Thermal Design Of A Single Slope Solar Still With Preheater Unit By Fresnel Lens Applications

A THESIS

SUBMITTED TO THE DEPARTMENT OF MECHANICAL ENGINEERING TECHNIQUES OF POWER

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR

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بسم الله الرحمن الرحيم

﴿ فَتَعَالَى اللَّهُ الْمَلِكُ الْحَقُّ ۗ وَلَا تَعْجَلْ بِالْقُرْآنِ مِن قَبْلِ أَن يُقْضَىٰ إِلَيْكَ وَحْيُهُ ۖ وَقُل رَّبِّ زِدْنِي عِلْمًا ﴾

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Declaration

I hereby declare that the work in this thesis is my own and has not been submitted to other organizations or for acquiring any other degree.

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To the one who honored me by bearing his name, my father, may God have mercy on him. To the light shining from my eyes, my third hand, my first miracle, and the abyss of my comfort to whom I miss her warm applause with joy at my achievement at this moment, and I do not miss her prayer that I reaped in every moment. in my soul, my beloved mother, may God have mercy on her. To my strength and my support after God, and I forget in my unity my sister and my brothers to my shelter and dependence, who was with me, step by step, my beloved husband to the candle of my path and the joy of my life, I am sorry for the default, my children (Rowan and Ali)

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Supervisor Certification

We certify that this thesis entitled “THERMAL DESIGN OF A SINGLE SLOPE SOLAR STILL WITH PREHEATER UNIT BY FRESNEL LENS APPLICATIONS” which is being submitted by (DOAA CHFAT HASAN) was prepared under our supervision at the Department of Mechanical Engineering Techniques of Power, College of Technical Engineering-Najaf, AL-Furat Al-Awsat Technical University, as partial fulfillment of the requirements for the degree of Master of Techniques in Thermal Engineering.

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Abstract

Water is one of the basic requirements for life to exist in any region of the Universe. The availability of water is necessary for the survival of all life on Earth. Many researchers have resorted to finding suitable solutions to get rid of water scarcity, and the simplest of these solutions was the process of solar distillation, especially in areas where sunrise hours abound. Solar stills are the simplest devices used to obtain distilled water. Several researchers have made attempts to improve the performance of single-slope-type solar still. The single basin solar is still the most well-known and tested among different basin types of solar designs. The main disadvantage of single-effect solar stills is their low productivity.

Numerous attempts have been made to improve the thermal performance of single-basin solar stills to solve this issue. One of these approaches is to expand the region that absorbs solar energy, however, this approach needs a huge area. This goal is achieved by using the corrugated absorber plate without having to increase the field size. Increased heat transfer rates from the absorber plate to the basin water result from increased solar radiation absorption area, which raises productivity. Theoretically examined the process of changing the shapes of the absorbent plate of single slope solar still (SSSS) using the COMSOL software version (5.5) program to develop and validate the three-dimensional mathematical model.

The investigation included an optimization process to obtain the best design for corrugated and arced plates. Also, the comparison for flat, corrugated, and arced absorbent plates results is carried out. The study revealed that the maximum water temperature and productivity of SSSS with a flat plate reached 74^{o}Cnd 2.8436 kg/m2 respectively. While

the SSSS with a corrugated absorbent plate has a higher maximum water temperature and productivity which reached 95 ^{o}C and 6.434 kg/m^{2} respectively, when (N=40 a=0.125 and b=0.25) and with arched plates reached 82 ^{o}C and 4.2354 kg/m^{2} respectively when (N=20 a=0.25 and b=0.25). The water level inside the still for all considered cases is remaining constant at all working hours at 1 cm. As for experimental experiences to increase the performance of conventional single slope solar still, the traditional (SSSS) system was integrated with a Fresnel lens and preheated water unit.

The sun's rays were manually tracked during the experiment period and kept the depth of water inside the basin of the still constant at a height of 1 cm during the study. Experiments were conducted at different heights between the surface of the preheated water unit and the base of the solar still. The heights are 24, 30, 34, and 38cm with corresponding productivity of 2.530, 2.650, 2.850, and 2.695 kg/0.25m^{2} respectively. The best results are obtained at the height of 34cm with a maximum water temperature of 96^{o}Cand productivity enhancement of 30.13% compared with classical solar still . The results of numerical and experimental studies for flat plate SSSS are compared and were in good agreement.

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NOMENCLATURE

Symbols	Definition	UNIT
A	Area	m^2
F	Volume force	N
Cp	Heat capacity at constant pressure.	J/kg. K
I	Solar radiation	W/m^2
m	Mass	Kg
P	Pressure	N/m^2
Ph	Hurly productivity	ml/h
Pd	Daily productivity	ml/day
T	Temperature	K
t	Time	S
U	Velocity field	m/s
v	Wind speed	m/s
K	Thermal conductivity	W/m.K
g	Gravity	m/s^2
h	Convection heat transfer coefficient between glass cover and Ambient	$W/m^2.K$
Q_r	Radiation heat transfer	J/s
Q_c	Convection heat transfer	J/s
Q_{cnd}	Condensation heat	J/s
Q_{ev}	Evaporation heat	J/s
Mev	Mass flow rate of water	Kg/s
L_{ev}	Latent heat for evaporation water	KJ/kg
Hr	Right height	cm
Hl	Left height	cm
BL	Basin Length	cm
SSSS	Single slope solar still	
CRSS	Corrugated solar still	
BW	Basin width	cm
Greek symbols		
A	Absorption coefficient	…..
E	Emissivity	…..
R	Reflectivity	…..
ε	Stefan-Boltizmann's constant	$W/m^2 K^4$
M	Dynamic viscosity	m^2/s
Subscripts		
a	Ambient	
b	Basin	
d	Daily	
g	Glass	
w	Water	

CHAPTER ONE

INTRODUCTION

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INTRODUCTION

1.1 Introduction

The availability of water is critical to the survival of life on Earth. Only 0.33 % of the total water available on the planet is fit for practical usage as fresh water [1]. Despite tremendous industrial expansion across the world, the majority of the world's water bodies are contaminated [2]. And, because clean water is a human right, numerous technologies and processes have been developed to create drinkable water [3].

Millions of households throughout the world are still subject to water shortages and lack access to safe and sufficient drinking water. More precisely, the following aspects of the case have been investigated:

a) More than two billion people live in water-stressed areas, and this figure is anticipated to rise.
b) Over one billion people lack access to clean and safe drinking water.
c) Every year, around 3.4 million people die as a result of drinking dirty water.
d) Millions of women and children spend many hours each day walking an average of 6 kilometers to fetch water.

Water distillation is one of the many procedures used in industrial and residential settings to get safe and drinkable water.

Furthermore, population growth, industrialization, and urbanization over the last several decades have resulted in increased demand for fresh water in the future, there is predicted to be a major water shortage. If people drink polluted water, they can contract illnesses including typhoid, polio, and cholera [4 and 5]. Desalination facilities must provide the needed quantity of drinking water for each country's population through 2025, and water shortages are predicted to affect a large number of people.

For developing countries, the availability of high-quality fresh water supplies is critical. Simple technology advancements can increase availability and so help to standardize rural regions more quickly. Rivers, lakes, and underground water reservoirs are examples of fresh water resources. Although water covers about 71% of the planet, 96.5 % of it is found in the oceans, 1.7 % in groundwater, 1.7 % in glaciers and ice caps, and 0.001 % in the air as vapor and clouds. Only 2.5 % of Earth's water is fresh water and 98.8 % of this water is in ice and groundwater [6].

Rivers, lakes contain less than 1% of all fresh water. According to the World Health Organization (WHO), the minimal amount of water necessary to meet basic needs is 20 liters per person per day. Apart from energy, clean water is a big challenge nowadays. More over 70% of the Earth's surface is covered by water. Only 2.5 % of the water on Earth is fresh water, with 97.5 % being salt water. Around 70% of this fresh water is frozen as icebergs in the polar regions, with the remainder in the form of soil moisture or deep aquifers where groundwater is not available for human consumption, as represented in Figure 1-1.

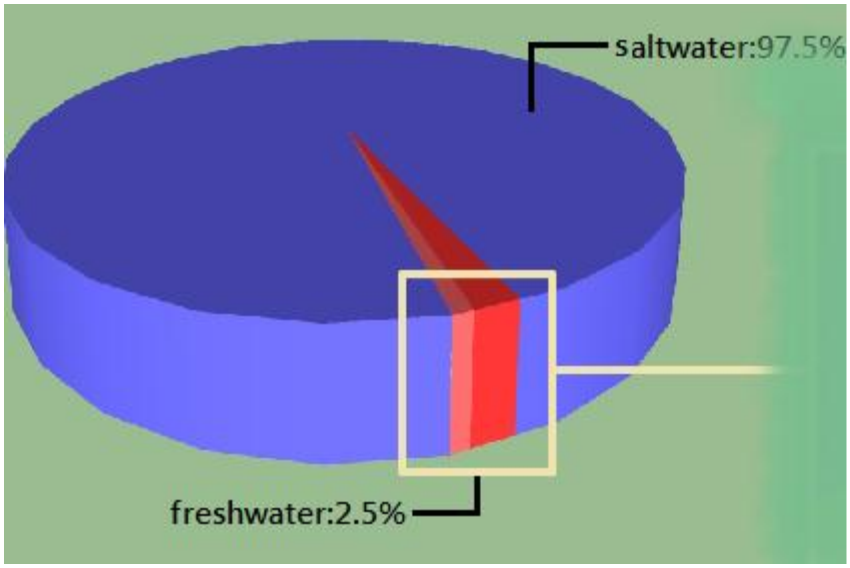


Figure1-1: Percentage Of Fresh And Salty Water On The Earth's Surface [7]

Solar water desalination is important in this regard, and therefore it is used to convert slightly saline and dirty water into distilled water. Solar stills are the simplest devices used to obtain distilled water and are used in almost all locations where solar energy is available. In the process of solar distillation, the water is evaporated, separating the water vapors from the dissolved salts/impurities, which condense as pure, clean water. In remote places, fresh drinking water should be fetched from a distance [8].

