 7:00 Am until it begins to increase and reaches the highest amount of 996 W/m^{2}at 12:15 pm and then begins to decrease, at average wind speed 2.659 km/hr. As for the ambient temperature, it starts to increase and continues to increase even after the radiation decreases, this is because the earth stores heat , so when the solar radiation decreases , the earth begins to emit heat . therefore, the ambient temperature remains high even after the solar radiation degreases. As noted in Figure 5.1, the ambient temperature begins to decrease after 3:00 Pm.

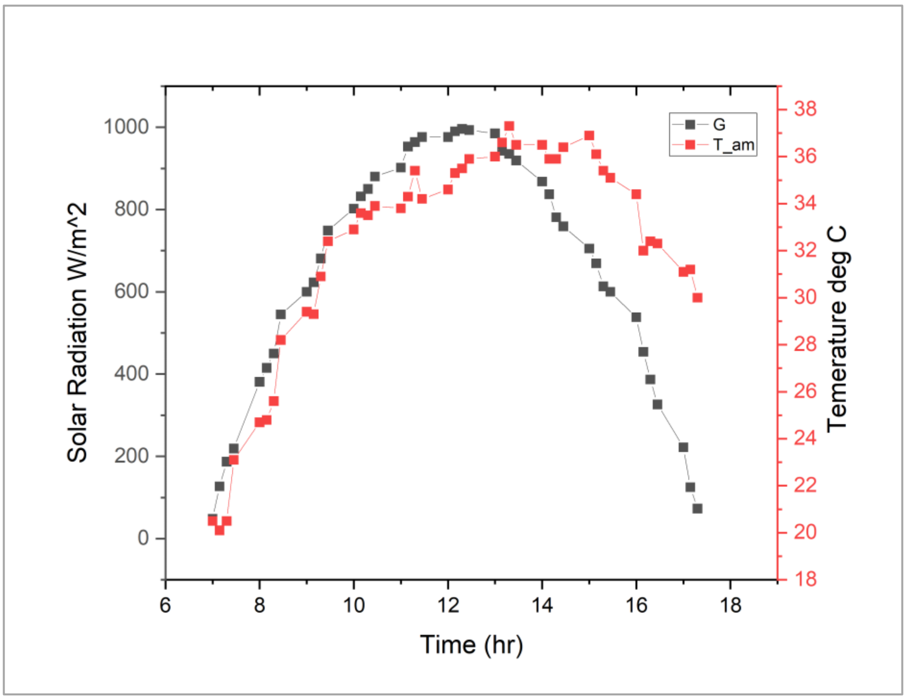


Figure 5.1 Variation solar radiation with ambient temperature during the experimental day at 25th march ,2021.

Figure 5.2 shows the temperatures of the inner and outer glass surface of the single solar still, the water temperature inside the single solar still, as well as the plate temperature and their differences with time. Note that the temperatures begin to increase with the increase in solar radiation. So, the temperature of the inner surface of the single solar still is higher than the outer surface, this is because the outer surface of the single slope solar still is exposed to wind speed that leads to a decrease in the surface temperature. The highest temperatures are obtained at 12:15 Pm, where the highest temperature obtained for water inside the solar still is 56.05 ^{0} C.when comparing with previous research researchers obtained at close condition water temperature at 52^{o}C [35].

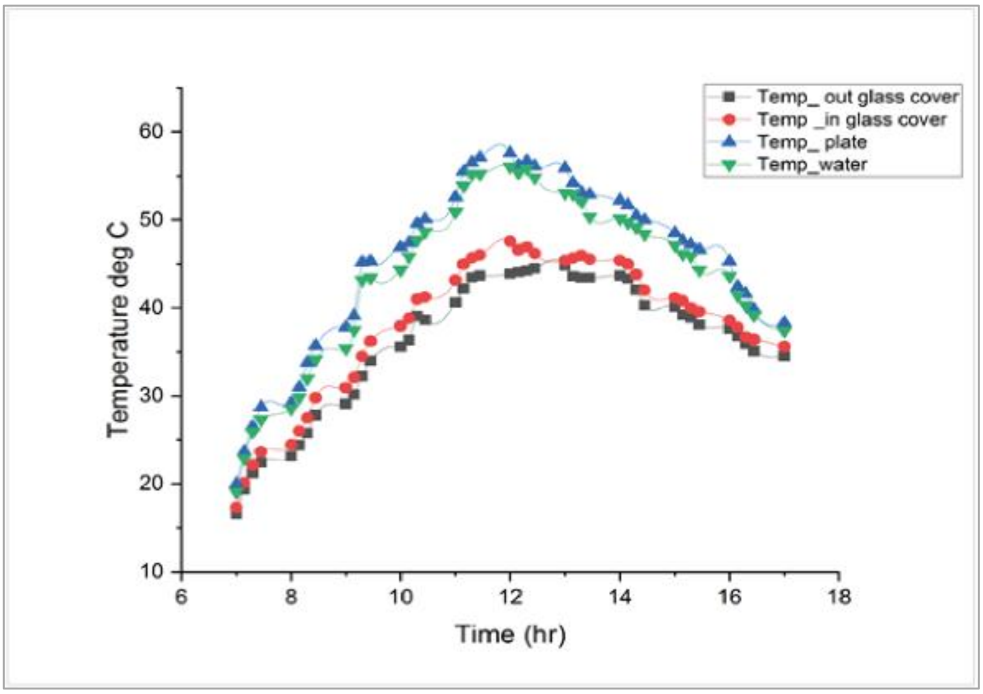


Figure 5.2. Variation temperature with time for the solar still at 25^{th} March, 2021.

The experiment was conducted at 16^{th} April, 2021, for a single-slope solar still. As shown in Figure 5.3, the solar radiation starts from 7:00 am until it begins to increase and reaches the highest amount of 1040 W/m^2 at 12:30 pm and then begins to decrease. As for the ambient temperature, it starts to increase and continues to increase even after the radiation decreases, this is because the earth stores heat , so when the solar radiation decreases , the earth begins to emit heat . therefore, the ambient temperature remains high even after the solar radiation degreases. As noted in Figure 5.3, the ambient temperature begins to decrease after 3:15 pm.Figure 5.4 shows the temperatures of the inner and outer glass surface of the single solar still, the water temperature inside the single solar still, as well as the plate temperature and their differences with time. Note that the temperatures begin to increase with the increase in solar radiation. So, the temperature of the inner surface of the single solar still is higher than the outer surface, this is because the outer surface of the single slope solar still is exposed to wind speed that leads to a decrease in the surface temperature .The highest temperatures are obtained at 12:45 pm, where the highest temperature obtained for water inside the solar still is 61.6^{o}C, because of the change in weather conditions from an increase in solar radiation, temperature and average wind speed during working hours, which amounted to 3.2813 km/hr.

This change in conditions leads to an increase in temperatures and thus an increase in the productivity of distilled water.

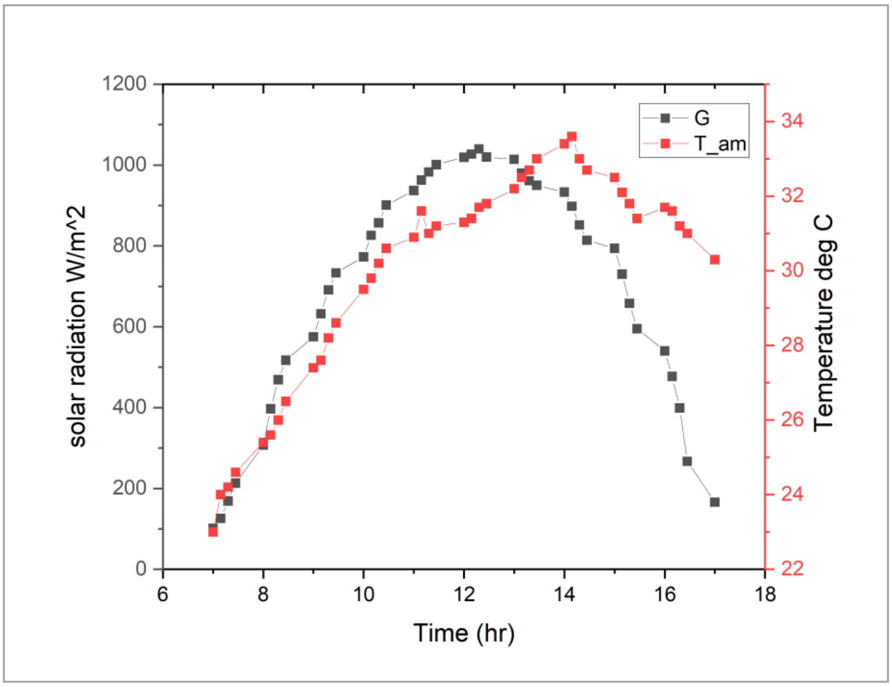


Figure 5.3. Variation solar radiation with ambient temperature during the experimental day at 16^{th} April ,2021.

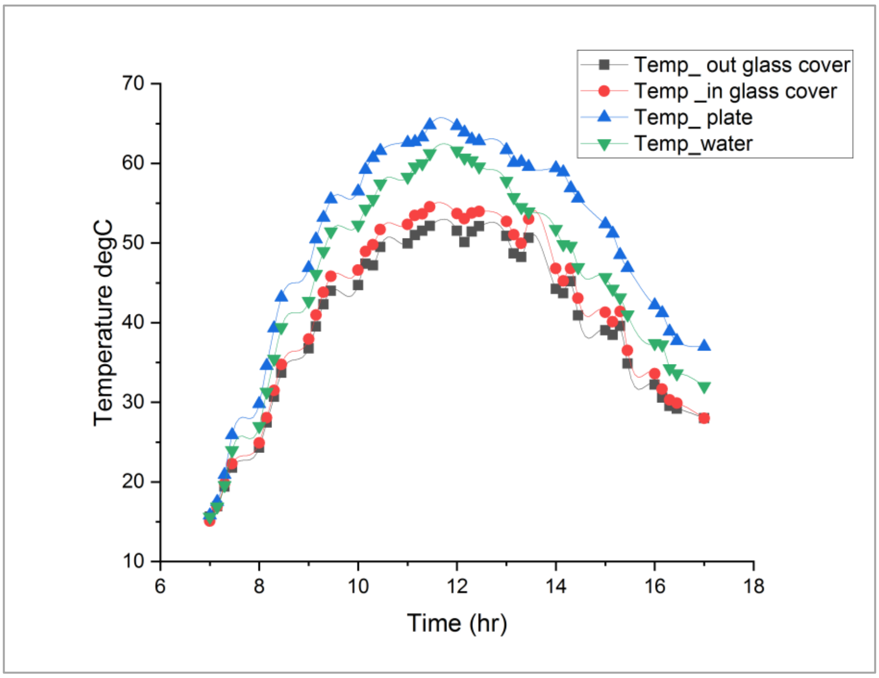


Figure 5.4 Variation temperature with time for the solar still at 16^{th} April, 2021

Another experiment was conducted with variable conditions that differ from the previous experiments at 5^{th}May, 2021, with the increase in solar radiation and ambient temperature and an average wind speed of 1.182 km /hr. for a single-slope solar still. As shown in Figure 5.5, the solar radiation starts from 7:00 am until it begins to increase and reaches the highest amount of 1110 W/m^2 at 12:00 pm and then begins to decrease. As for the ambient temperature, it starts to increase and continues to increase even after the radiation decreases, this is because the earth stores heat , so when the solar radiation decreases , the earth begins to emit heat . therefore, the ambient temperature remains high even after the solar radiation degreases. As noted in Figure 5.5, the ambient temperature begins to decrease after 3:30pm. Figure 5.6 shows the temperatures of the inner and outer glass surface of the single solar still, the water temperature inside the single solar still, as well as the plate temperature and their differences with time. Note that the temperatures begin to increase with the increase in solar radiation. So, the temperature of the inner surface of the single solar still is higher than the outer surface, this is because the outer surface of the single slope solar still is exposed to wind speed that leads to a decrease in the surface temperature .The highest temperatures are obtained at 12:45 pm. where the highest temperature obtained for water inside the solar still is 63^{o}C.

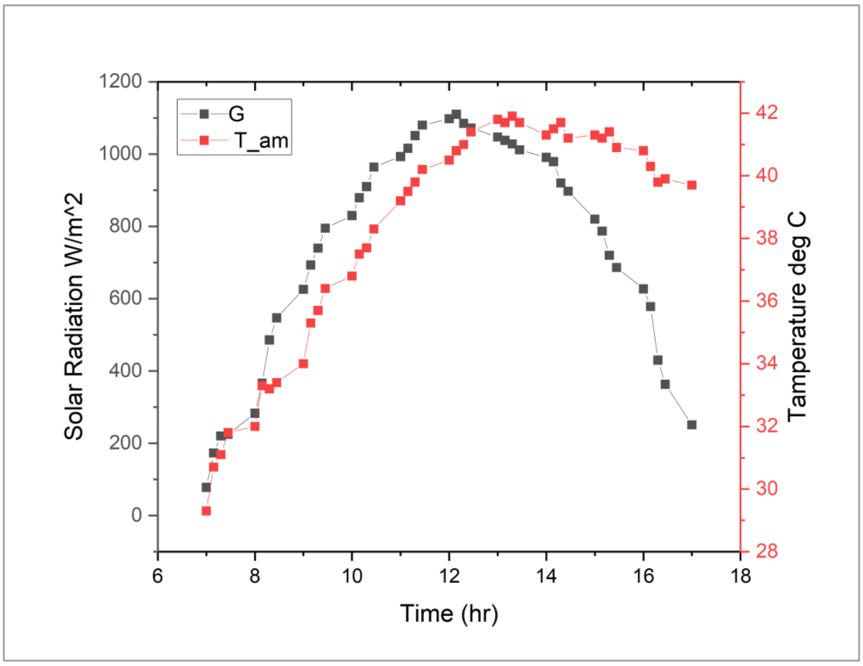


Figure 5.5 variation solar radiation with ambient temperature during the experimental day at 5^{th} May ,2021

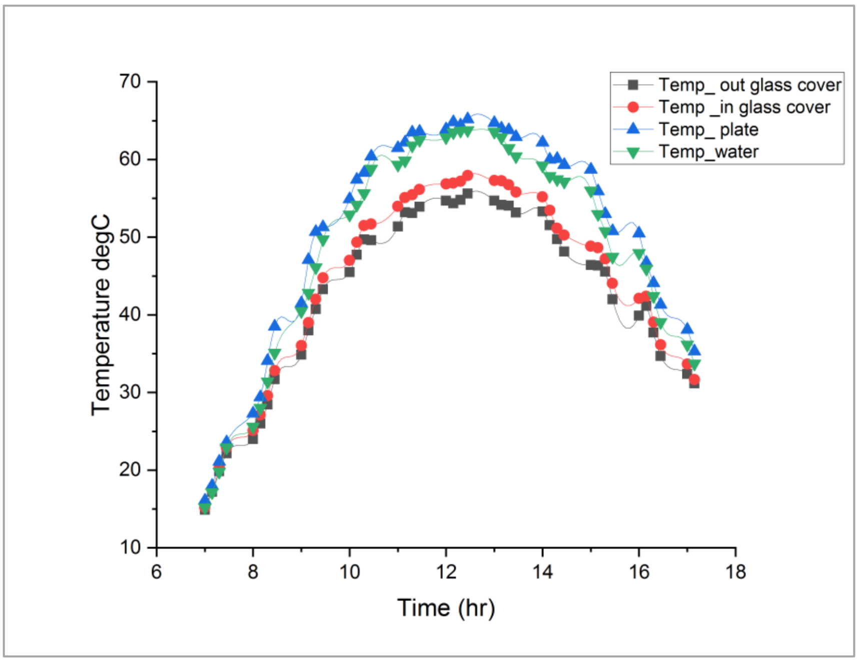


Figure 5.6 variation temperature with time for the solar still at 5^{th} May ,2021

Figure 5.7 shows the productivity of distilled water from Single Solar Still device during March, April and May, 2021. The productivity of distilled water increases gradually at 8:00 am. The productivity of distilled water at 25^{th} March during the day was 2.545 kg/m^2/day.The highest productivity is obtained at 12:00 Pm by 0.4123 kg/m^2, then the productivity begins to decrease with a decrease in solar radiation. At 17^{th} of April, the productivity of distilled water during the day was 3.86 kg/m^2/day. The highest productivity is obtained at 01:00 pm at 0.72 kg/m^2. Then the productivity of the distilled water begins to decrease as a result of lower temperatures inside the solar distillation apparatus when the solar radiation decreases. At 5^{th} of May, the productivity of distilled water during the day was 4.16 kg/m^2/day , and the highest productivity is obtained at 01:00 pm by 0.821 kg / m^2. Then the productivity of distilled water begins to decrease as a result of lower temperatures inside the solar distiller. The salinity of the distilled water was also measured using the TDS device, which amounted to 85 ppm. The salinity of the distilled water in the bottles sold in the market is 75 ppm , while the salinity of the beach water ranged from 1000 to 1150 ppm.The difference in productivity as shown in figure 5.7 during the initial hours of the day is due to wind speed that may affect temperatures ,as the greater the wind speed that passes over the surface of the solar still leads to an increase in the condensation process and the opposite occurs when the wind speed decreases. And due to the humidity inside the solar still where the higher the humidity inside the basin the less the productivity .

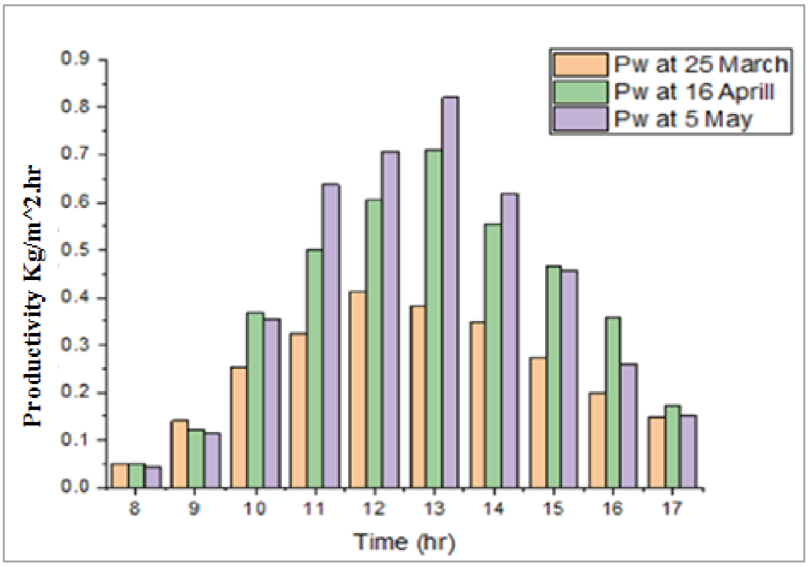


Figure 5.7 Productivity variation with Time at 25th March, 16thApril, 5th May 2021.

The hourly efficiency of the three experiments was calculated when using the solar still only. Figure 5.8 shows the hourly efficiency at 25^{th} of March, 16th April and 5th May. which reached 24.2% during the day 25th. The highest efficiency was obtained at the highest productivity at 12:00 pm, about 39.06%. The thermal efficiency at $16^{th}$of April, which reached about 35.56% during the day, where the highest efficiency obtained at 1:00 pm was 69.66% at 5^{th} of May. An efficiency of 36.31% was obtained during the day. The highest hourly efficiency obtained at 1:00 was 65.423%. the discrepancy in thermal efficiency shown in figure 5.8 , where at 16th April , it was noticed at approximately 1 pm the results showed the highest efficiency than 25th march and 5th may . this is due to weather condition that affect temperature, which leads to an increase or decrease in the results thermal efficiency.

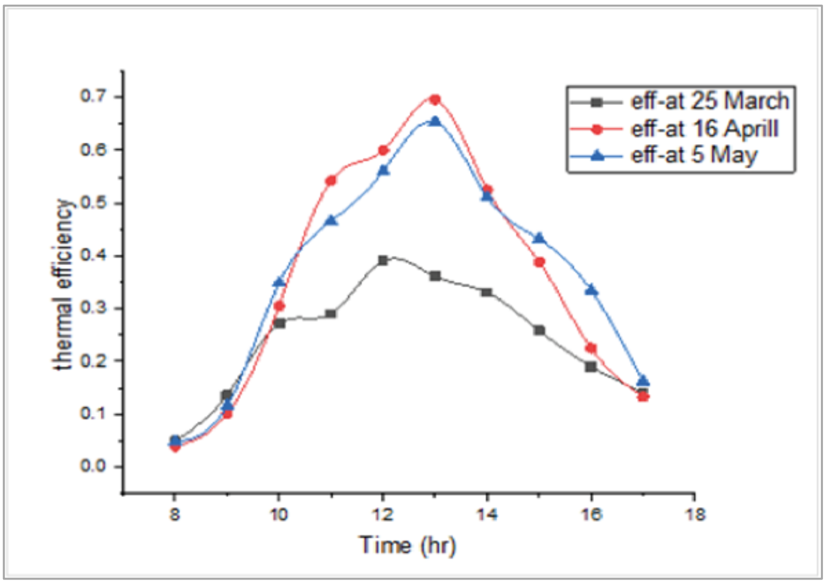


Figure 5.8 Thermal Efficiency at 25th March, 16th April and 5th May. Year 2021

5.2.2. Single solar still with PTC (use HTF Water)

An experiment was conducted using a single solar still with a parabolic trough collector (PTC) that increases the water temperature inside the single solar still to increase the evaporation process. Several experiments were conducted on different days and with variable conditions in terms of solar radiation, ambient temperature and wind speed. Experiments were also conducted in similar conditions using the single solar still alone or with PTC and comparing them in terms of the productivity of distilled water.

An experiment was conducted at 31^{th} of March to model a parabolic trough collector (PTC) with a single solar still. As shown in Figure 5.9 Where the increase in solar radiation and ambient temperature and an average wind speed of 2.78 km /hr. The solar radiation starts from 7:00 am until it begins to increase and reaches the highest amount of 997 W/m^2 at 12:15 pm and then begins to decrease. As for the ambient temperature, it starts to increase and continues to increase even after the radiation decreases, this is because the earth stores heat , so when the solar radiation decreases , the earth begins to emit heat . therefore, the ambient temperature remains high even after the solar radiation degreases. As noted in Figure 5.9, the ambient temperature begins to decrease after 3:30 pm. Figure 5.10 shows the temperatures of the inner and outer glass surface of the single solar still, the water temperature inside the single solar still, as well as the plate temperature and their differences with time. Note that the temperatures begin to increase with the increase in solar radiation.So, the temperature of the inner surface of the single solar still is higher than the outer surface, this is because the outer surface of the single slope solar still is exposed to wind speed that leads to a decrease in the surface temperature. The highest temperatures are obtained at 12:30 pm. where the highest temperature obtained for water inside the solar still is 66.05^0 C.

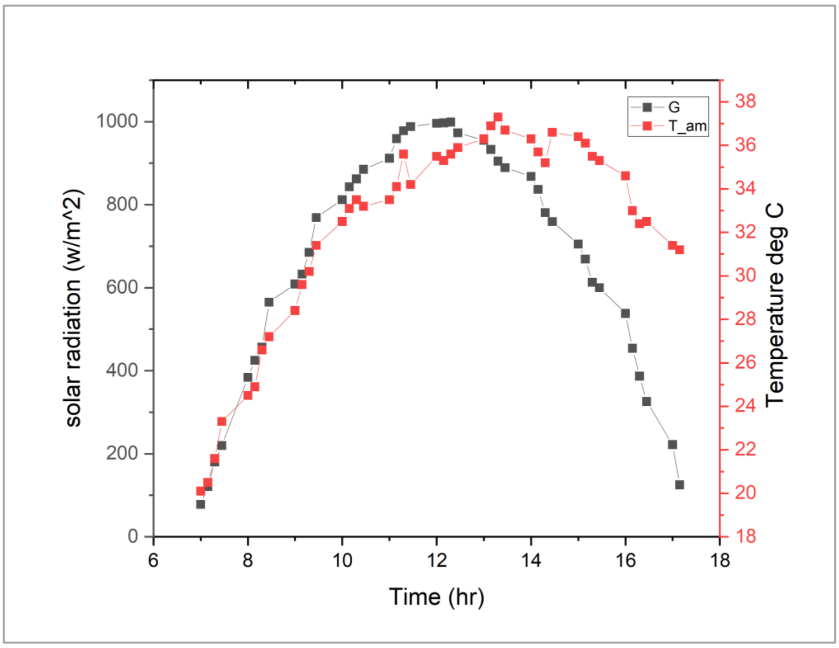


Figure 5.9 Variation solar radiation with ambient temperature during the experimental day at 31th of March ,2021

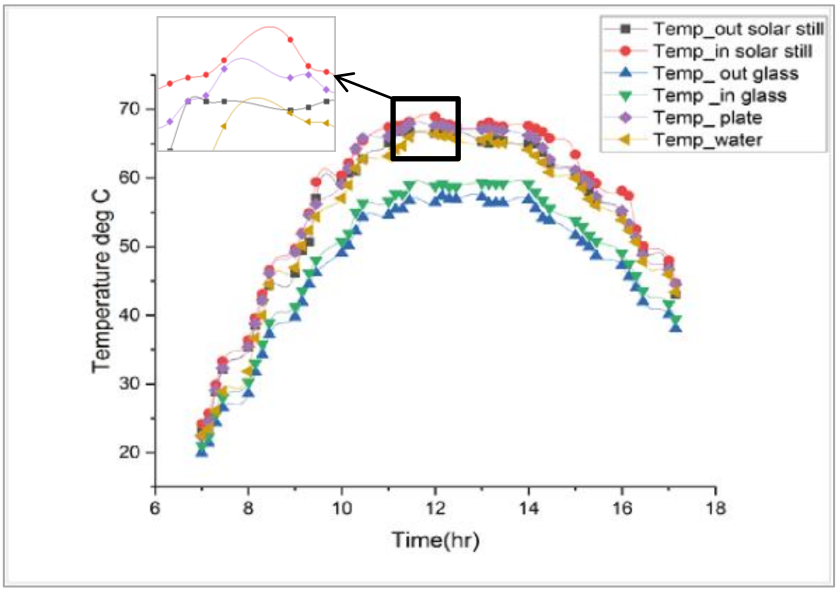


Figure 5.10 Variation temperature with time for the solar still with PTC at 31th of March, 2021

Figure 5.11 shows the temperatures of the heat transfer fluid entering to and exiting from the receiving tube and the surface temperature of the tube, where the highest temperature of the fluid leaving the receiving tube reached 67.6 ° C at 12:15 pm.