1.2 Solar Desalination

Solar distillation is a proven method. The Arab chemist was the first to employ it in 1551. Della Porta (1589), Lavoisier (1862), and Mauchot (1869) are known to have used this approach [9]. The term "Solar Still" is frequently used to describe a solar water distillation system [10]. According to Alpesh Mehta et al (2011), the Solar Still may be used to cleanse sea water and remove salt/mineral components including Na, Ca, As, Fe, and Mn. Bacteria such as E.coli, Cholera, and Botulin us can also be eradicated Solar Still operates on the same concept as the natural water cycle [11]. To extract a part of pure water from a salt water source, each of the water treatment techniques identified in Table 1-1 uses up a lot of energy. The process is fed salt water (feed water), and the outcome is one output stream of clean water and another of high-salt effluent. Kalogeria [12] calculated that producing 1000 m^3 of fresh water per day would take 10,000 ton of oil per year. This is critical because it entails a recurring power usage that few of the world's water-scarce regions can pay in a handful of oil-rich nations, large commercial desalination units employing fossil fuels are used to complement conventional water supplies. Because of this energy need and the high cost of plants, it is choosing solar energy for the desalination process. Other nations in the globe do not have the money or oil resources to allow them to expand in a similar fashion. The sun desalination processes are categorized as illustrated in figure1-2 based on the evaporation and condensation techniques used.

Table 1-1: Different Types Of Water Treatment Methods [13].

Serial no	Name of the type.	Description
1	Reverse osmosis	Saline water is driven through specific membranes under high pressure, allowing water molecules to pass but not dissolved salts.
2	Vapor compression	Here, boiling water vapor is compressed adiabatically, and the vapor is superheated. After cooling to saturation temperature, the superheated vapor is condensed at constant pressure. Mechanical energy is used in this procedure.
3	Distillation	Water purification can be accomplished by a variety of methods, including distillation. This need an energy input, which can be provided by solar radiation. Water is evaporated in this procedure, separating water vapour from dissolved particles, which is then condensed into pure water.
4	Multistage flash distillation	The MSF procedure is made up of a succession of features known as phases. Condensing steam is utilized to pre-heat the seawater supplies at each step. The method approaches optimal total latent heat recovery by fractionating the entire temperature differential between the warm source and saltwater into a large number of phases. This system's operation necessitates the presence of pressure gradients in the plant [14]
5	Multiple-effect distillation	Stills with two or more compartments are known as multiple-effect basin stills. The upper compartment's floor is the bottom compartment's condensing surface. The condensing vapor's heat generates enough energy to evaporate the feed water above it. Due to the reuse of latent heat of condensation, multiple-effect solar desalination systems are more productive than single-effect systems [15].
6	Freezing	In principle, the notion is interesting since freezing requires less thermodynamic energy than evaporation, as water's latent heat of fusion is 6.01 kJ/mole, but the latent heat of vaporization at 100 1C is 40.66 kJ/mole. A normal refrigeration cycle is utilized to chill the product water stream until ice develops in refrigeration freezing. The ice is scraped away and melts [15].

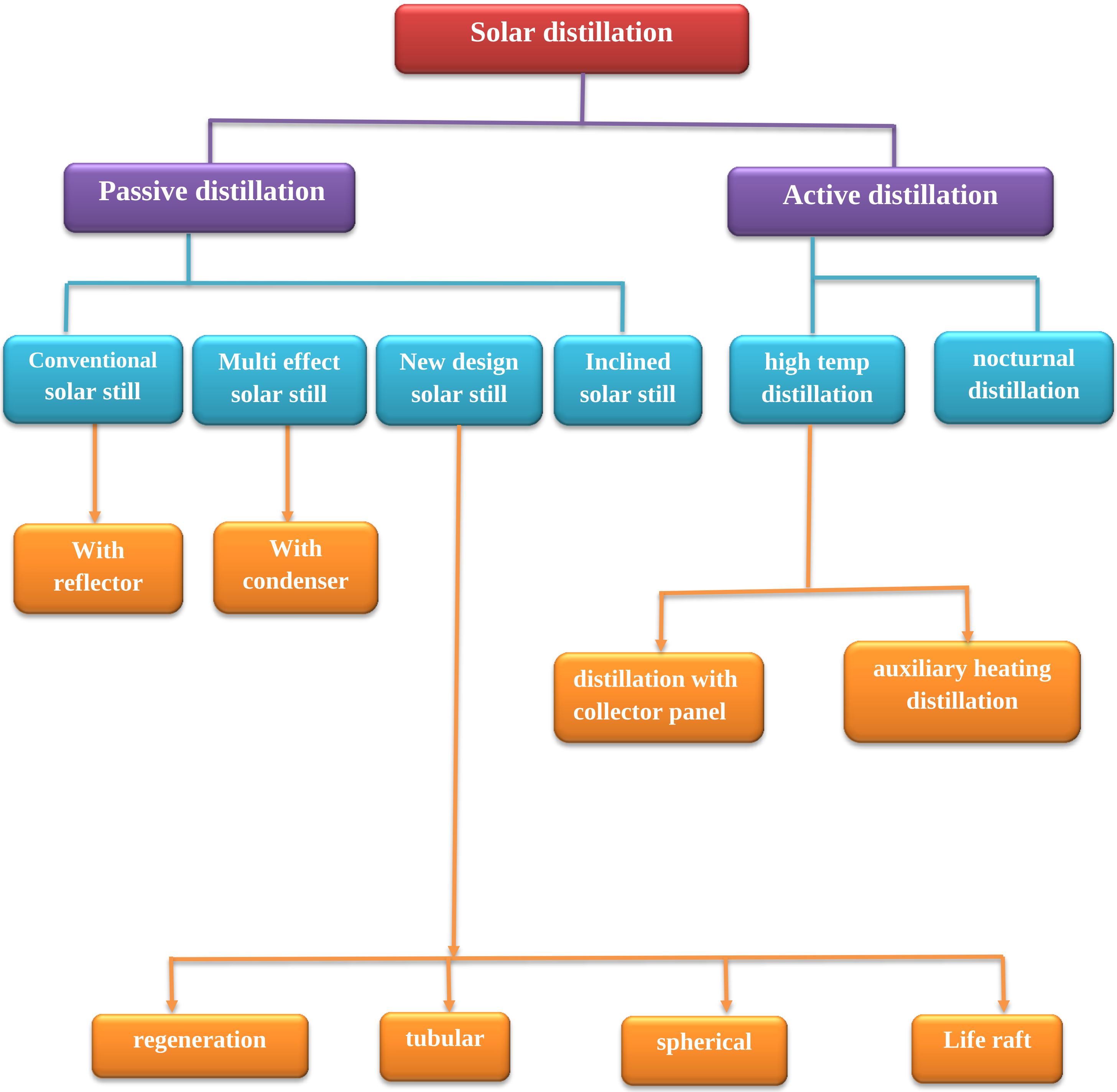


Figure1-2: Solar Distillation Classification [13].

1.3 Solar Thermal Energy Desalination

1.3.1 Solar Powered Humidification-Dehumidification (HDH) Desalination.

The evaporation of brackish water is followed by a condensation process in humidification-dehumidification technology. These two stages of the process were carried out in separate compartments. Figureure1-3 shows a simplified illustration of the HDH system. Between these two chambers, a forced or natural airflow will circulate. In the dehumidification compartment, brackish water passes through a mesh of pipes, then via a heat exchanger to raise water temperature before being dispersed over a packed bed in the humidification compartment. A carrying gas passes through the bed, converting to humid air that is routed to the dehumidification compartment, where freshwater is produced as a result [16]. Because the HDH system produces freshwater mostly through heat exchange and air circulation, it requires an external energy feed source, which is often fossil fuels [17]. Recent studies [18 and 19] investigated the integration of an HDH system with a heat exchanger powered by a renewable energy source. Despite this, the HDH system's main flaw is its low thermal compatibility.

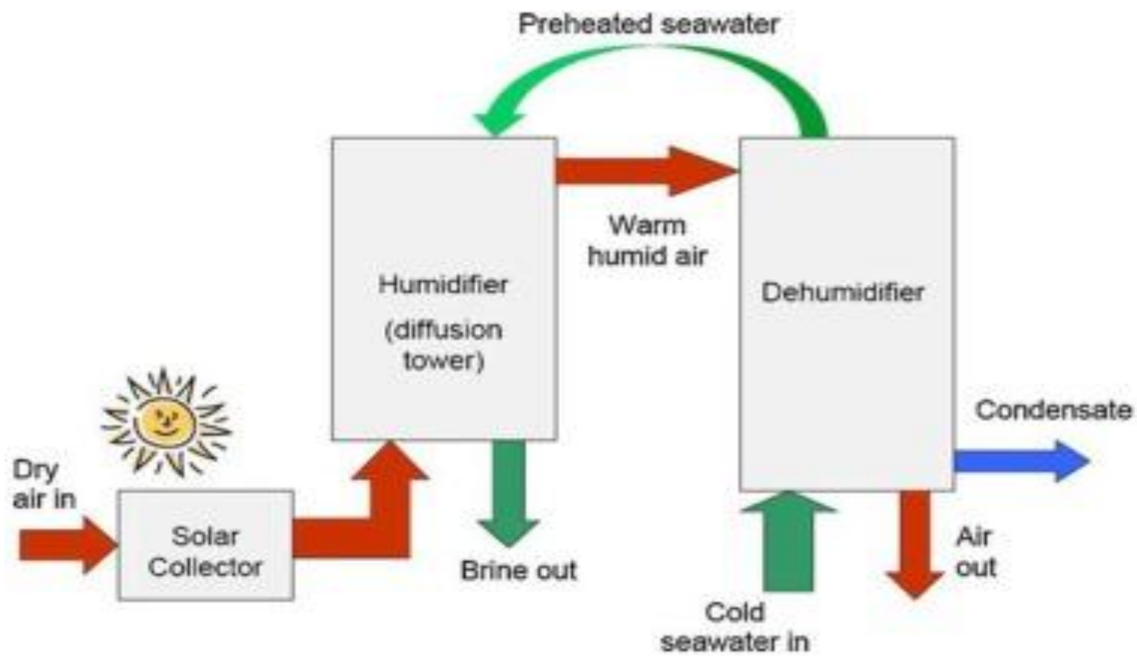


Figure1- 3: A simplified illustration of the HDH system [19].