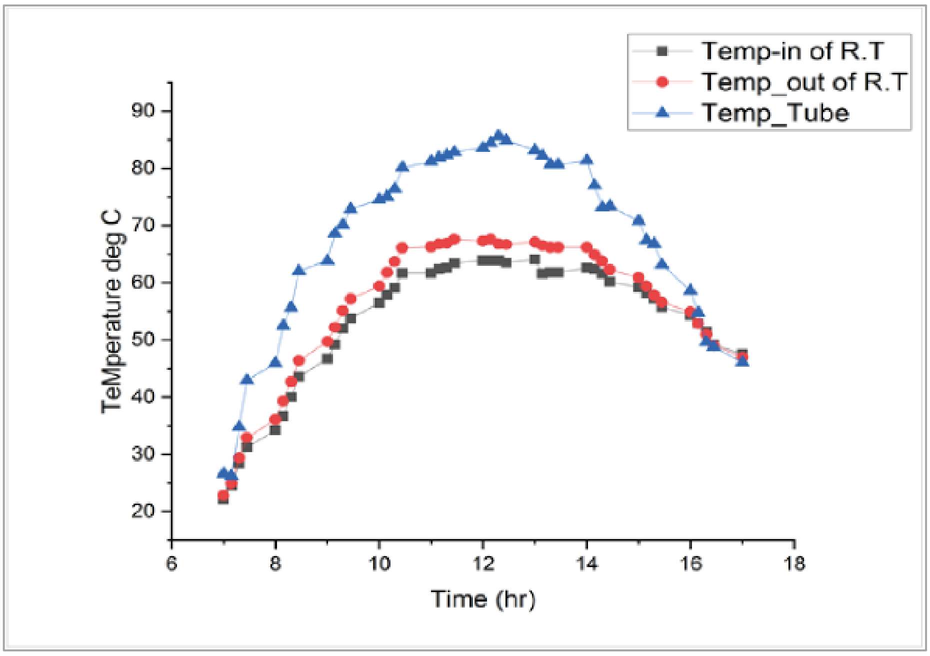


Figure 5.11 Variation temperature with time for receiver tube of the PTC at $31^{\text{th}}$of March, 2021

Another experiment with the solar still was conducted with PTC at 17^{th} of April, under conditions that differed from the previous experiment in terms of solar radiation, ambient temperature and an average wind speed of 2.87 Km/hr. As shown in Figure 5.12, the solar radiation starts at 7:00 am until it begins to increase and reaches the highest amount of 1059 W/m^2 at 12:15 pm and then begins to decrease. As for the ambient temperature, it starts to increase and continues to increase even after the radiation decreased, this is because the earth stores heat , so when the solar radiation decreases , the earth begins to emit heat . therefore, the ambient temperature remains high even after the solar radiation degreases. As noted in Figure 5.12, the ambient temperature begins to decrease after 3:30 pm.

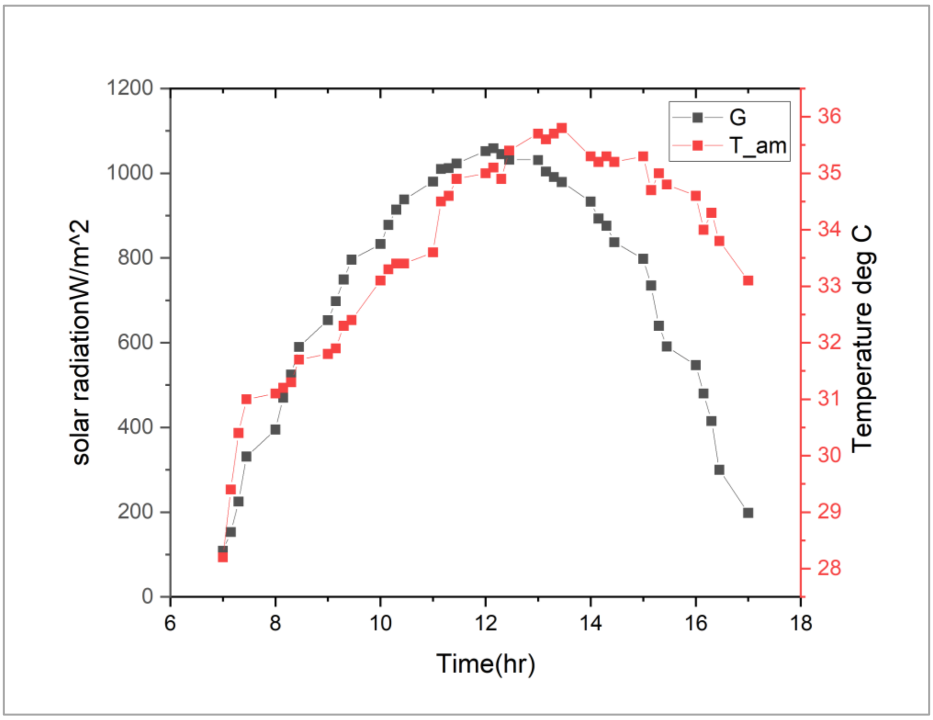


Figure 5.12 Variation solar radiation with ambient temperature during the experimental day at $17^{th}$of Aprill ,2021

Figure 5.13 shows the temperatures of the inner and outer glass surface of the single solar still, the water temperature inside the single solar still, as well as the plate temperature and their differences with time. Note that the temperatures begin to increase with the increase in solar radiation. So, the temperature of the inner surface of the single solar still is higher than the outer surface, this is because the outer surface of the single slope solar still is exposed to wind speed that leads to a decrease in the surface temperature. The highest temperatures are obtained at 12:30 pm, where the highest temperature obtained for water inside the solar still is 71.4^{o}C.

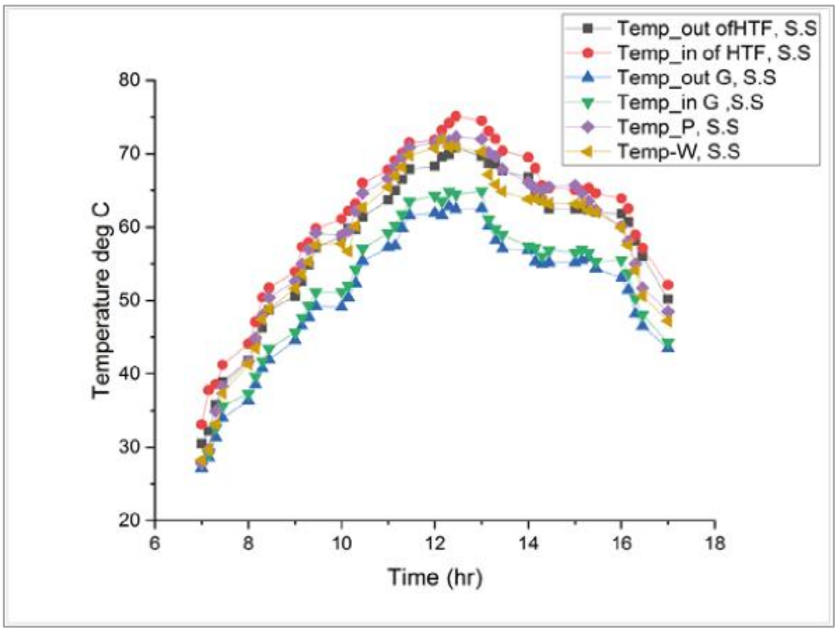


Figure 5.13. Variation temperature with time for the solar still with PTC at 17th of Aprill, 2021

Figure 5.14 shows the temperatures of the heat transfer fluid entering to and exiting from the receiving tube and the surface temperature of the tube, where the highest temperature of the fluid leaving the receiving tube reached 74.5° C at 12:15 pm.

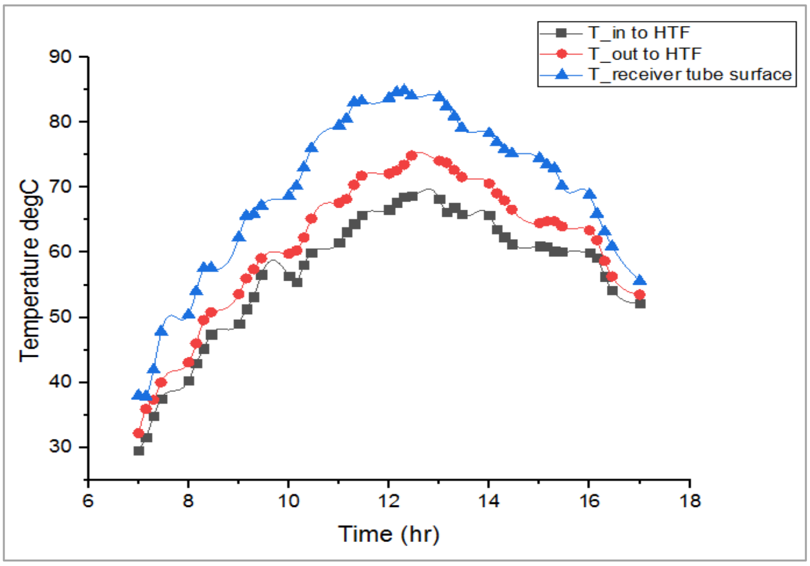


Figure 5.14 Variation temperature with time for receiver tube of the PTC at 17th of April, 2021.

Another experiment of the solar still was done with PTC at 6^{th} of May, 2021. In variable conditions from the previous experience in terms of solar radiation, ambient temperature and average wind speed of 2.84 km/hr. As shown in Figure 5.15 the solar radiation starts from 7:00 am until it begins to increase and reaches the highest amount of 1140 W/m^2 at 11:45 pm and then begins to decrease, this is because the earth stores heat , so when the solar radiation decreases , the earth begins to emit heat . therefore, the ambient temperature remains high even after the solar radiation degreases. As for the ambient temperature, it starts to increase and continues to increase even after the radiation decreases. As noted in Figure 5.15, the ambient temperature begins to decrease after 4:00 pm. Figure 5.16 shows the temperatures of the inner and outer glass surface of the single solar still, the water temperature inside the single solar still, as well as the plate temperature and their differences with time. Note that the temperatures begin to increase with the increase in solar radiation. So, the temperature of the inner surface of the single solar still is higher than the outer surface, this is because the outer surface of the single slope solar still is exposed to wind speed that leads to a decrease in the surface temperature. The highest temperatures are obtained at 12:15 pm, where the highest temperature obtained for water inside the solar still is 73.95^0 C.

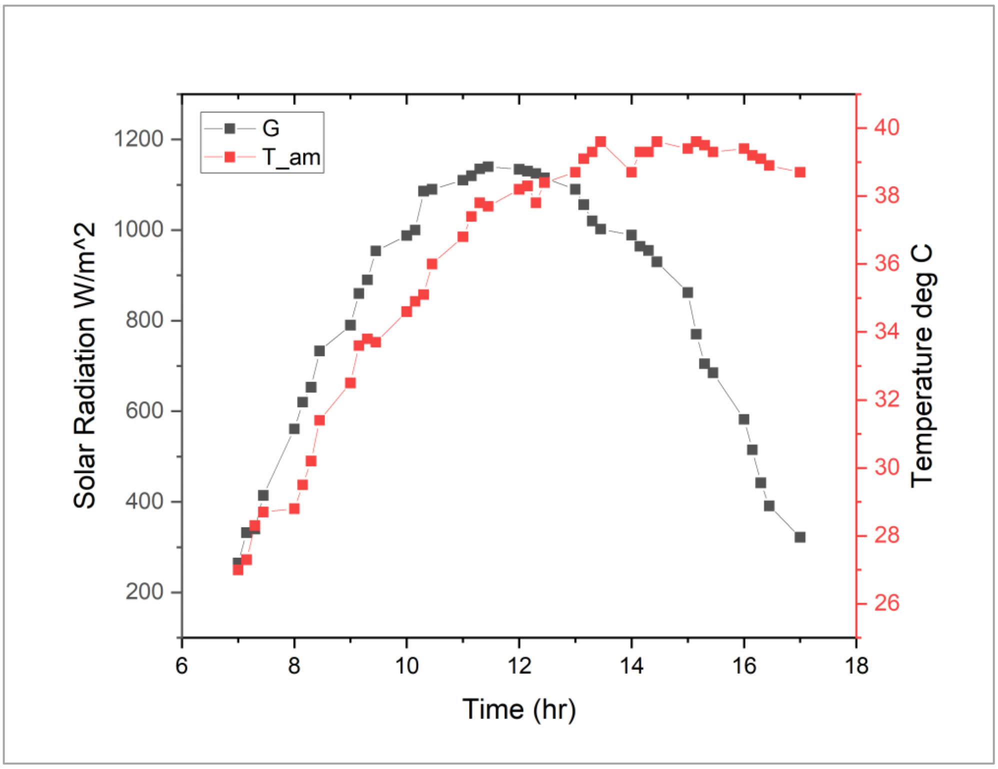


Figure 5.15 Variation solar radiation with ambient temperature during the experimental day at 6th of May, 2021

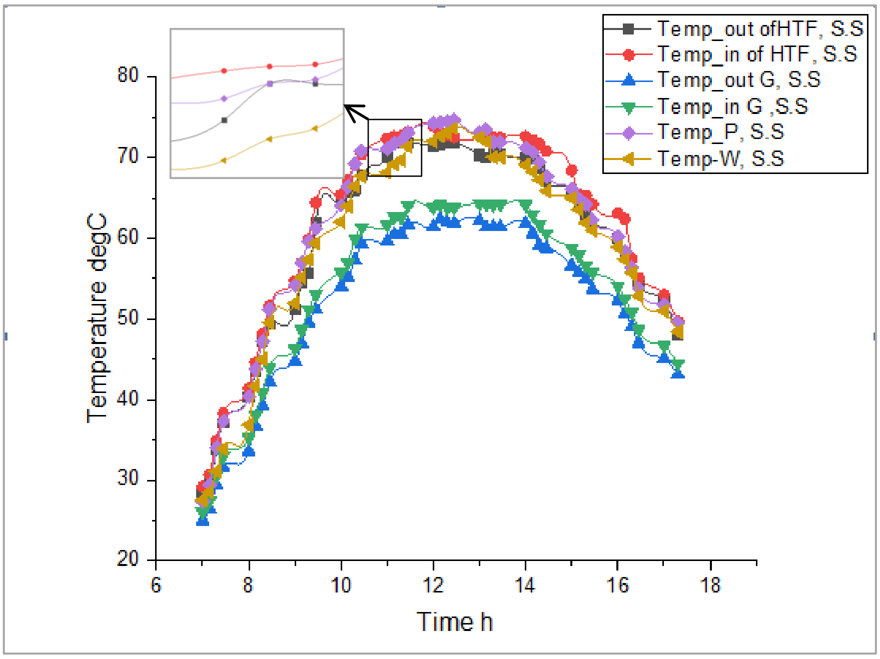


Figure 5.16 Variation temperature with time for the solar still with PTC at 6thof May, 2021

Figure 5.17 shows the temperatures of the heat transfer fluid entering to and exiting from the receiving tube and the surface temperature of the tube, where the highest temperature of the fluid leaving the receiving tube reached 74.5 °C at 12:15 pm.