1.3.2 Solar Membrane Distillation

To separate pure distillate water from warm water, membrane distillation employs hydrophobic membranes. A pressure differential generated by a temperature difference allows water vapor to pass through the membrane. The MD module has a variety of evaporation stages as part of a nearly optimal counter-current flow mechanism, allowing for a high evaporation heat recovery. Only water vapor can flow through the hydrophobic membranes used in the procedure water vapor diffuses from the hot side of the membrane to the cooler side due to the temperature differential between the two sides. The hot side is cooled and the cooler side is heated by this evaporation and condensation process. Energy is saved by using counter-current flows, as in Figure 4 [20 and 21].

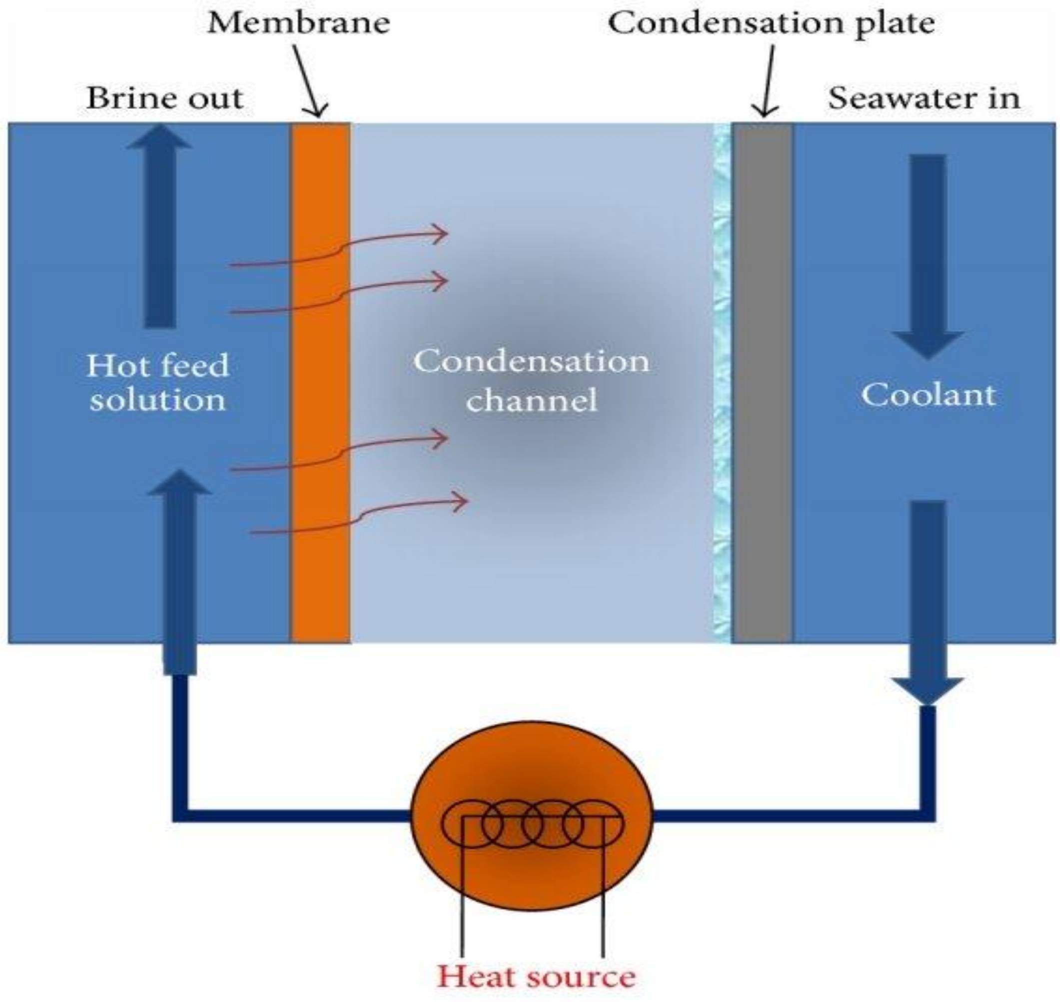


Figure1- 4: Schematic Demonstration Of The Membrane Distillation Process [21].

1.3.3 Solar Stills

Solar desalination is still one of the simplest and oldest methods of water desalination. A solar still is one type of solar desalination and is made up of a basin and a transparent material that allows incoming solar radiation to pass through to the salty water in the basin for heat absorption and evaporation. Solar still absorbs solar energy, evaporates salty water, and condenses fresh water all inside a single container. Solar stills are direct collecting systems by definition. Sun distillation with solar stills is a well-established technique. It is utilized to create fresh water all over the world due to its low maintenance requirements. To increase solar flux absorption, the basin is usually painted dark or black. The sun rays collected by the basin heat the water, raising the water vapor pressure until some of the saline water evaporates, as seen in Figure 5. The water vapor rises and condenses on the cold glass cover, then runs down to the collection reservoir through a directing tube [22].

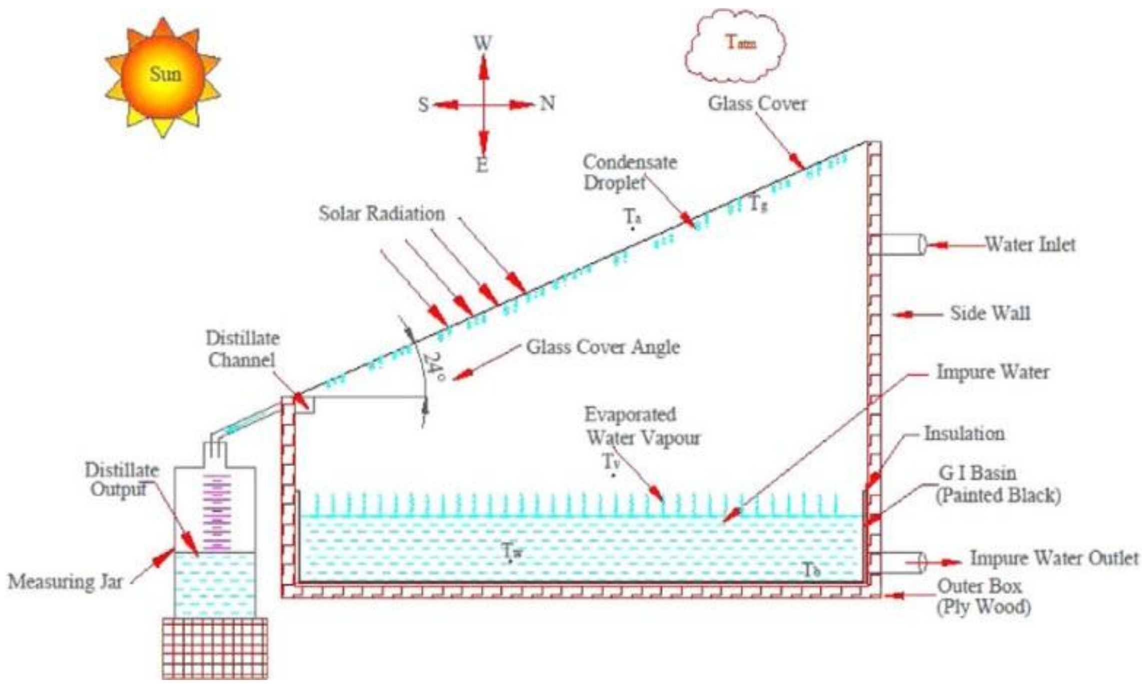


Figure1- 5: Single slop solar still [23].

1.3.3.1 Advantage Of Solar Distillation

The simple installation, small-size method works at a lower cost for providing pure water in houses and small communities, is simple in design, does not require stationary accessories (vanes, motors, etc.), and is an environmental friend because it only uses renewable energy and does not pollute the environment. It is not necessary for the operator to have significant understanding of work, maintenance, or any potential failure. Iraq is one of the few nations in the world that has sunshine for nearly the whole year. Figure1- 6 depicts the sun irradiation in Iraq.

1.3.3.2 Disadvantages Of Solar Distillation

This approach necessitates huge areas of land with abundant sun radiation. It is susceptible to weather conditions. Productivity and efficiency are low.