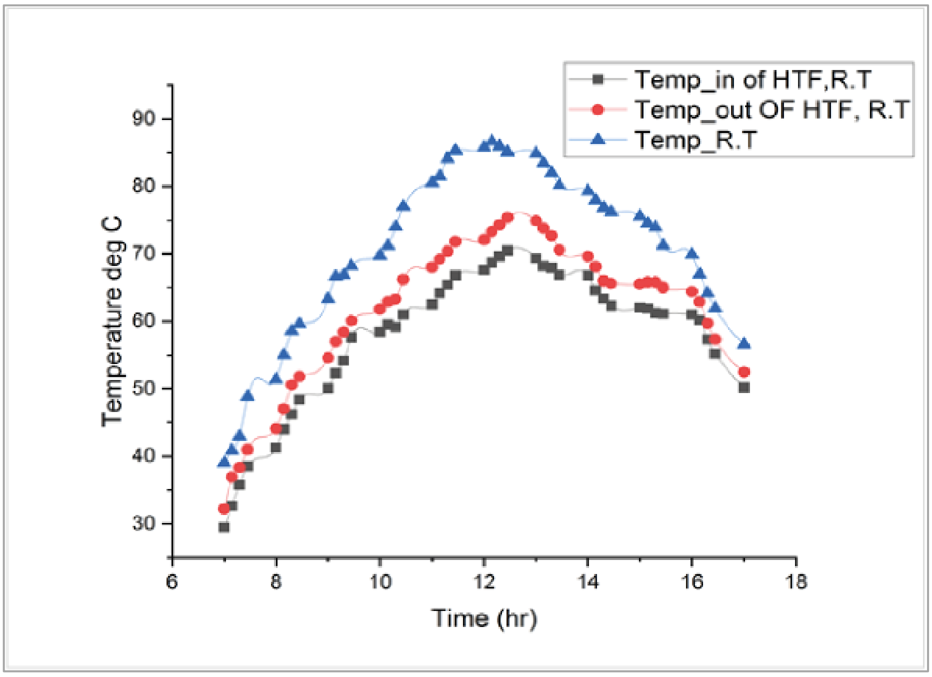


Figure 5.17 Variation temperature with time for receiver tube of the PTC at 6th of May, 2021.

Figure 5.18 shows the productivity of distilled water from single solar still with PTC device during March, April and May 2021. The productivity of distilled water increases gradually as of 8:00 am. The productivity of distilled water for March during the day was 3.619 kg / m^2 /day. The highest productivity is obtained at 12:00 pm by 0.7449 kg / m^2, then the productivity begins to decrease with a decrease in solar radiation. At 17th of April, the productivity of distilled water during the day was 5.26119 kg/m^2/day. The highest productivity is obtained at 12:00 pm at 0.89817 kg / m^2. Then the productivity of the distilled water begins to decrease as a result of lower temperatures inside the solar distillation apparatus when the solar radiation decreases. At 5th of May, the productivity of distilled water during the day was 6.83382 kg/m^2/day. The highest productivity is obtained at 01:00 pm by 1.2721 kg / m^2, then the productivity of distilled water begins to decrease as a result of lower temperatures inside the solar distiller. The salinity of the distilled water was also measured using the TDS device, which amounted to 85 ppm. The salinity of the distilled water in the bottles sold in the market is 75 ppm, while the salinity of the beach water ranged from 1000 to 1150 ppm. The difference in productivity as shown in figure 5.7 ,due to wind speed that may affect temperatures ,as the greater the wind speed that passes over the surface of the solar still leads to an increase in the condensation process and the opposite occurs when the wind speed decreases. And due to the humidity inside the solar still where the higher the humidity inside the basin the less the productivity .

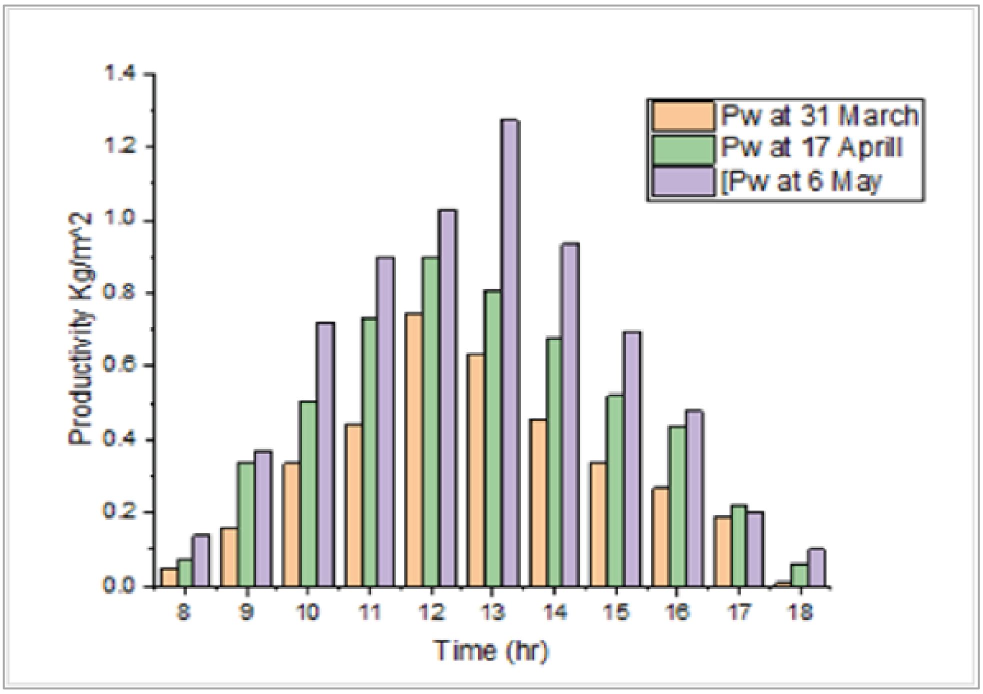


Figure 5.18 Productivity variation with time at days 31th March ,17th April, 6th May.2021

The hourly efficiency of three experiments was calculated when using the single solar still with PTC when using water as a fluid running inside the tubes. Figure 5.26 shows the hourly efficiency at $31^{th}$of March ,17th April and 6th May, which reached 33.85 % during the day 31th March. The highest efficiency was obtained at the highest productivity at 12:00 pm, about 62.50%. The thermal efficiency 17^{th} of April, which reached about 40.83 % during the day, where the highest efficiency obtained at 1:00 pm was 70.43 %. At $6^{th}$of May, an efficiency of 46.24% was obtained during the day. The highest hourly efficiency obtained at 1:00 was 93.75%.The discrepancy in thermal efficiency shown in figure 5.8, this is due to weather condition that affect temperature, which leads to an increase or decrease in the results thermal efficiency.

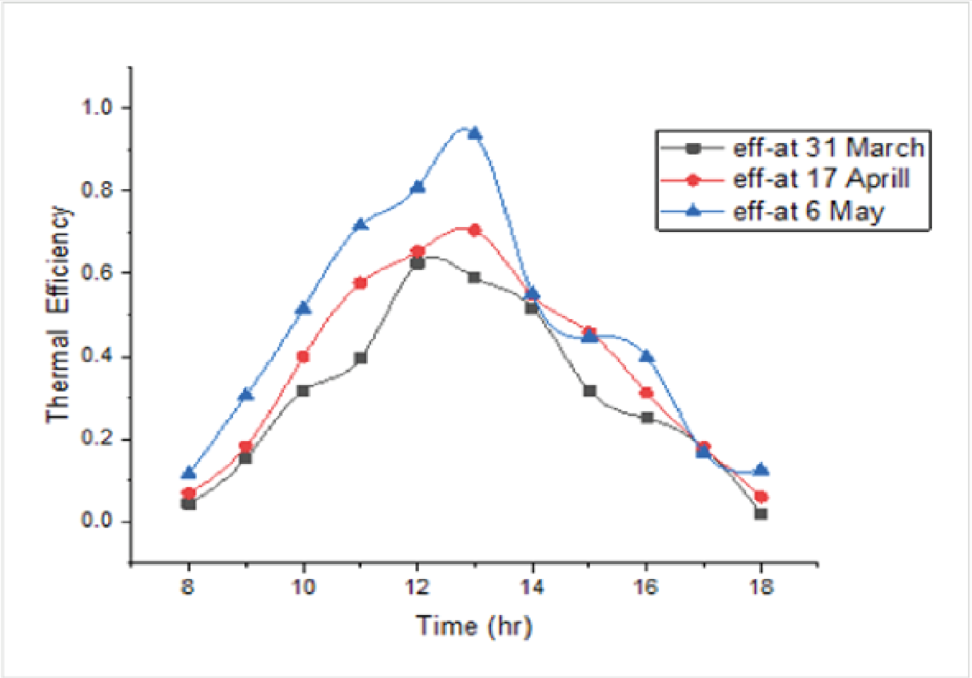


Figure 5.19 Thermal Efficiency at days 31th March,17th April and 6th May. 2021

5.2.3. Single solar still with PTC (use HTF Nanofluid)

An experiment was conducted on the solar still with PTC using a Nanofluid heat transfer fluid that runs inside the receiving tube. The experiment was done at 23^{th} of June, 2021. average wind speed of 3 km/hr. As shown in Figure 5.20 the solar radiation starts at 7:00 am until it begins to increase and reaches the highest amount of 1261W/ m^2at 12:00 Pm and then begins to decrease. As for the ambient temperature, it starts to increase and continues to increase even after the radiation decreased, this is because the earth stores heat , so when the solar radiation decreases ,the earth begins to emit heat . therefore, the ambient temperature remains high even after the solar radiation degreases. As noted in Figure 5.20, the ambient temperature begins to decrease after 4:00 pm. Figure 5.21 shows the temperatures of the inner and outer glass surfaces of the single solar still, the water temperature inside the single solar still, as well as the plate temperature and their differences with time. Note that the temperatures begin to increase with the increase in solar radiation. So, the temperature of the inner surface of the single solar still is higher than the outer surface, this is because the outer surface of the single slope solar still is exposed to wind speed that leads to a decrease in the surface temperature. The highest temperatures were obtained at 1:00 pm., where the highest temperature obtained for water inside the solar still was 76.1^0 C.

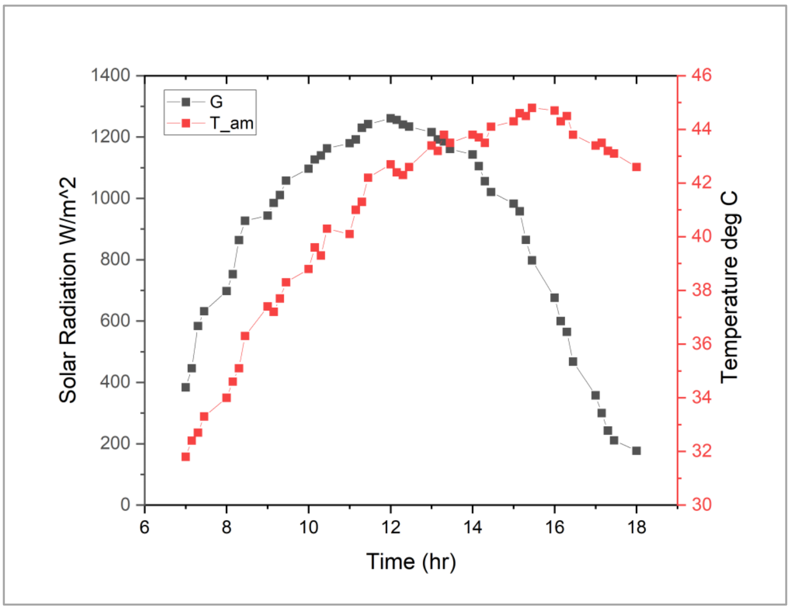


Figure 5.20 Variation solar radiation with ambient temperature during the experimental at 23th of June, 2021.

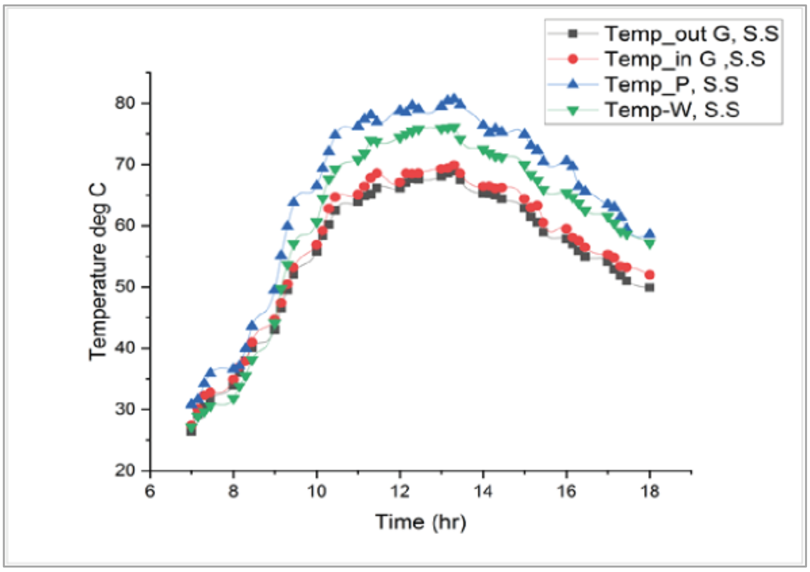


Figure 5.21 Variation temperature with time for the solar still with PTC at 23th of June, 2021.

Figure 5.22 shows the temperatures of the heat transfer fluid (Nanofluid) entering to and exiting from the receiving tube and the surface temperature of the tube. Where the highest temperature of the fluid leaving the receiving tube reached 80.1° C at 12:30 pm.

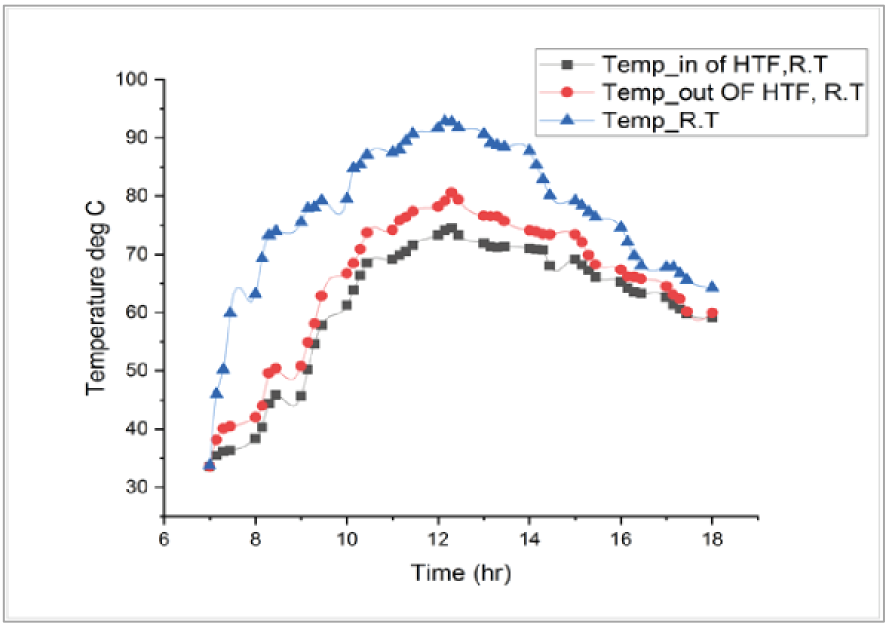


Figure 5.22 Variation temperature with time for receiver tube of the PTC of June, 2021.

An experiment was done at 24^{th} of June, 2021. using nanofluid as a fluid that runs inside the receiving tube until it passes through the heat exchanger. When the average wind speed is1.84 Km/hr. As shown in Figure 5.23, the solar radiation starts at 7:00 Am until it begins to increase and reaches the highest amount of 1210 W/ m^2at 12:00 Pm and then begins to decrease. As for the ambient temperature, it started to increase and continues to increase even after the radiation decreased, this is because the earth stores heat , so when the solar radiation decreases , the earth begins to emit heat . therefore, the ambient temperature remains high even after the solar radiation degreases. As noted in Figure 5.23, the ambient temperature begins to decrease after 4:00 pm. Figure 5.24 shows the temperatures of the inner and outer glass surfaces of the single solar still, the water temperature inside the single solar still, as well as the plate temperature and their differences with time. Note that the temperatures begin to increase with the increase in solar radiation. So, the temperature of the inner surface of the single solar still is higher than the outer surface, this is because the outer surface of the single slope solar still is exposed to wind speed that leads to a decrease in the surface temperature. The highest temperatures were obtained at 1:00 pm., where the highest temperature obtained for water inside the solar still was 78°C.

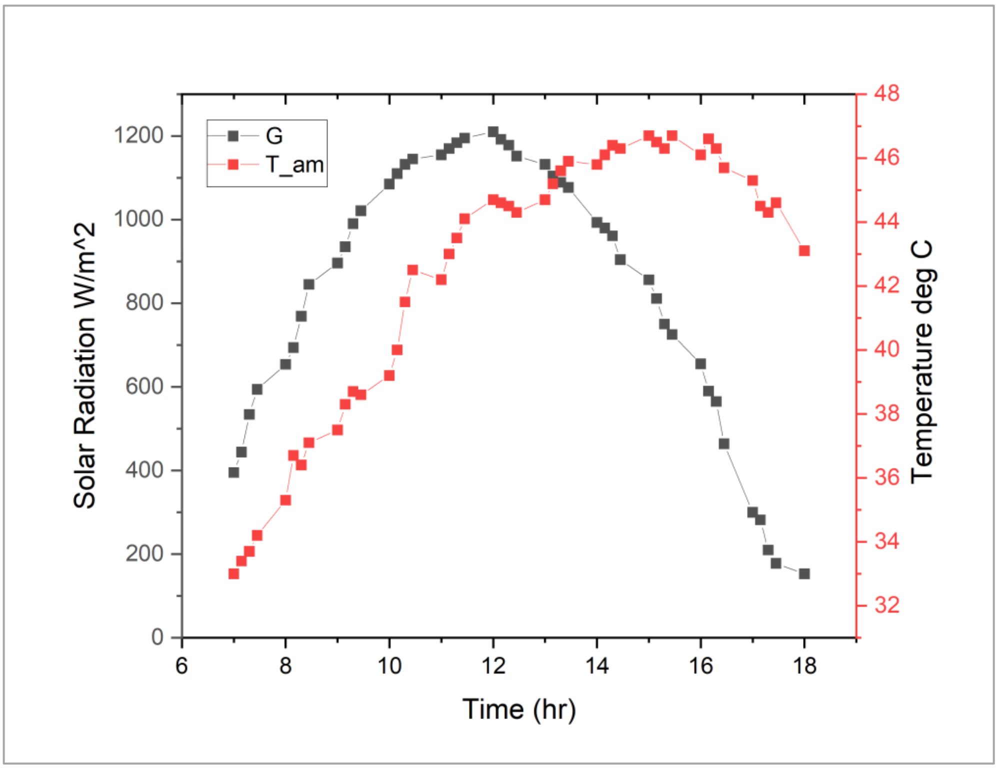


Figure 5.23. Variation solar radiation with ambient temperature during the experimental day at 24th of June, 2021.

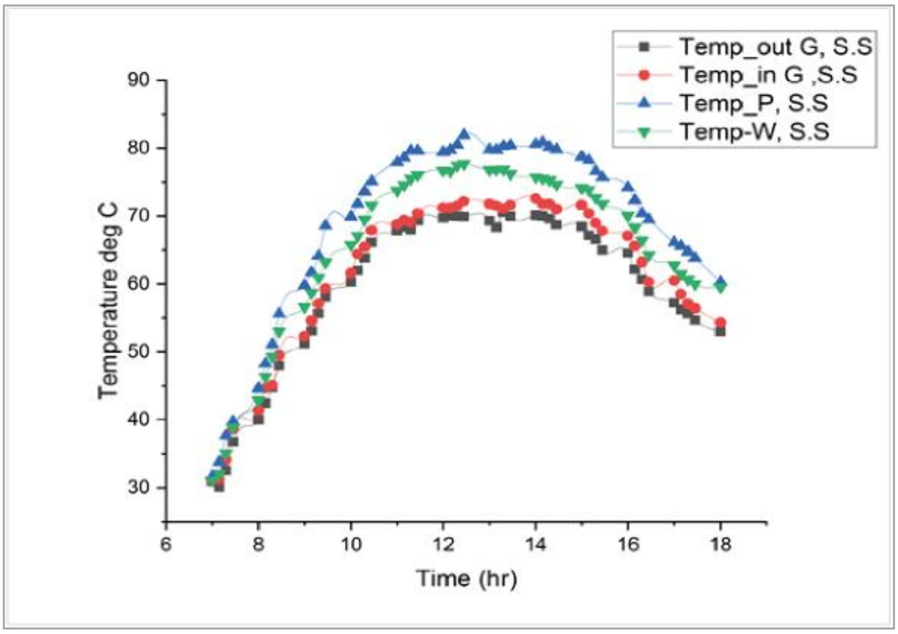


Figure 5.24. Variation temperature with time for the solar still with PTC at 24th of June, 2021.

Figure 5. 25 shows the temperatures of the heat transfer fluid (Nanofluid) entering to and exiting from the receiving tube and the surface temperature of the tube, where the highest temperature of the fluid leaving the receiving tube reached 85.1^0 C at 1:00 pm.

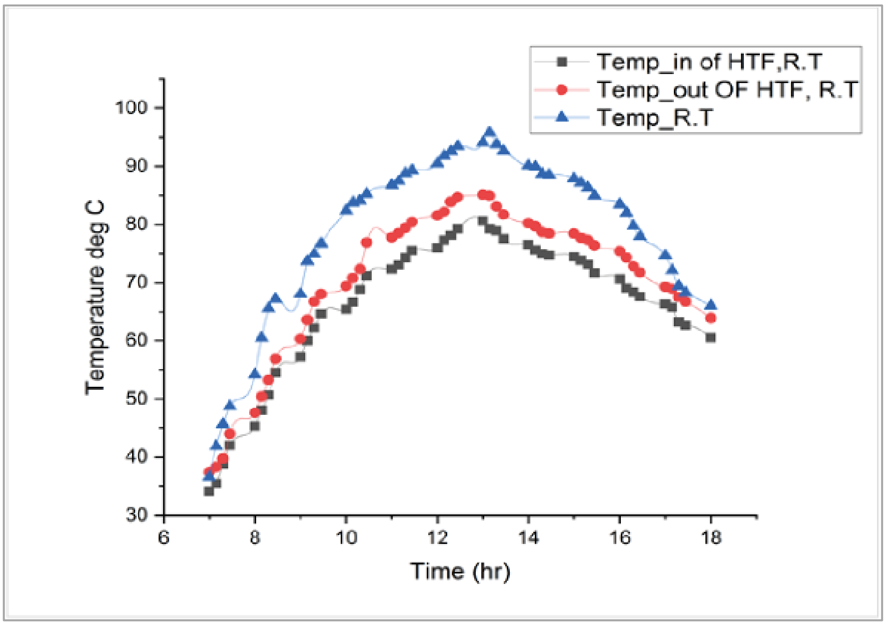


Figure 5.25 Variation temperature with time for receiver tube of the PTC at 24th of June,2021.

Figure 5.26 productivity of distilled water from single solar still with PTC, using nanofluid as working fluid inside tubes at 23th, 24th June, 2021. The productivity of distilled water at day 23th was obtained 8.74 kg/m^2/day , as the productivity of distilled water gradually increases from hourly 8:00 am, and the highest productivity is obtained at 01:00 pm at 1.332 kg/m^2. Then the productivity of distilled water begins to decrease as a result of lower temperatures inside the solar distiller when the solar radiation decreases. At 24th June, the productivity of distilled water was obtained during the day 9.01812 kg/m2/day .The highest productivity was obtained at 01:00 pm by 1.221 kg/m^2. The difference in productivity as shown in figure 5.26 during the initial hours of the day is due to wind speed that may affect temperatures ,as the greater the wind speed that passes over the surface of the solar still leads to an increase in the condensation process and the opposite occurs when the wind speed decreases. And due to the humidity inside the solar still where the higher the humidity inside the basin the less the productivity .

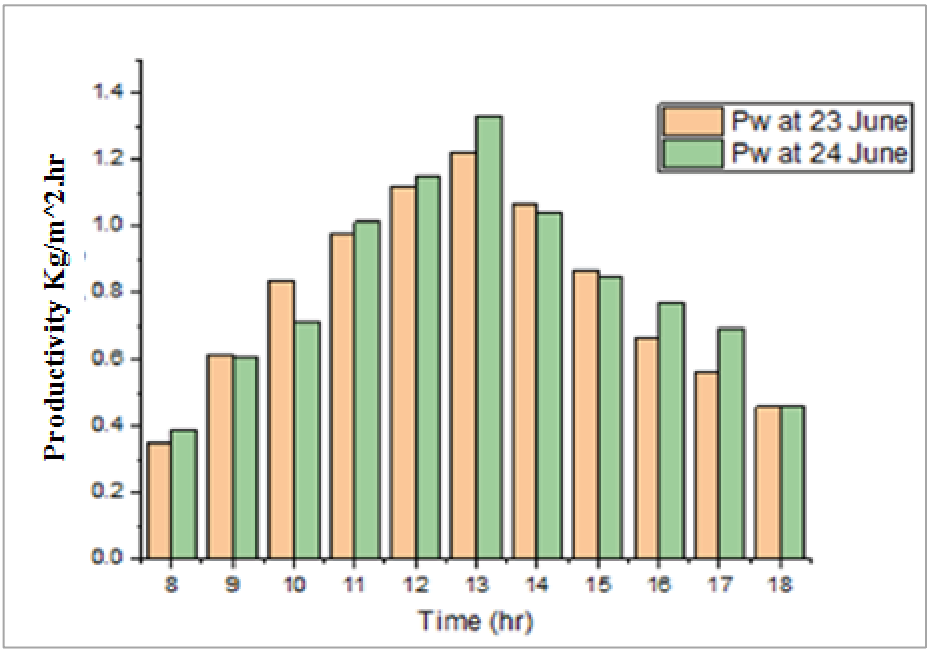


Figure 5.26 Productivity variation with Time at day 23th and 24th June. year 2021.

The hourly efficiency of two experiments was calculated when using a single solar still with PTC when using Nanofluid as a fluid running inside the tubes. Figure 5.27 shows the hourly efficiency at 23th and 24thof June, which reached 61.75% at 23$^{th.}$ June. The highest efficiency was obtained at the highest productivity at 12:00 pm, about 92.21%. The thermal efficiency at 24thof June, which reached about 62.14%, where the highest efficiency obtained at 1:00 pm was 93.33%.