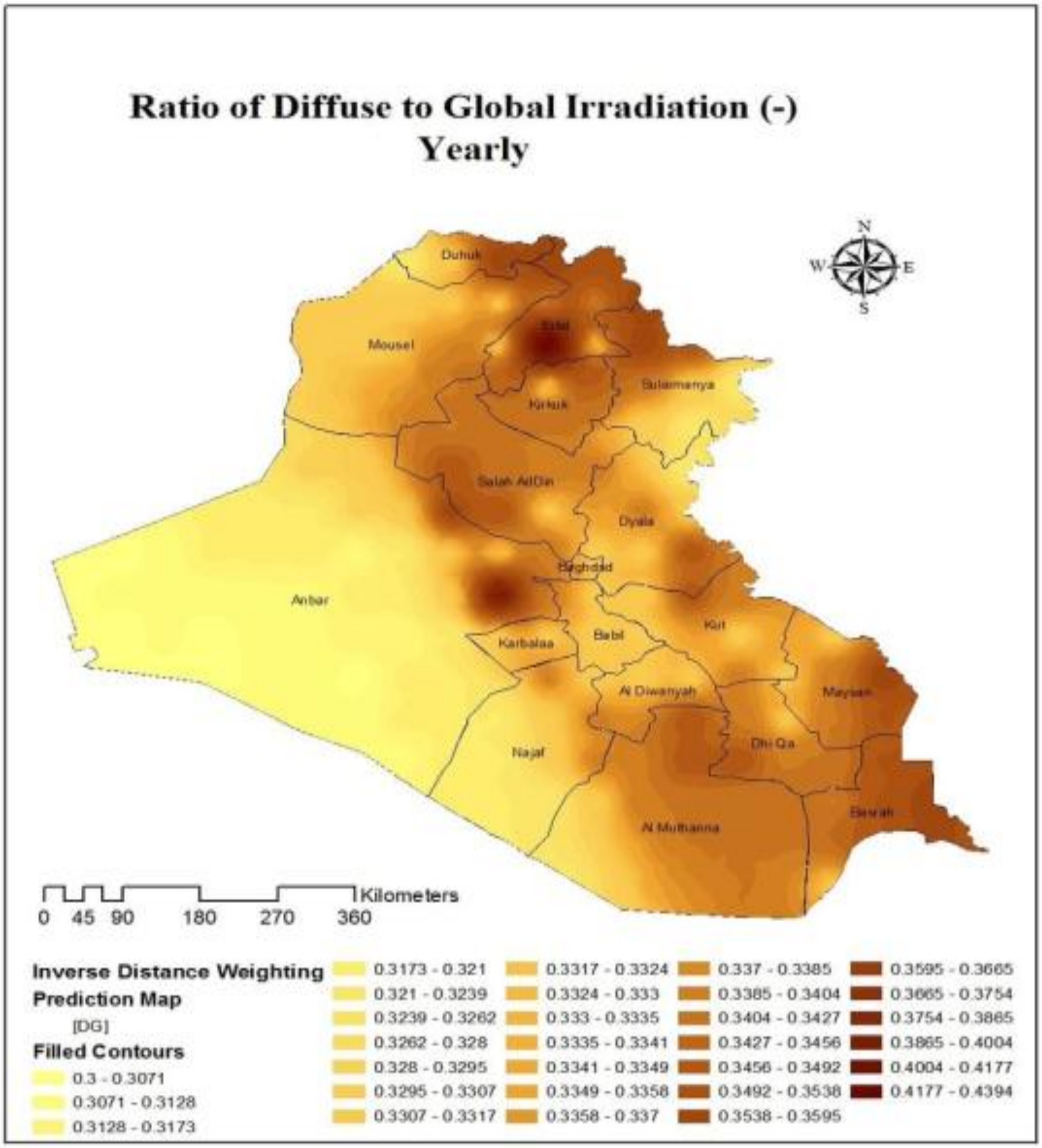


Figure1- 6: View Representation For The Sun Irradiation In Iraq [24].

1.4 Problem statement

Desalination of brine by solar-powered systems is a practical and promising technology for producing potable water in regions that suffer from water scarcity especially. The abundant solar radiation intensity throughout the year and the available brine resources are two favorable conditions for using desalination solar technology to produce fresh water, even for domestic use. The present study aims to improve solar still performance and increase its productivity by Proposing novel manufacturing of two small scale solar-powered desalination systems are manufacturing and operating, the first, with a preheated water unit and Fresnel lens and the second is conventional single slope solar still

1.5 Objective of The Thesis

1. Augment the fresh water producing in addition to solar still productivity, the preheated water unit with aid of Fresnel lens are applied, and hence there are two manners to provide the distilled within the same system.
2. Enhance the solar still productivity itself by the preheating of raw water.
3. Improve the performance of preheated water unit with the use of tracking system.
4. Study the effect of environmental condition on the performance of the system.
5. Developing a 3-D Mathematical Model (Using Comsol Multiphasic v5.5).
6. These studies took place under the climatic conditions of Al-Diwaniyah-Iraq (latitude 31.99° N, longitude 44. 93° E).

1.6 Thesis Outline

This thesis is divided up into six chapters, each of which deals with a different part of the work's scope:

Chapter One: This chapter presented of the background information on solar desalination.

Chapter Two: A thorough evaluation of the existing literature is provided by highlighting and summarizing the published material that is pertinent to the goal of this study.

Chapter Three: This chapter discusses the process of developing the 3-D Model, the validation process, to arc plate and corrugated plate.

Chapter Four: This chapter provided a detailed explanation of the fabricated SSSS, measuring tools, as well as the auxiliary equipment and experimental procedures that took place during the experimental work.

Chapter Five: The finding of the experimental and numerical investigation is discussed in this chapter

Chapter Six: Conclusion, and future recommendations.

Chapter Two

Literature Review

Chapter Two

Literature Review

2. Introduction

Distillation is the process of heating a liquid solution or a liquid-vapor mixture to produce a vapor, then collecting and condensing that vapor. A solar still distills water by evaporating it using the sun's heat, after which it is cooled and collected, purifying it. This method is used in locations where drinking water is scarce to obtain clean water from salty or filthy water by exposing it to sunshine[25].

Among the several ways of water distillation, it has been noticed that distillation in a single slop solar still is the easiest, cheapest, but has the lowest productivity rate. As a result, increasing its productivity will make it a suitable option for home drinking water needs in distant areas. Numerous experimental and numerical research has been conducted on various types of solar stills. A significant amount of effort was put into traditional solar stills in order to acquire the optimal type by examining the influence of environmental, operational, and type characteristics on the performance of the solar still. The current work investigates and determines the influence of some parameter on the solar still's performance.

2.1 Influence of Solar Parameters

Solar still production is influenced by a number of factors. Thus, there are two primary criteria that have a direct impact on the performance of the solar still. The first set of parameters are climate-related, while the second set of parameters are design-related.

2. 1. 1 Climate-related variables

Badran 2007 [26] showed experimental improvement in the production rate of SSSS up to 35% as the wind speed increased from 2.7 m/s to 5 m/s.

Afrand et al. (2010) [27] presented a numerical simulation of sunlight in an Iranian single-basin desalination facility. The still has a 1 m^2 area and a glass cover with a 25° inclination angle to catch additional solar energy. A numerical method was used to estimate the temperatures of the glass cover, water surface, and humid air. The results of July and December were compared. The findings revealed that productivity was higher in July than in December, and that solar still efficiency was maximum around midday, with efficiency and still output values being linked to solar radiation.

Kalifa and Ali (2015) [28] described an indoor experiment to manage and deliver a consistent wind speed to the SSSS glass cover. The fundamental advantage of the indoor procedure is that it eliminates the impact of other elements that determine wind speed. They evaluated wind speeds ranging from 0 to 4.1 m/s. When the wind speed was increased to 1.14 m/s, the result showed a significant 44.7 % increase in production. However, when the wind speed increases, there is a drop in this proportion. In other words, raising the wind speed to (2.06, 2.92, and 4.01) m/s might result in a minor improvement of 9.1 % , 11.6 % , and 5.5 % , respectively, over the 1.14 wind speed.

Hassanain G. Hameed et al. (2017) [29] tested how a wind speed of 0.9 to 4 m/s influenced the findings in Iraq/Najaf. The speed is controlled by an axial fan oriented to the solar still translucent cover's surface. According to the experimental statistics, when the velocity reaches 4 m/s, there is 22.8% increase in the productivity rate this is due to a larger temperature difference between the glass cover and the basin water. They found under the range of speed used, with the external wind there is reducing in the glass cover temperature and increasing in the condensation rate.

Hassanain G. Hameed et al. (2018) [30] experimental investigation to increase the solar still productivity of passing air at different velocities on still cover was given. In addition to air velocity, a wire panel mesh set in a still basin was employed. while employing wire screen mesh with an air velocity of 2.5 m/s enhanced output by up to 36.6 % .

El-Maghlany et al 2020 [31] considered varying the water level in an SSSS starting from 20 cm and down to 0.5 cm. Their theoretical investigation showed a sound agreement with the previous studies where the highest recorded accumulated productivity was 2.523 l/day as the water depth was set to 0.5 cm. Despite that, there is hardly any difference as the water level increased up to 1 cm, where the productivity associated with 1 cm water thickness is found to be 2.508 l/day. Nonetheless, the lowest recorded productivity was 1.517 l/ day as the water depth was set to 20 cm.

2.2 Design parameters:

Velmurugan et al. (2008) [32] conducted a test theoretically and experimentally to augment evaporation of the still basin water, fins were integrated at the basin of the single solar still. Experimental results were compared with ordinary basin type still and still with wicks. The energy balance equations were solved analytically and compared with experimental results .It was found that 29.6% productivity increased, when wick type solar still was used, 15.3% productivity increased when sponges were used and 45.5% increased when fins were used.

Madhlopa and Johnstone 2009 [33] created a model and computed the performance of a standard solar still with a disjoined condenser. The system included three basins, one of which was positioned in the evaporation chamber and the others in the condenser (basins 2, and 3). Over basin 3, there was an opaque glass cover. The upper half of the cover had been shielded from the sun's rays. The system's performance was compared to that of a traditional still under identical conditions. Despite this, the results showed theoretically and experimentally that the models produced 62 % more than the conventional yield as shown in figure (2-2) .