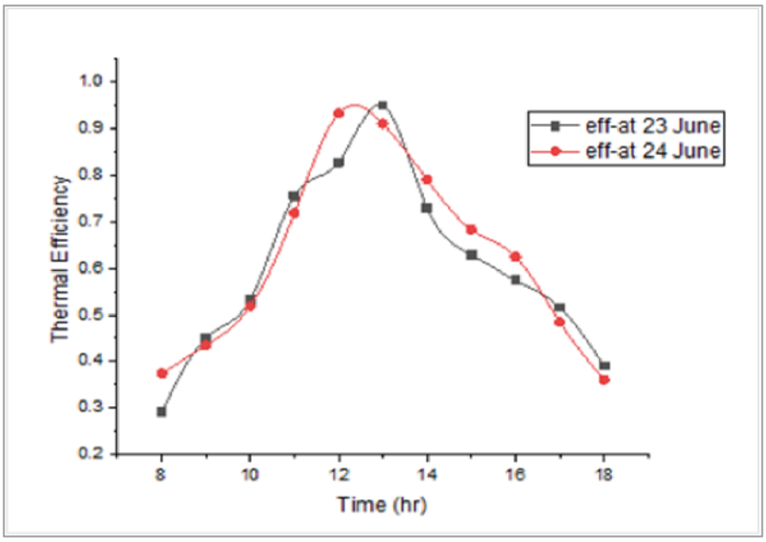


Figure 5.27 Thermal Efficiency with Time at day 23th and 24th June. Year 2021.

5.3. Comparison

5.3.1. Comparing theoretical and experimental results

The data of the experimental work was entered into the COMSEL program in terms of weather conditions and temperatures. It was found through the results that there is a good agreement between the theoretical and experimental results temperature and productivity. As the error rate between water temperatures inside the solar still was approximately 5%., the temperature of the inner glass surface of the solar distiller is 3.09%, as shown in Figure 5.28.

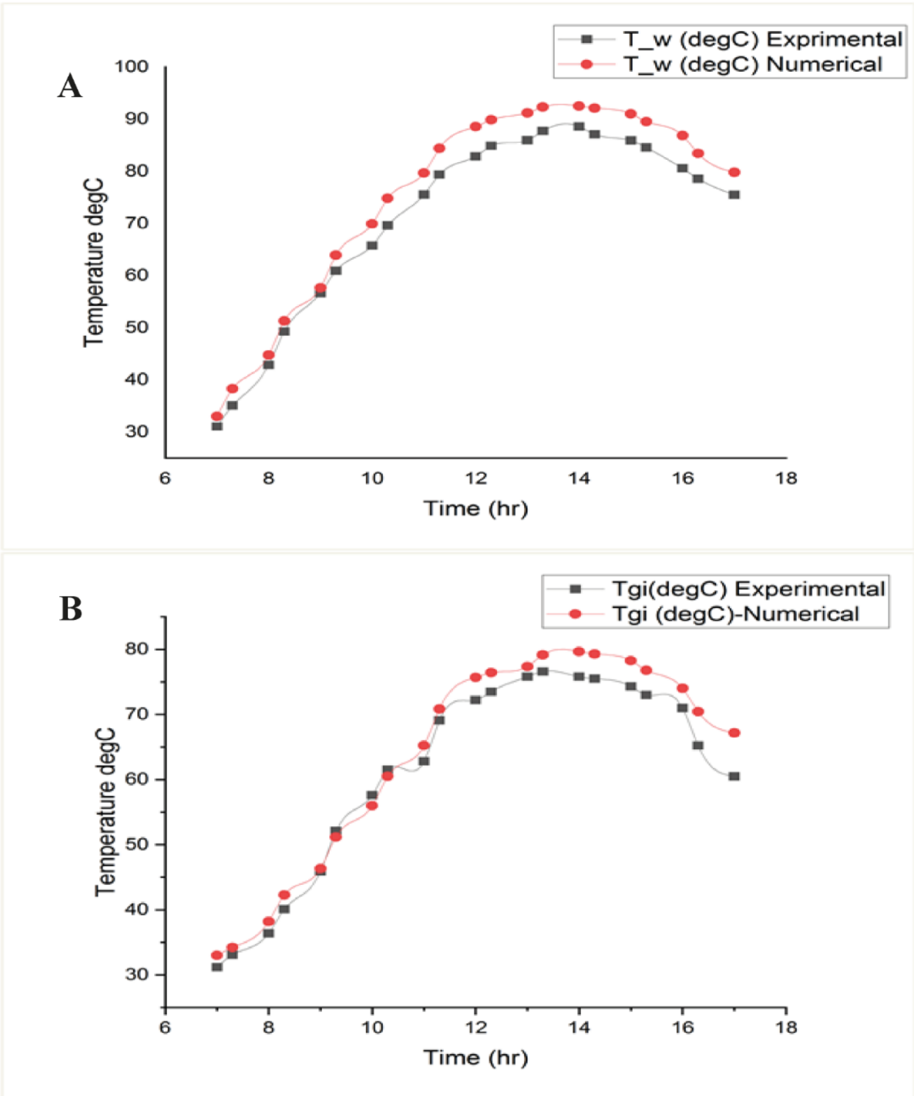


Figure 5.28. Comparing theoretical and experimental results (A) water temperatures inside the solar still (T_w), (B) Temperature of the inner glass surface of the solar distiller (T_{gi})

As for the productivity of distilled water, there is a good convergence between the theoretical and experimental results. The productivity of distilled water in relation to the theoretical results during the day is about 5.35017 Kg / m^2. As for the experimental results, the productivity of distilled water was about 5.15569 Kg /m^2, whereas the error rate is about 3.635%. At 7th May,2021, as shown in Figure 5.29

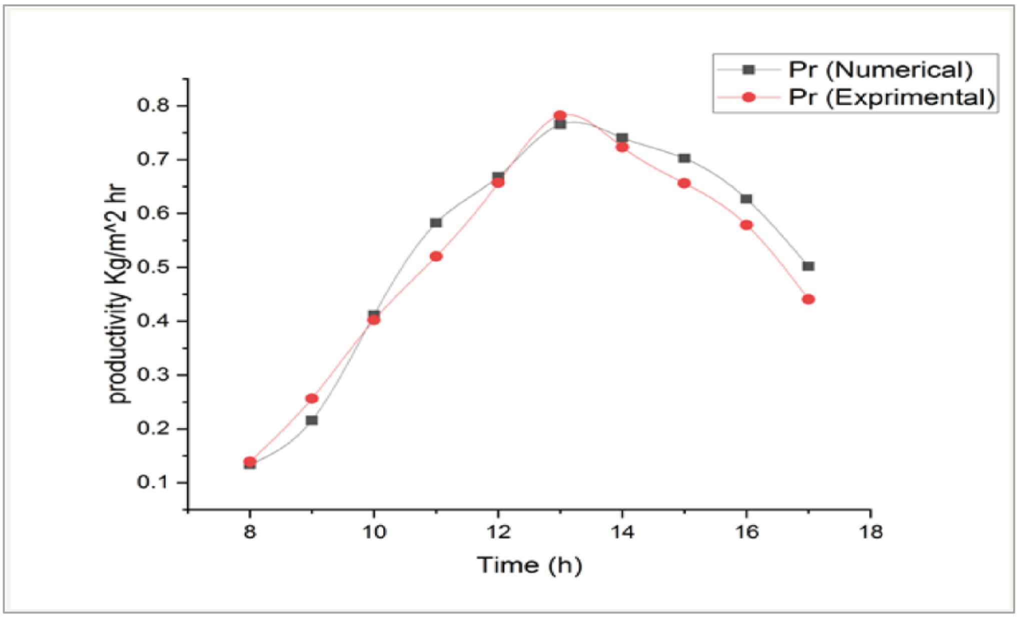


Figure 5.29. Comparing Productivity between Theoretical and Experimental results, at 7th May,2021

5.3.2. Comparison productivity of the single solar still only and with PTC

A comparison was made between the productivity of the solar still at 3r May 2021 and the productivity of the solar still with PTC at 2sd May 2021 and at very close weather conditions. When water is used as a fluid that runs inside the pipes between the receiver tube and the heat exchanger inside the solar still. The productivity will improve when using PTC with solar still by 36.130% as in Figure 5.30.

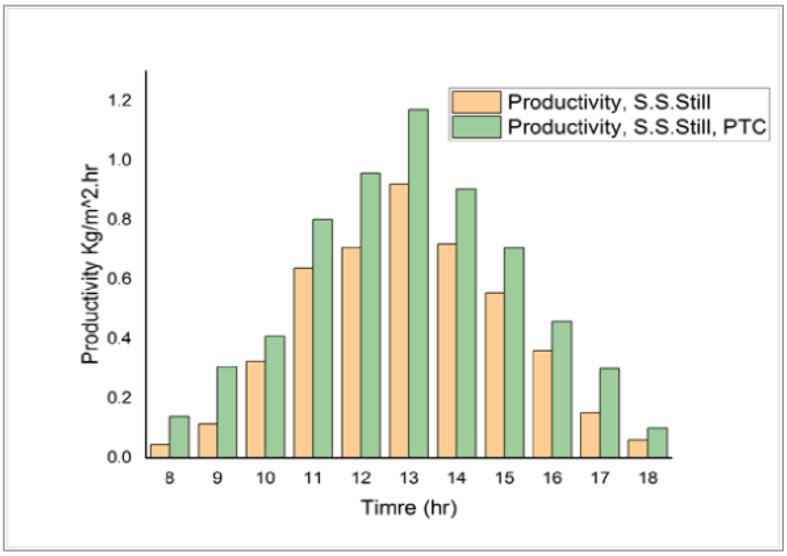


Figure 5.30 Comparison productivity of the single solar still only and with PTC

5.3.3. Comparison of the productivity of the single solar still with PTC (use the water), and the single solar still with PTC (use the Nanofluid).

A comparison was also made between the productivity of the solar distiller with PTC when water is used as a fluid that runs inside the pipes between the receiving tube and the heat exchanger inside the solar still at 20th June 2021 and between the productivity of the solar still with PTC using nanofluid as a fluid flowing inside the tubes at 22th June 2021, and at very close weather conditions. The yield will be improved when PTC is used with the solar still when using the nanofluid. By 34.217% as in Figure 5.31, with very close weather conditions.

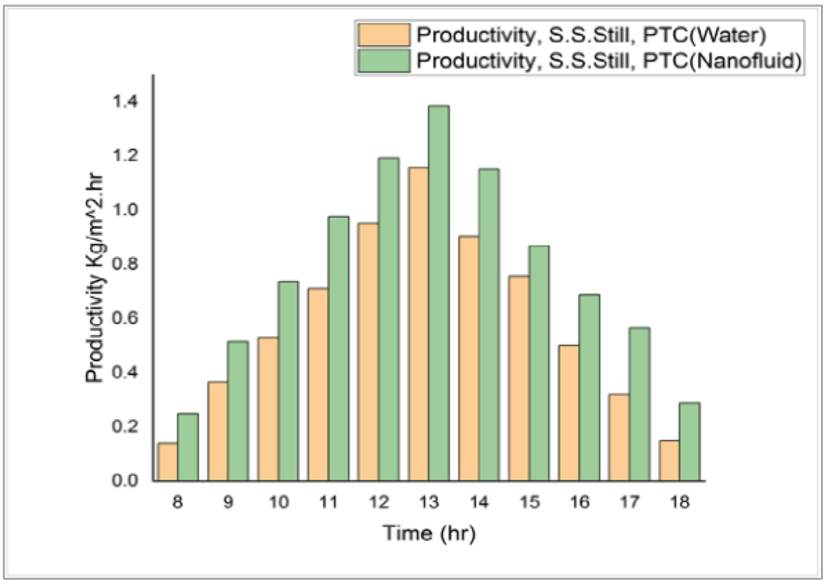


Figure 5.31 Comparison of the productivity of the single solar still with PTC (use the water), and the single solar still with PTC (use the Nanofluid).

5.3.4. Comparison of current study with other studies

Many researchers have studied the performance of solar still with PTC and several different techniques and got variable results. In order to compare the results in terms of improving the productivity of fresh water, Figure 5.32 was made to compare the daily productivity of each study.

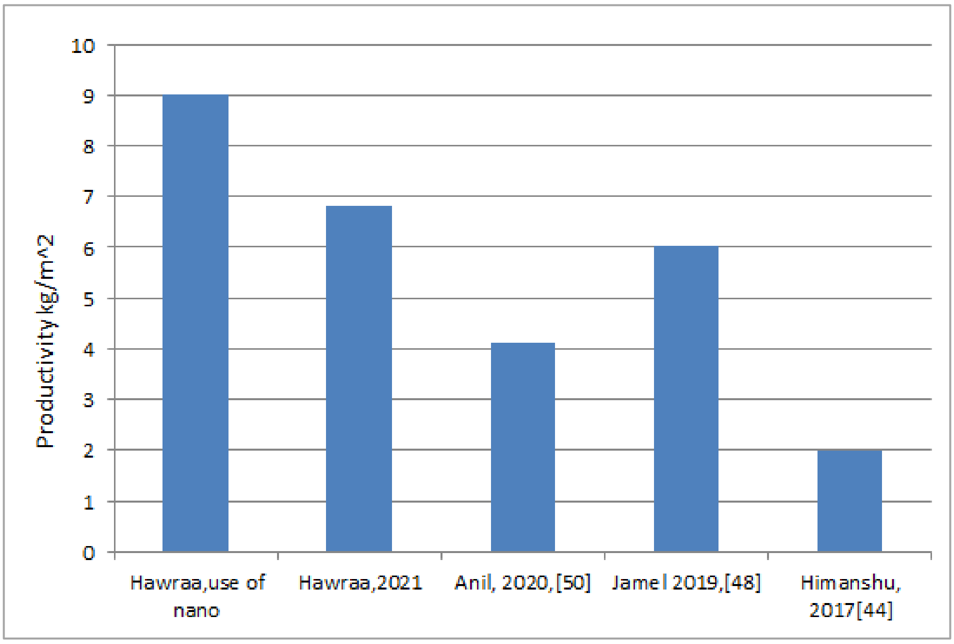


Figure 5.32Comparison of current study with other studies.

CHAPTER SIX: Conclusions and recommendations

6.1. Conclusions

The productivity of the solar still is affected by several factors and varies according to the surrounding weather conditions. It also depends mainly on the process of evaporation and condensation that occurs inside the solar still. In this chapter, the conclusions about the results related to theoretical and experimental results that were presented previously will be discussed.

When a simulation was performed by COMSOL 5.5 of a parabolic trough collector model with a solar device. In this work, two designs of heat exchanger inside the solar still were examined and the best design was selected to improve the productivity of distilled water in terms of obtaining the highest temperatures under the weather conditions of Najaf city - Iraq (32° 1 'N / 44° 19' E). From the simulation, the following conclusions were drawn:

1- Using a heat exchanger inside the solar still which is a incorporator (absorber plate and pipes), we will get the highest temperatures from the winding heat exchanger. The highest water temperature inside the solar still when using the heat exchanger incorporator (absorber plate and pipes) was about 92.53^0 C and the temperature of the inner glass surface 79.651^0 C at 2:00 pm, higher than the winding heat exchanger temperatures of 86.78^0 C and 72.472^0 C, respectively.

2- Also, the productivity of distilled water when using an incorporator (absorber plate and pipes) heat exchanger is higher than the other heat exchanger, reaching 5.35017 Kg/m^2, while the productivity when using a winding heat exchanger is 4.5 Kg/m^2.

3- The PTC increases the fluid temperatures inside the single solar still basin. When more solar radiation falls on the PTC and reflected on the receiving tube increases, the temperature of the fluid increases. The hot fluid comes out of the receiving tube and then enters the solar still through the tubes and passes through the heat exchanger that increases the temperature of the water inside the single solar still basin to increase the evaporation process. It was concluded that the use of PTC with the single solar still obtains the highest temperatures compared to the traditional single solar still.

4- The productivity and performance of the solar distiller with the use of PTC is much better than that obtained through conventional solar distillation when water is used as a fluid running inside the tubes. The productivity improvement rate during March is 41.9%, during April 59.375%, and in May, 45.03%, in similar weather conditions. The thermal efficiency also increases during the day when the single slope solar still combined with the PTC be of the thermal efficiency is 46.24%, while in the conventional single slope solar still the thermal efficiency is 35.56%.

5- The productivity of distilled water and the thermal efficiency of the conventional solar distiller increases when combined with PTC using copper oxide nanofluid (CuO) as a fluid flowing inside the tubes (PTC receiver tube and heat exchanger tube inside the single solar still basin). The improvement in productivity compared to water use is 34.217%. The thermal efficiency also increases, reaching 62.136% during the day.

6.2. Recommendations

Several recommendations can be presented for future studies to enhance the work of single solar still with PTC.

1. Using different types of nanofluids with different concentrations.
2. Using technology to cool the outer surface of the single solar still to improve the condensation process.
3. Using the PCM inside the single solar still basin.

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Appendix –A

Thermocouple Calibration

One of the temperature sensing equipment used in many engineering experiments is thermocouples. In the experimental work, 14 T-type thermocouples were used and calibrated using a data logger and a thermometer (mercury thermometer) .Where all thermocouples are connected to the data logger and the other end of the temperature sensor is placed in a basin of pure water, the temperature of which is gradually raised from zero to 100 ^{0} C with a step of 20 degrees. As shown in Figure and Table A.1 .

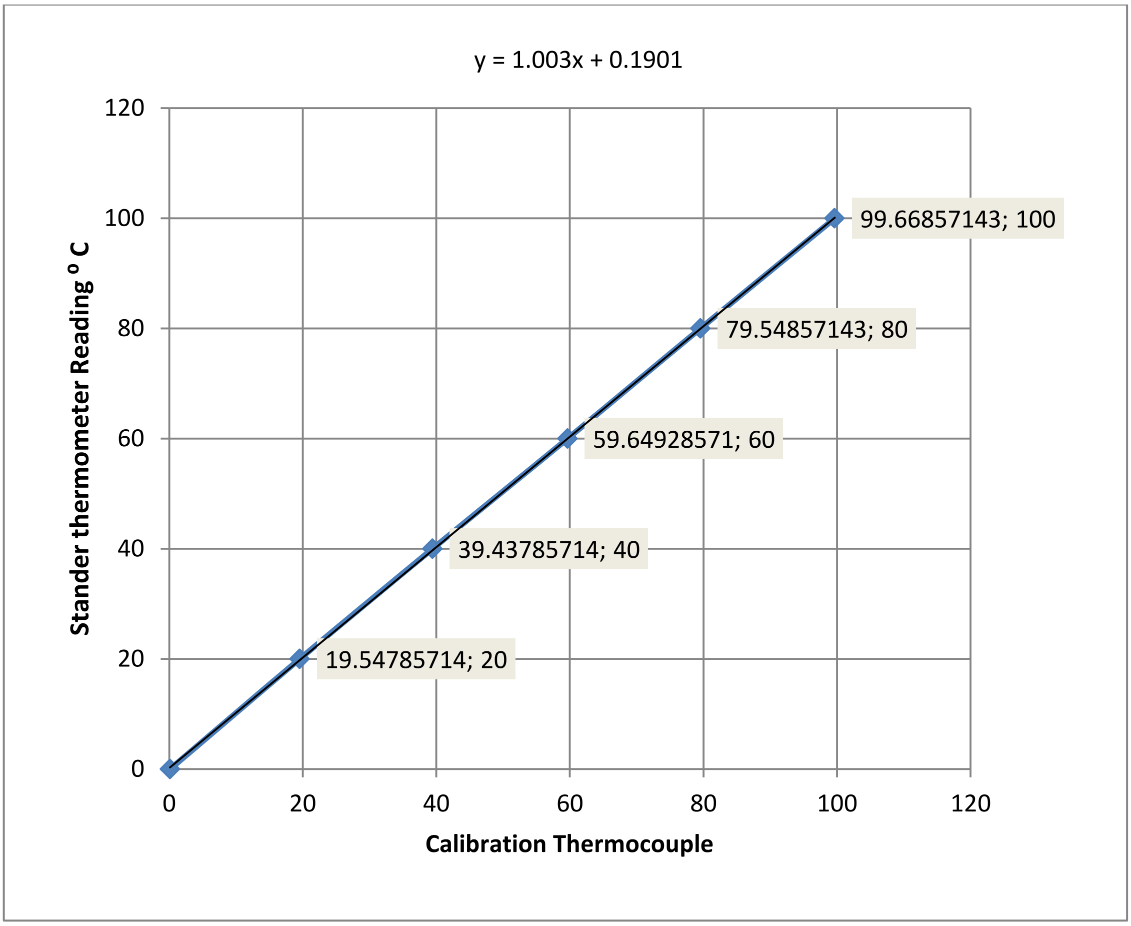

Figure A.1 . Calibration of thermocouple

Table A.1. thermocouple Correction formula

Senser	Location	Correction formula
S1	Receiver Tube(inlet)	Y=1.00093x+0.1572
S2	Receiver Tube(outlet)	y=1.00006x+0.5732
S3	Receiver Tube Surface I	y=1.0065x+0.03785
S4	Receiver Tube Surface II	y=1.00196x+0.476
S5	Single solar still (inlet) I	y=1.00814x+0.0386
S6	Single solar still (outlet) II	y=1.00376x+0.1187
S7	Outer Glass Cover I	y=1.00022x+0.2361
S8	Outer Glass Cover II	y=1.0015x+0.127
S9	Inner Glass Cover I	y=1.00134x+0.411
S10	Inner Glass Cover II	y=1.00148x+0.339
S11	Heat exchenger inside the S.SS I	y=1.00392x+0.143
S12	Heat exchenger inside the S.SS II	y=1.00711x+0.111
S13	Water inside S.SS I	y=0.9993x+0.466
S14	Water inside S.SS II	y=0.9983x+0.446

Appendix -B

NANOPARTICLE'S PROPERTIES

Nanoparticles Specifications

nanoparticles (manufactured by Guangzhou Hongwu Material Technology Co., Ltd.) were used to prepare the nanofluids. The properties of nanoparticles for CuO are listed in Table 1. Figure 1 shows scanning electron microscopy (SEM) for nanomaterials used in the study.

Table 1 details and properties of nanoparticles

Details	CuO
Appearance	Dark brown powder
Purity	99%
Size (nm)	D: 30-50 nm
Thermal conductivity (W/m.K)	76.5
Density (kg/m3)	6400
Specific heat (j/kg. K)	531

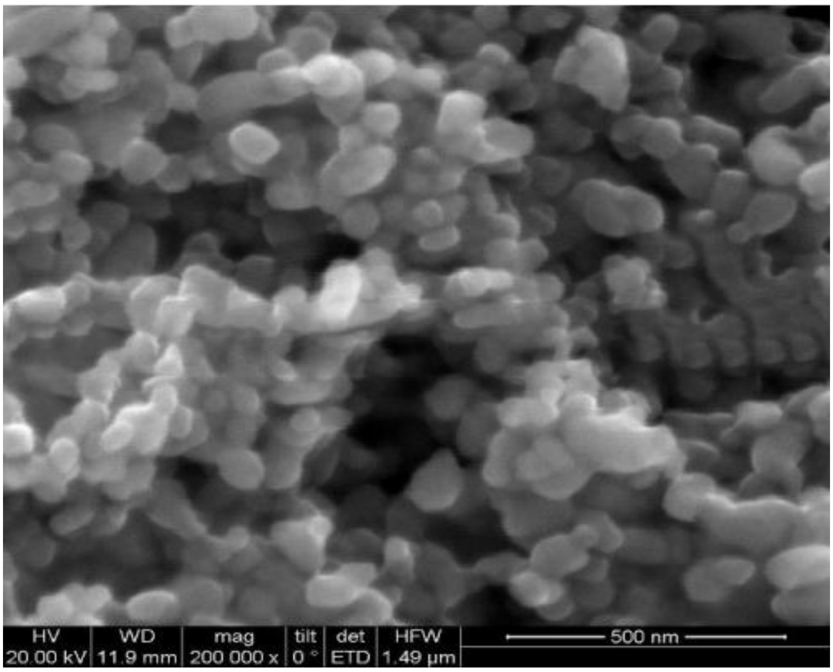

Figure 1. SEM images for CuO

Appendix –C

Publications

1-

Al-Furat Journal of Innovations in Mechanical and Sustainable Energy Engineering (FJIMSE) Published by Al-Furat Al-Awsat Technical University (ATU) / Iraq

A Review on ImprovementTechniques of Freshwater Productivity for Solar Distillation Systems

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Abstract. Solar desalination is known as a method used to turn brackish into potable water owing to high population density and automation, consumable water demand continues to increase. and the system used for desalination is known as a solar still. The main types of solar stills include active and passive solar stills fresh water is obtained from passive solar stills without the use of high-grade energy(electrical energy). several researchers framed mathematical expressions, performed experiments, and confirmed the outcome of the different types of solar stills This paper analyzed the methodologies used in previous years to enhance the efficiency of active and passive solar stills. using types of absorbent materials, reflectors, and a sun tracking device is introduced the solar energy intensity is maximum and thus improves absorption production by 380%, an overall increase in efficiency of 2% will increase production to around 22% in some research, Through this study, The results showed that the use of wire nets and sand in the container increases the daily output of freshwater by about 3.1%, 13.7% in winter, about 3.4% and 14.1% in summer. It also turns out that the productivity of distillation is 20 L / m^2 over the inverter compared to 5 kg / m^2 in the conventional system. Results also show that the efficiency of the solar still is affected by the kinds, design, and heat storage system.

Keywords: Solar Desalination, Solar Concentrator, External Reflector

1. INTRODUCTION

Solar water desalination is the technique in which salty or brackish water is a very important problem the shortage of freshwater is growing. This problem is increasing continuously, due to changes in weather conditions and population growth, which affect many countries of the world. As the earth contains mostly saline water by more than 97% .therefore, it is possible to use different water treatment processes to produce fresh water from brine the solution to this problem is solar water desalination.

Researcher Hamza et al.[1]study shows that using sponge cubes can greatly enhance daily production, the increase was 255% in the production of distillates compared to the same conditions to a water basin empty from sponge cubes. Yasuhito et al.[2] theoretically studied a basin with external and internal reflectors, an engineering method has been proposed to find the solar radiation reflected by these reflectors, the results showed that the use of these reflexes increases the production of water distillation. Researcher Shukla et.

2-

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NUMERICAL SIMULATION OF RECEIVER TUBE FOR PARABOLIC TROUGH COLLECTOR WITH SINGLE SOLAR STILL

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ABSTRACT

A numerical simulation study was carried out to model the absorption pipe of the parabolic trough collector with the single-slope solar still. Simulations were carried out in the comsol 5.4 g program to obtain the best design of the solar still and to improve the yield of the distilled water. The number of heat exchanger tubes changed inside the solar still 6,8,10,12 tubes. The diameter of the heat exchanger tubes (0.5 cm, 1 cm, 1.5 cm) was also changed. The results showed that when increasing the number of tubes inside the heat exchanger, the best temperatures were obtained. When the number of 12 tubes, the highest temperature of the water inside the solar still is obtained at 93.597ºC, and the highest temperature of the surface of the inner glass of the solar still is 72.791ºC at 1:07 pm. As it turns out, as the diameter of the heat exchanger tubes increases, the temperature of the water inside the single solar still increases, 99.93ºC. And the surface of the inner glass of the solar distiller was 79.991ºC at 1:06 pm. The work was done on February 18, 2021 in AL-Najaf City-Iraq (32° 1 'N/44° 19' E)

Keywords: Parabolic trough collector, solar still, fresh water.