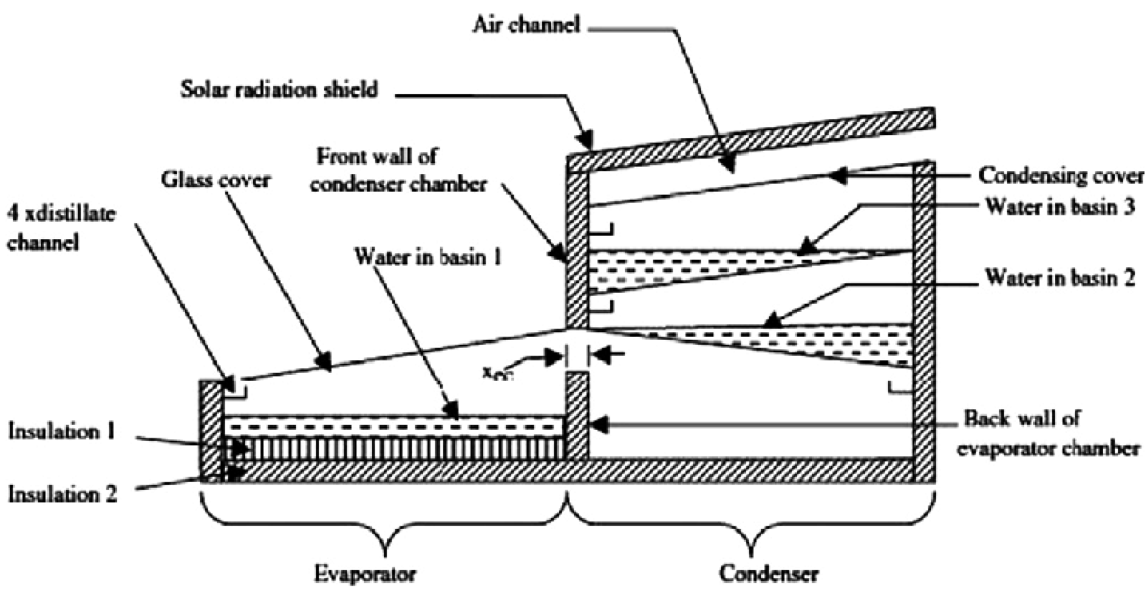


Figure 2-1:Across-Section Of The Present Solar Still Showing The Evaporator And Condenser Unit [33].

M. Boubekri et al. (2011) [34] conducted a test theoretically in which they used external and interior reflectors to augment the total amount of solar energy produced. The investigation took place in Constantine, Algeria, on typical winter, spring, and summer days. The results indicate that reflectors have a significant effect on the increase in regular distillate output throughout the winter months compared to the summer and spring. This increase is approximately 72.8 % in winter. in spring 40,33 % and7,54 % in summer.

Theoretically, according of H. Tanaka (2011) [35], observed that the outside reflector would reflect sunlight onto the basin liner and boosting the distillate effectiveness. The total distillate quantity produced by the inner and outer reflectors is anticipated to be 41%, 25%, and 62% more than that produced by a typical type of basin still existent at the spring equinox, summer, and winter solstices, respectively.

Omara et al.2011 [36] improved the solar still behavior experimental study by increasing the size of the still absorber. To the still production improvement, three stills were created. As indicated in figure (2-1), the first still was a conventional still, the second was a finned type still, and the third was a corrugated solar still and water depth same, the behavior of three stills was tested. When compared to a solar still, the production of the finned still increased by 40% while the output of the corrugated still increased by 21%. The conventional, finned, and corrugated stills had efficiencies of 35 % , 41 % , and 47.5 % , respectively.

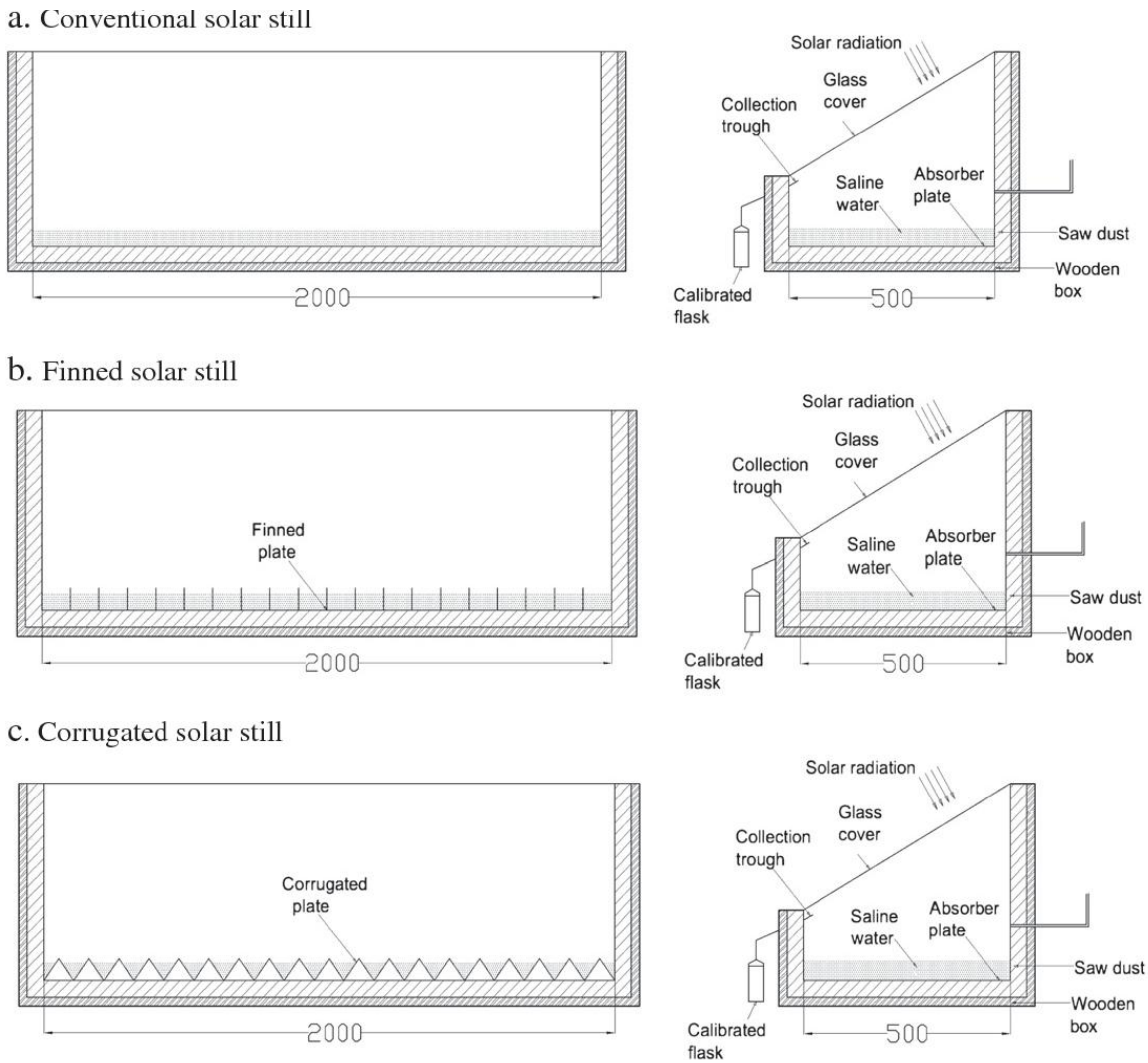


Figure2-1: Cross Section View Of Single Slope Still [36]

The parameters of the corrugated solar still (CrSS) and conventional solar still (CSS) are investigated experimentally by Omara et,al [2015][37] The effect of saline water depth (1, 2, and 3 cm) on CrSS performance was also investigated using the double layer wick material and reflectors together inside the CrSS .The CrSS's overall productivity and efficiency improved, the productivities of CrSS with wick and reflectors are about 145.5 % higher than the CSS, and the daily efficiency of CrSS and CSS is approximately 59 % and 33 % , respectively, during experiments.

Pankaj et al. 2016 [38] discussed theoretically the most recent technological advancements in solar distillation at the Indian Institute of Technology. They emphasized the importance of presenting a comprehensive review of the effects of various operating parameters on the performance of solar distillation units, including solar intensity, wind velocity, ambient temperature, inlet water temperature, glass angle, and water depth. In the passive solar still, they reported 3.5-5 L/m^2

Estahbanati et al. 2016 [39] studied the integration of internal reflectors (IR) with SSSS experimentally and theoretically. The authors proposed a mathematical model that accounts for the possibility of reflecting incident radiation on the walls. Their research revealed increases in production of 22%, 65%, and 34% for the winter, summer, and full year, respectively.

Rajaseenivasan and Srithar 2016[40] conducted an experimental and theoretical study of single basin solar still with square and circular fins in Chennai, India as shown in figure (2-3). They performed many experiments on a solar still, changing the depth of water (1 to 3cm) to test how it influenced distillate. They also compared the experimental and theoretical analyses of the fin's solar still variations. They discovered that the square fin in solar still produces the most distillate when compared to the circular fin.

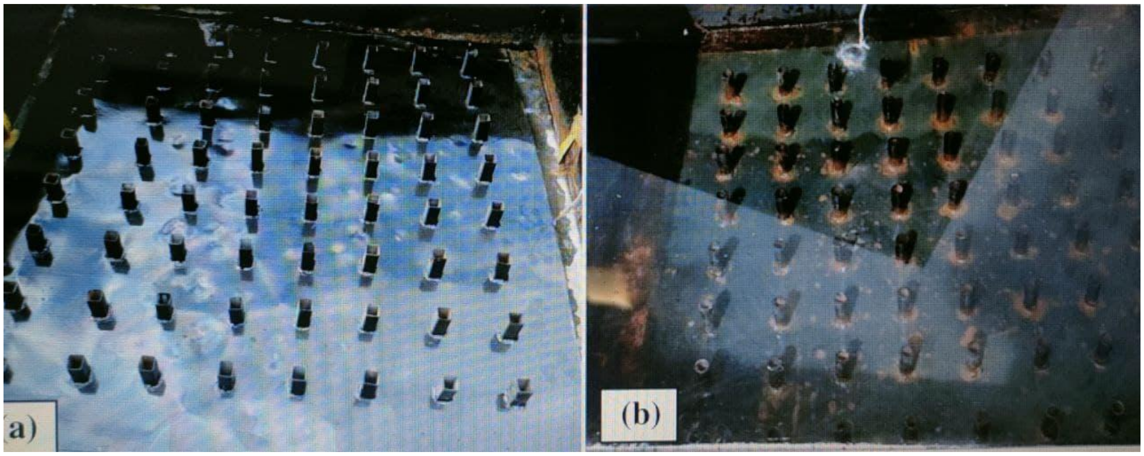


Figure 2-3: Depicts Round And Square Fins Connected To A Single Basin Solar Still.[40]

Shalaby et al.2016 [41] found a 12% improvement in productivity when employing a v-corrugated solar still with a paraffin wax phase change material put underneath the absorber plate.as shown in figure (2-4). The experimental and theoretical analysis reveals that the solar still with the PCM under the corrugated plate obtains the highest thermal performance among the other analyzed configureurations. The daily productivity of the still with the PCM is 12% and 11.7% better than that of the v-corrugated still without the PCM and with the PCM using wick, respectively.

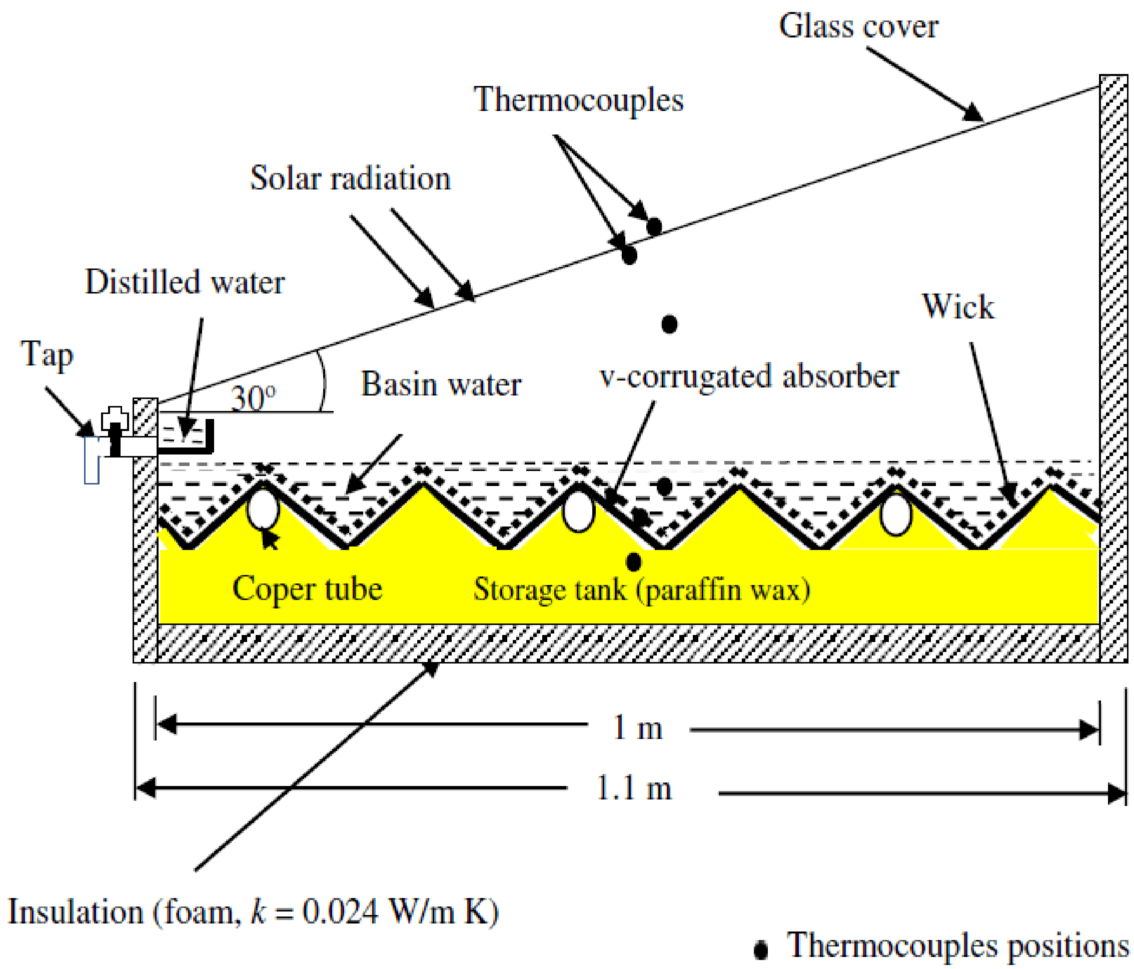


Figure:2-4 Single slope single basin solar still with corrugated absorber plate (VSBSS) with PCM as a heat storage medium. [41]

A.E. Kabeel et al.2017[42] studied the effects of nanomaterial on the solar still experimentally. Cuprous oxides (CuO) were chosen as a material for nanoparticles. To improve the effectiveness of the solar still, nanoparticles were mixed into the black paint on the walls. The weight concentrations of cuprous oxide nanoparticles used in the experiments varied from 10% to 40%. It has been discovered that incorporating nanoparticles into paint enhances heat transfer rate and saline water temperature. The suggested system's solar still productivity outperforms the conventional still. The results showed that using CuO nanoparticles increased the distillate by 16% and 25% when compared to the standard solar still (CSS) at weight fraction concentrations of 10% and 40%, respectively. The distillation system's payback time for the upgraded still utilizing CuO nanoparticles is around 96 days at a weight fraction of 10%, which is significant when compared to 89 days for CSS

Lei Mu et al. (2019) [43] used a Fresnel lens led to focus the sun radiation of a specific region on a fixed point in order to optimize the heat transfer coefficient, as well as a fan to push air on the front glass of the still. The experimental findings revealed an improvement in productivity and efficiency of 467 % and 87 % , respectively.

Adhil et.al 2020 [6] used Fresnel lens, sun tracker, and PCM. Through his study. He concluded that the total experimental output in the case of Fresnel lenses is nearly 6.38 times more than the output in the case of ordinary solar distillation. The total yield of material with a phase change is slightly higher than that of material without a phase change.

Bataineh et al. 2020 [44] examined adding internal reflectors to the SSSS. The findings of their theoretical and experimental tests demonstrated the capacity of integrating internal reflectors to increase average daily productivity and efficiency in this arrangement. The observed productivity was 4.0965 l/ m^2.day, with a stated efficiency of 29.1% higher than traditional SSSS.

Parimal et al. 2020 [1] conduct an experimental and a theoretical investigation in which they use a Fresnel lens to increase the overall efficiency of a typical Single Slope Solar Still (SSSS) with a single basin. Once adjusted in the morning, the Fresnel lens-fitted frame stayed in the same position throughout the day without tracking. The depth of the water in the basin was maintained constant throughout the test at 0.02 m. The distillate yield of a single basin SSSS fitted with a Fresnel lens is 3 to 3.5 times that of a standard SSSS. The overall efficiency of the system has also been increased by more than 32.19 precent more than the conventional.

Vikrant and Sandip2020 [45] attempt to improve solar still energy efficiency and production by modifying the shape of the absorber plate modified solar has been tested using a stepped-corrugated absorber plate During the testing theoretical and experimental, it was observed that the thermal performance of modified solar still is greater to that of conventional solar still. When compared to typical solar stills, the average basin saline water temperature and temperature difference between saline water and condenser glass cover for stepped-corrugated solar stills are 19.67 and 105.75 precent higher, respectively. The average energy efficiency, exergy efficiency, and productivity of stepped-corrugated solar are still 259.61, 418.61, and 147.93 precent greater, respectively.

Hitesh Pancha et al. (2021) [46] conducted experimental study on the usage of nanoparticles to improve solar still (SS) production. Manganese Oxide (MNO2) is chosen as a nanoparticle material and employed in SS

To increase production, the nanomaterial is mixed with the black chrome paint used on the SS inner surface. MNO_2 weight concentrations ranging from 20% to 50% were. This been shown to improve heat transmission and water temperature. The introduction of the MNO_2 nanoparticle has increased the production of the SS by 19.5 precent. It when compared to SSSS alone.

2.3 Scope of the present work

From a summary of the literature, it can be summarized as follows: -

1 - According to the literature review, the Fresnel lens, corrugated absorber plate, and square and circular fins seem the type of the most proven techniques for improving thermal performance which tense to water productivity –nonetheless, further experimental and theoretical (numerical, analytical) studies are needed to fully comprehend this essential enhancement technique.

2 - Adding pins like fins on the absorber plate or making it corrugated and adding materials increasing water productivity.

3 - There is a shortage of experimental data and designable correlation concerning the Fresnel lens method. however, investigating the effect of adding fins on the absorber plate or adding a Fresnel lens is critical .in addition, studying the temperature of the water inside the basin due to the Fresnel lens adding and optimizing the height of preheated water unit surface is essential for the heat exchanger working with this enhancement techniques.