I. INTRODUCTION

Energy is one of the most dangerous problems in the world. A high-performance solar collector is required to deliver elevated temperatures with good efficiency. The Solar Parabolic Trough Collector was able to acquire systems with light structures and low-cost technologies for the application of process heat up to 400°C (solar PTC). These systems can generate temperatures between 50 and 400°C efficiently [1]. Valladares et al [2] A numerical analysis of the optical, thermal and fluid dynamic behavior of a single-pass solar PTC was proposed and the research was expanded by replacing the absorber with a concentric circular heat exchanger counter-flow (double-pass). Hachicha et al [3] A visual model for computation was developed to show the distribution of irregular solar flux around the receiver. This model is based on the finite-size method and ray-tracing techniques, taking into account the position of the sun. The results received showed good compliance with the experimental and analytical results. Many previous works have been carried out on different solar still types to improve their productivity and thermal efficiency [4], [5]. The parabolic trough collector is currently concentrated solar systems are closely employed as one of the various solar energy converters [6]. A new optical efficiency analytical model and an updated integration algorithm to simulate the performance of a vacuum tube receiver parabolic trough collector (PTC) have been suggested and implemented by Weidong et al [7].The system's optical efficiency was simulated by the algorithm of numerical integration . Taking into account the lack of costs, the annual yield was often simulated. Ananthsornaraj et al. [8] Three-dimensional numerical modeling of the future of the parabola is carried out by coupling the Monte Carlo ray tracing method (MCRT) with the finite volume method (FVM), to investigate the flux distribution irregularities on the outside of the receiver. About Bilal et al [9] Under transient climate conditions, the thermal output of a solar parabolic trough has been numerically analyzed by the Collector (PTC). For the thermal efficiency of the PTC, the receiver tube length and the geometry of the heat transfer fluid (HTF) were simulated. They noticed that the overall thermal efficiency of the solar collector reached during the summer

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An Experimental Work on the Performance of Single Solar Still with Parabolic Trough Collector in Hot Climate Conditions

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Keywords:

solar distillation, productivity, parabolic trough collector, single slope solar still

ABSTRACT

This study investigated the production of single slope solar still and the influence of combining with a parabolic trough collector. The effect of the different working fluid types on freshwater productivity, outlet working fluid temperature, heat gain, and thermal efficiency has been studied under the weather conditions of south city of Iraq/ Najaf (32 ° 1' N / 44 ° 1' E). The first type was water and the second type is nanofluid. The results of the comparison showed when using water as a working fluid flowing inside the receiving tube for different days; the highest temperatures were obtained at 12:00 pm, and the average productivity of distilled water was obtained in May and June 2021 were 4.5358 and 6.733 $kg/m^2/day$ respectively. While when using the nanofluid as a working fluid flowing inside the Parabolic Trough Collector (PTC) receiver tube, the outlet temperatures were rising for the same comparison days with an increase in the productivity of distilled water. Where the freshwater productivity during the day was 8.745328 $kg/m^2/day$ as, and it was 9.018119 $kg/m^2/day$ during the other day. A productivity analysis was carried out for two different working fluid types (Water and nanofluid instead of water) as a fluid running inside the receiving tube of PTC. The freshwater produced from PTC (with nanofluid) was a 42.2% improvement in productivity compared with conventional PTC.

1. INTRODUCTION

Water is an essential component of human nutrition; the amount of pure potable water consumed each day for cooking and other family activities are between 20 and 50 Liters of clean potable water. The drinking water (freshwater) is a significant concern in many parts of the world, regardless of whether they are developed or developing countries, due to a lack of clean water. Imposing wastewater treatment methods from various sources to make it potable can help to solve the problem of pure water supply to a large extent. To clean the contaminated water, a number of technologies are available. The evaporation method using a solar still is one of the oldest and easiest ways to do so. To work, this technique simply requires sunlight and a small amount of manpower. As a result, it may appeal to both developing and emerging countries [1]. Fathy et al. [2] investigated the performance of a double-slope solar still with a parabolic trough complex (PTC) connection. The oil tubes connected to the PTC convert the solar energy that has fallen on it to solar energy. The solar stator contains an annular heat exchanger with finned tubes. Freshwater yields of 8.53 and 4.03 $kg/m^2/day$ are still linked to consistent PTC in two seasons (summer and winter). Hassan et al. [3] Using a parabolic trough collector, the effect of a middle made of salt water on the work of dual-action solar energy has been studied experimentally. Steel wire mesh, transparent salt water, and sand impregnated with salt water were used in the bowl as salt water media. The introduction of wire nets and sand increased daily fresh water output by about 3.1%, and by 13.7% in winter, nearly 3.4% and 14.1% in summer. Al-Shamkhee et al. [4] The performance of pre-designed and produced water systems was investigated in an experimental study. For the first time, a wastewater desalination project was implemented at Najaf, Iraq (32° 1'N / 44° 1' E). The proposed design attempts to increase distilled water output by including a parabolic solar basin. The first outcomes, the primary results show an 11% increase in system efficiency, and the results also show that orienting the PTC to the north or south is optimum for preserving system efficiency. Riffat et al. [5] The performance of a V-shaped solar concentrator has been explored for water desalination applications. They claimed that the v-trough solar concentrator is a superior approach for small and medium-scale water desalination, with a 38% efficiency at 100°C transfer fluid temperature at the concentrator output. Hassan et al. [6] The influence of brine middle and capacitor type on single slope solar energy work was studied experimentally. A typical solar stator fitted with a glass condenser and a still solar fitted with a flipper coated heat sink condenser are both tested. The use of a wire reticulum condenser, as well as a heat distributed and sand condenser, increased the freshwater output. Madiouli et al. [1] have experimentally examined the effect of combining a flat plate collector and running a standard sloped solar still. In addition to the parabolic trough complex supported by a spherical layer filled with glass, which works as a heat storage mechanism for the system. The results indicate that solar intensity combined with a parabolic trough collector can lead to excellent results.

Morad et al. [7] the heat transfer and energy balance

4- submission to 1st International Conference on Achieving the Sustainable Development Goals.

Numerical Simulation of Heat Exchanger inside the single solar still with PTC

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Abstract: Water is a necessary for human survival, individuals consume between 20 and 50 liters of clean water each day for drinking, cooking, and other household activities. Contaminated water is not only unsanitary, but also dangerous to one's health. The main aim of this study is to improve the productivity of solar water desalination by selecting the best solar still design. The best design for the single solar still is selected by a simulation was made in the COMSOL 5.5 program by use of two designs of heat exchanger, one of which is 8-pipe and the other is a incorporator (absorber plate and pipes) .as well as to improve productivity. Using a heat exchanger inside the solar still which is an incorporator (absorber plate and pipes) we will get the highest temperatures from the 8-pipe heat exchanger. The highest water temperature inside the solar still when using the heat exchanger incorporator (absorber plate and pipes). was about 92.53^0 C and the temperature of the inner glass surface 79.651^0 C at 2:00pm, higher than the 8-pipe heat exchanger temperatures of 86.78^0 C and 72.472^0 C, respectively. Also, the productivity of distilled water when using an incorporator (absorber plate and pipes) heat exchanger is higher than the other heat exchanger, reaching 5.35017 Kg/m^2 hr during the day. While the productivity when using an 8-pipe heat exchanger is 4.5 Kg/m^2 hr.

Keywords: Parabolic trough collector, solar still, fresh water.

1. Introduction

Freshwater is an important source of life for all living organisms on the planet. In the community, water supply and management are crucial development. Rapid population growth and industrialization are two examples of rapid population increase and industrialization primary causes of rising freshwater demand and, hence, lower levels of groundwater. Solar energy has the greatest potential to meet future energy requirements among the many alternative energy sources.

Hiroshi Tanaka et al.[1] used a basin type still with internal and external reflectors. When performing a numerical analysis of the mass and heat transfer, it was found that the external and internal reflectors increase the productivity of the distillate, as the average, external reflectors 48% for the type of single-slope basin that remains all year round. **A.A. El-Sebaii et al**. [2]Numerical simulations were carried out utilizing stearic acid as a PCM on typical summer and winter days .The evaporative heat transfer coefficient is increased by 27% when 3.3 cm of stearic acid is used beneath the basin liner .A daily productivity of 9.005 (kg/m^2 day) was achieved on a summer day, with an efficiency of 85.3 percent, compared to 4.998 (kg/m^2 day) when the still was used without the PCM. **Hitesh Pancha** [3]Investigated the effect of transmittance on glass cover thickness, use three various thicknesses of glass cover, such as 4 mm, 5 mm, and 6 mm. After six months of testing, it was determined that a 4 mm and 5 mm glass cover thickness increased average distillate output by 27% and 12%, respectively, as compared to a 6 mm glass cover thickness. **As for A.S. Abdullah** [4] therhas presented a 0.5 m^2 solar air heater collector, as well as the solar still and was experimental work.He also utilized a substance to store heat from the aluminum filler behind the absorption plate to keep the temperature stable and collect distilled water during the night. The results show that the productivity will increase by 112% compared to the traditional system when using a solar air heater. It was also found that the use of aluminum filler inside the solar still under the absorption plate increases the water productivity. Besides, **A.M.I. Mohamed et al** [5] assessed the performance and productivity of the proposed desalination system for solar humidification and dehumidification, a theoretical simulation model was created.The study's suggested desalination system was determined to be appropriate for operation using a parabolic trough solar collector. Summer is when the freshest water is produced; production time is at its highest in the summer, accounting for 42% of the day. **Weidong Huang et al** [6] used a novel analytical model for optical performance and a modified integration technique to predict the performance of a parabolic trough solar collector with vacuum tube receiver.When the distance between the reflection point and the focus point increases, the energy absorbed by the receiver decreases and the angle at which the receiver tube reaches decreases, resulting in an average optical efficiency of Equivalent solar

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الخلاصة

الماء ضروري لبقاء الإنسان ، ويستهلك الأفراد ما بين ٢٠ إلى ٥٠ لترًا من المياه النظيفة يوميًا للشرب والطبخ والأنشطة المنزلية الأخرى. المياه الملوثة ليست فقط غير صحية ، ولكنها تشكل أيضًا خطرا على صحة الفرد. الهدف الرئيسي من هذه الدراسة هو الحد من هذه المشكلة وتحسين إنتاجية المياه العذبة ، وكان الهدف الأساسي من هذه الدراسة هو استكشاف وتطوير تصميم النظام الشمسي الثابت باستخدام PTC الذي له تأثير إيجابي على الإنتاجية التراكمية.تم العمل نظريا وتجريبيا في ظل الظروف المناخية لمدينة النجف في العراق(32° 1' N / 44° 19' E). نظريا يتم اختيار أفضل تصميم للمقطر الشمسي الفردي من خلال محاكاة تم إجراؤها في برنامج COMSOL 5.5 باستخدام تصميمين للمبادل الحراري ، أحدهما عبارة عن ٨ أنابيب متعرجة والآخر عبارة عن وحدة دمج (لوحة ممتصة وأنابيب). وكذلك لتحسين الإنتاجية. تستخدم الموائع النانوية كسوائل تعمل داخل الأنابيب. باستخدام مبادل حراري داخل الساكن الشمسي وهو عبارة عن مدمج (لوح ممتص وأنابيب) ، سنحصل على أعلى درجات الحرارة من المبادل الحراري المتعرج. كانت أعلى درجة حرارة للماء داخل المقطر الشمسي عند استخدام مدمج المبادل الحراري (لوحة الممتص والأنابيب) حوالي 92.53ºC ودرجة حرارة سطح الزجاج الداخلي كانت 79.651ºC عند ٢:٠٠ مساءً ، أعلى من درجات حرارة المبادل الحراري المتعرج البالغة 86.78ºC and 72.472ºC، على التوالي. كما أن إنتاجية الماء المقطر عند استخدام مبادل حراري مدمج (لوح ممتص وأنابيب) أعلى من المبادل الحراري الآخر ، حيث تصل إلى 5.35017 كغم / م ٢. بينما تبلغ الإنتاجية عند استخدام مبادل حراري متعرج 4.5 كجم / م ٢. في هذه الدراسة ، أجريت التجارب من مارس إلى يونيو. أظهرت النتائج أنه عند استخدام وحدة التقطير الشمسي فقط ، تم الحصول على أعلى إنتاجية للماء المقطر في شهر مايو عند 4.16 كجم / م ٢ وكانت الكفاءة الحرارية 36.31%. يتم الحصول على إنتاجية أعلى عند دمجها مع PTC البالغة 6.83382 كجم / م ٢ في ظل ظروف مناخية شديدة التقارب ، وبكفاءة حرارية تبلغ 46.24% خلال النهار. أظهرت نتائج المقارنة أنه عند استخدام المائع النانوي كسائل عامل يتدفق داخل أنبوب استقبال مجمع الحوض المكافئ (PTC) ، كانت درجات حرارة خروج الماء ترتفع خلال نفس أيام المقارنة مع زيادة إنتاجية الماء المقطر. بلغ معدل تحسين الإنتاجية 34.217% . كما تزداد الكفاءة الحرارية لتصل إلى حوالي 62.14% خلال النهار.

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جمهورية العراق

وزارة التعليم العالي والبحث العلمي

جامعة الفرات الأوسط التقنية / الكلية التقنية الهندسية– النجف

دراسة وتقيم تجريبي لمقطر شمسي احادي الميل متصل مع مجمع شمسي مكافئ مع دراسة تأثير الموائع النانوية

رسالة مقدمة الى

قسم هندسة تقنيات ميكانيك القوى

جزءا من متطلبات نيل درجة الماجستير في تقنيات الحراريات في هندسة

ميكانيك القوى

من

حوراء فاضل عبد حسن

اشراف

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