As clearly demonstrated by the survey of the literature, although a relatively good number of studies have been carried out regards the achievement of the Fresnel lens, pirs -like fins to enhance thermal performance and increase water productivity, there is no attention focused on the present study aims to fill this gap by investigating the effect of Fresnel lens and corrugated absorber plate on water productivity.

Table 2-1 Summary of the literature review

NO	Author	Investigation Scope	Type of Study	Finding
1.	Badran 2007[26]	Wind speed	Experimental	The production rate improved by 35% as the wind speed increased from 2.7 m/s to 5 m/s while an increase of 53% was noticed for the temperature increase from 28 to 32°C . the duration of 8am -5 pm
2.	Afrand et al. (2010) [27]	Glass cover Water surface Humid air	Theoretical	The findings revealed that productivity was higher in July than in December, amounting to the productivity of 4.81l/m2 in July and 3.67 l/m2 in December. efficiency was maximum around midday, with efficiency and still output values being linked to solar radiation. the duration of 6 am -5 pm
3.	Kalifa and Ali 2015 [28]	Wind speed	Experimental	An appreciable increase of 44.7% in productivity during the test when a wind speed of 1.14 m/s is applied. Increasing the wind speed further to 2.06, 2.92, and 4.01 m/s will cause further, but modest, increases of 9.1% and 11.6%, and 5.5% respectively from the 1.14 m/s wind level the duration of 8:30 am to 1:30 pm
4.	Hassanain G. Hameed et al 2017 [29]	Wind speed	Experimental	The production rate improved by 22.8% when the air velocity increased from 0.9 to 4 m/s. the duration of 8am to 9pm
5.	Hassanain G. Hameed et al 2018 [30]	Wind speed	Experimental	The production rate improved by 36.6% the duration of 8am to 5pm

6.	El-Maghlany et al 2020 [31]	Water depth	Theoretical	The productivity in 1cm 2.508 l/day. the duration of 6 am -5 pm
7.	Velmurugan et al. (2008) [32]	Fins, wicks and sponge	Theoretically and Experimentally	The production rate improved by 45.5%,29.6% and 15.3% Fins, wicks and sponge respectively. duration of work is 9 am - 5pm
8.	Madhlopa and Johnstone 2009 [33]	Three basins	Theoretically and Experimentally	The production rate improved by 62%. the duration of work is 24h
9.	M. Boubekri et al. (2011) [34]	Reflectors	Theoretical	The production rate improved by 72.8 % in winter. in spring 40,33 % and7,54 % in summer. the duration of work is 7am-5pm
10.	H. Tanaka (2011) [35],	Reflector	Theoretical	The production rate improved by 41%, 25%, and 62% on the spring equinox and summer and winter solstice days. the duration of work is 8 am-4 pm
11.	Omara et al.2011 [36]	Corrugated plate, fin	Experimental	The production rate improved by 47.5% for corrugated plates and 41% for fin. the duration of work is 24h
12.	Omara et,al [2015][37]	Water depth	Experimental	The production rate improved by 145.5% the duration of work is 9 am -5 pm
13.	Pankaj et al. 2017 [38]	Solar intensity wind velocity ambient temp	Theoretical	The productivity is 3.5-5 l/ m^2 .the period of 7 am to 9pm
14.	Estahbanati et al. 2016 [39]	Reflector	Theoretically and Experimentally	The production rate improved by at winter, summer and the entire year by 65%, 22% and 34%, respectively.. the period of 7 am to 7pm
15.	Rajaseenivasan	Square and	Theoretically	the square fin in solar still

	and Srithar 2016[40]	circular fins	and Experimentally	produces the most distillate when compared to the circular fin. reached the productivity of 0.6 kg/m^2/h for a square fin and 0.46 kg/m^2/h for a circular fin from 9 am- 6 pm
16.	Shalaby et al.2016 [41]	v-corrugated and paraffin wax	Theoretically and Experimentally	The production rate improved by 12% and 11.7%when still with the PCM better than those for the v-corrugated still without the PCM and with the PCM using a wick, respectively was duration of work is 8 am - 10 pm
17.	A.E. Kabeel et al.2017[42]	Nanomaterial (CuO)	Experimental	The production rate improved by 25% the duration of work is 9 am -8 pm
18.	Lei Mu et al. (2019) (43)	Fresnel lens	Experimental	The production enhancement rate improved by 467% to reach productivity with FRL 9.22 L/m2 /day while without FRL achieving an of only 1.625 L/m2 /day. the duration of work is 9 am -10 pm
19.	Adhil et.al 2020 [6]	Fresnel lens ,sun tracker and PCM	Experimental	The production rate improved by 6.38 %higher than the productivity achieved by ordinary solar still. the period of 9 am to 4 pm
20.	Bataineh et al. 2020[44]	Reflectors	Theoretically and Experimentally	The observed productivity was 4.0965 l/ m^2.day, with a stated efficiency of 29.1% higher than traditional SSSS. Was duration of work is 8 am - 7 pm
21.	Parimal et al. 2020 [1]	Fresnel lens	Theoretically and Experimentally	The production rate improved by 32.19% over the conventional. was the duration of work 8 am - 4

				pm
22.	Vikrant and Sandip2020 [45]	Corrugated plate	Theoretically and Experimentally	The productivity of stepped-corrugated and conventional solar still is 3.38 and 1.36 kg/m2/day, respectively . the duration of work 8 h.
23.	Hitesh Pancha et al.(2021)[46]	Nanomaterial (MNO2)	Experimental	The production rate improved by 19.5% the duration of work is 7 am -7 pm
24.	Present Work 2022	Fresnel lens with Preheated water unit	Theoretically and Experimentally	Productivity of 2.850 $kg/0.25m^2$with enhancement of 30.13$^o/_o$. the duration of work7am -5 pm.

CHAPTER THREE

NUMERICAL MODELING

CHAPTER THREE

NUMERICAL MODELING

3.1 Introduction

Computational Fluid Dynamics (CFD) is an important field of fluid mechanic researches. CFD analyzes fluid issues qualitatively by using a variety of numerical techniques. Previously, CFD approaches were not widely used because of the high computing power needs, which were difficult to use [47]. At the moment, since various technical improvements have been made in terms of boosting the computing capability of CFD tools and devices, the use of CFD is becoming more popular by the day. CFD has a broad range of application regimes, including heat and mass transfer, aerodynamics, and so on. The use of CFD software has the potential to minimize experimental efforts, manufacturing costs, and save time [48].

CFD may be used to assess a particular issue and estimate the results of an experiment before it is carried out. As a result, CFD is a significant tool for the research and development business since it is efficient, time and effort-saving. For researchers and scientists, there is now a large choice of CFD software programs available, including ANSYS, MATLAB, Solid Works, COMSOL MULTIPHYSICS, and others. COMSOL MULTIPHYSICS is one of the most powerful computational software programs [49, 50].

3.2 Comsol Multiphysics

COMSOL Multiphysics is a strong piece of componential software that may be used to perform optimization techniques. Where various designs may well be modeled and compared to determine the ideal configureuration without the need for experimental effort. COMSOL

Multiphysics is a computational approach based on governing partial differential equations. These equations include momentum, mass, and energy conservations in the context of this study, where a fluid-thermal-based model is studied [51]. Geometry may be split into numerous nodes using the COMSOL technique, and these equations will be solved for each node for a preset duration. Nonetheless, it is critical to include boundary conditions that aid those equations in defining the physics involved in the examined instance. The answer will provide specific information about the model under consideration, such as the temperature gradient, pressure gradient, and flow parameters. To do the aforementioned CFD analysis on any given case study, follow the flow chart in Figure 3-1.

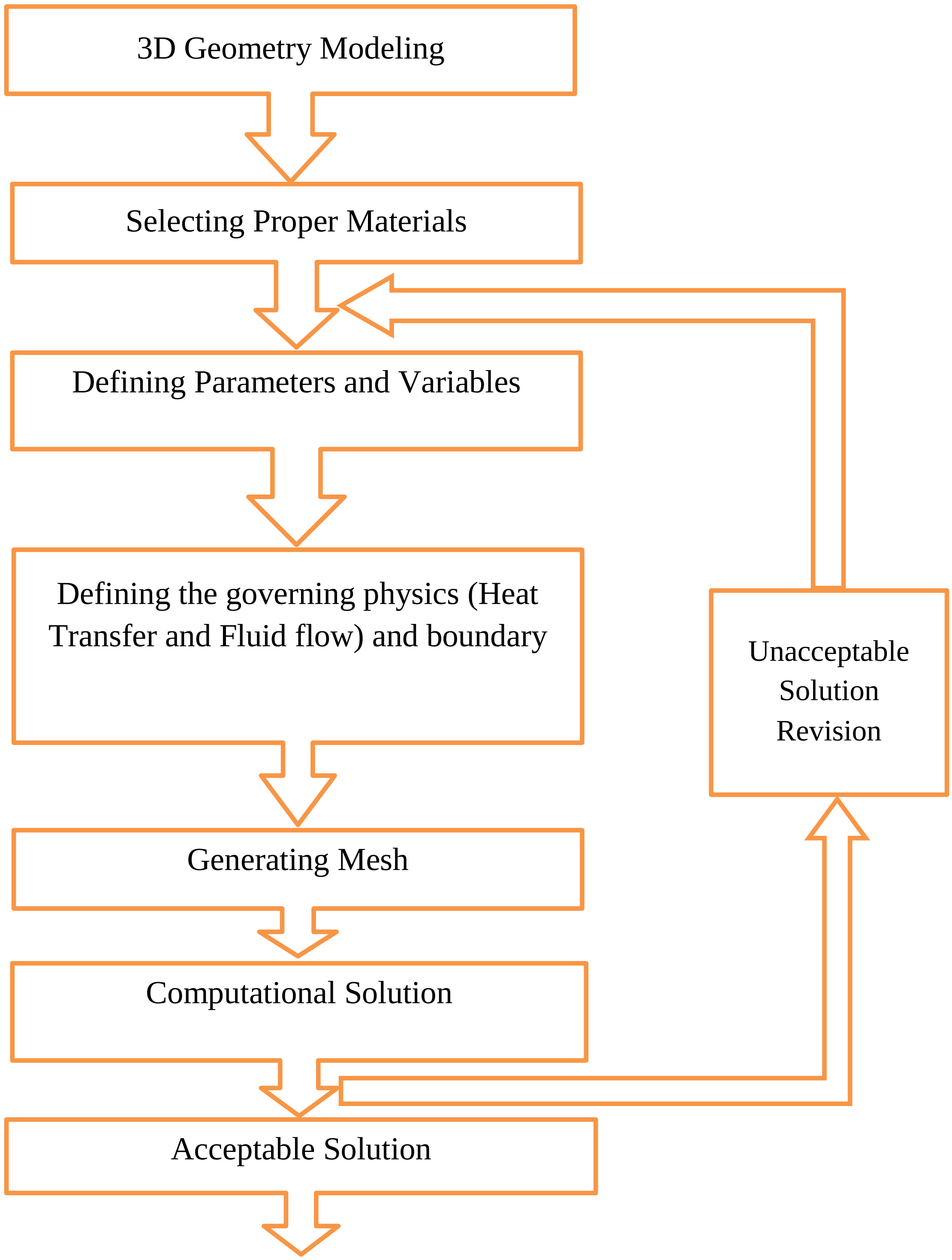


Figure3-1. Representation Of General Computational Analysis Procedure For COMSOL Multiphysics.

3.3 Problem Statement

According to the literature study, most research has concentrated on experimentally improving SSSS performance, whereas CFD modeling and analysis have gotten less attention. CFD gives a complete comparison of SSSS productivity characteristics and boundary conditions. Optimizing SSSS may help increase its output rate. Comsol Multiphysics can investigate solar still condensation and evaporation rates, including conduction and radiation. The data may be used to enhance the design with an optimum configureuration to increase SSSS yield. In this study, a 3-D SSSS model was created using Comsol Multiphysics. This chapter discusses the processes required in building this model.

3.4 Geometrical Modeling of Single Slope Solar Still

To carry out the CFD study, a mathematical model of a system must be created. The Comsol Multiphysics 5.5 software program was used to build the geometrical model of SSSS based on the dimensions presented in this research. The SSSS is made out of a Polystyrene rectangular box with a 32.1° slanted angle on top and a translucent 4 mm glass. The inclination angle was determined by the latitude of Al-Diwaniyah City (31.99° N and 44.93° E), where the experimental work will be carried out. Figureure 3-2 is a schematic diagram of a single-slope solar still.

The Polystyrene box has a basin size of 41cm x ٦2 cm and two heights due to the inclined angle; the right height (H_r) is 36 cm and the left height (H_l) is 9 cm. Furthermore, a rectangular galvanized iron sheet with the same interior dimensions as the box in which it will be installed serves as an absorber layer with a thickness of 2 mm. At the same time, this sheet is sprayed with black thermal paint to minimize reflectivity and increase absorptivity. At all times, the water level in the basin was regulated at 1 cm. There is no need to insulate the Polystyrene box's sidewalls and bottom since it is an insulating material in and of itself, with thermal conductivity of 0.030 W/m.k [52]. The SSSS sloped face faces south.

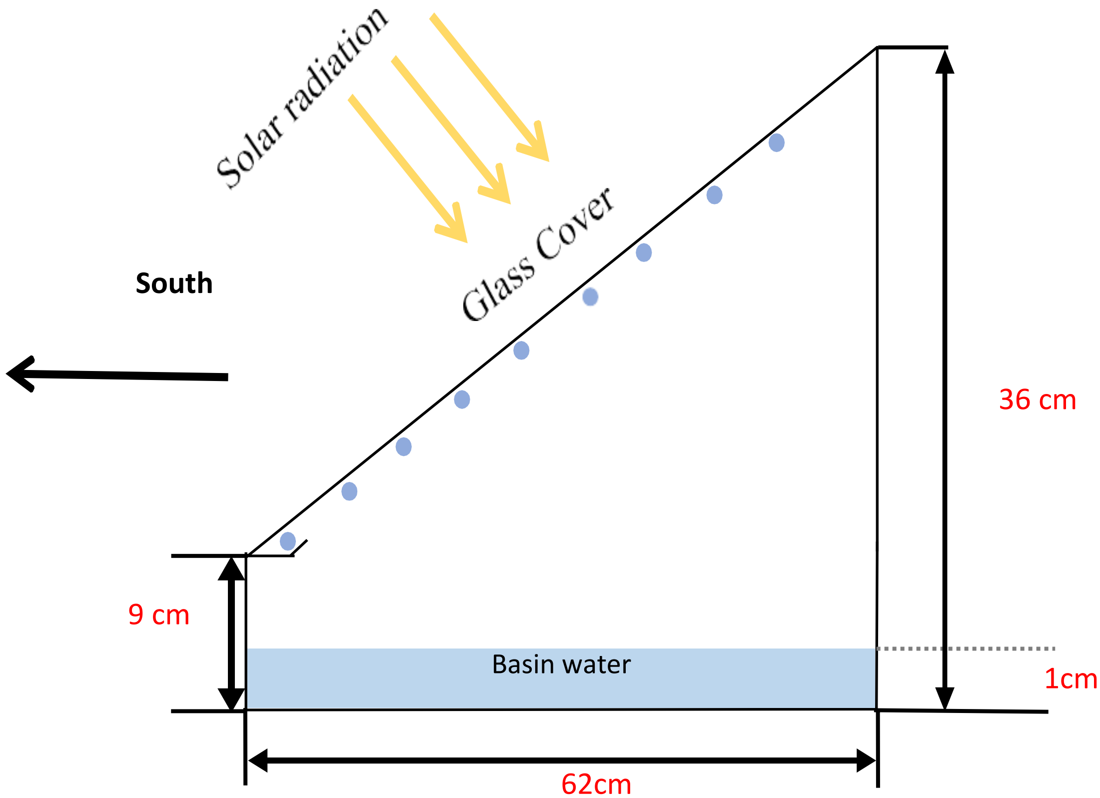


Figure 3-2. A Dimensional Representation of the Proposed SSSS

Comsol Multiphysics includes a collection of design instructions that assist the user in creating a variety of 2D or 3D models. SSSS model that was developed. These instructions were used to generate a 3D model of SSSS based on the dimensions provided above. Figureure 3-2 shows the model of SSSS.

3.5 Meshing Model

A CFD software's computational process necessitates the establishment of concentration points (nodes) to investigate the included physical phenomena. The Comsol meshing tool separates the geometry to be examined into nodes, allowing governing equations to be solved for each node. The amount and distribution of created mesh nodes have a major impact on simulation outcomes. Simultaneously, the number of nodes should be sufficient to represent the physical behaviors of SSSS during the simulation. The time necessary to complete the SSSS analysis is directly affected by the number of nodes. As a result, it is critical to determine the appropriate number of nodes to model a certain case study while reducing simulation time to a minimum. In general, mesh convergence research will be an effective method for determining the optimal number of nodes for a given issue. Figure 3-3 depicts the distribution of nodes on all SSSS surfaces graphically. The mesh forms used are tetrahedral, which offered a succinct distribution at narrow edges. A high-grade mesh density and distribution are critical for providing exact analytical findings. This may be accomplished by increasing the number of dispersed nodes and comparing some of the analysis's dependent characteristics, such as water temperature, glass temperature, productivity, and so on. Any simulation, however, cannot be carried out without certain assumptions and the definition of specific parameters and time-dependent variables such as solar radiation, wind velocity, and ambient temperature. These factors will be presented in the next sections

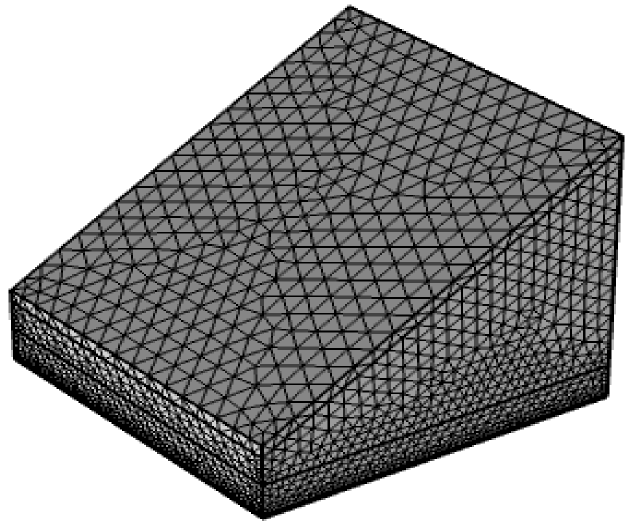


Figure3-3. Graphical representation of nodes distribution on all domains of SSSS.

3.6 Investigation of Mesh Convergence

Generally, once these critical parameters have been determined, numerical simulation and hence convergence analysis may be performed. Figure 3-٤ and 3-٥ show that various numbers of nodes, ranging from 2715 to (130211), were considered. Low mesh densities of less than (2715) nodes yielded stepped results, whilst greater densities of more than 130211 nodes yielded converged results.

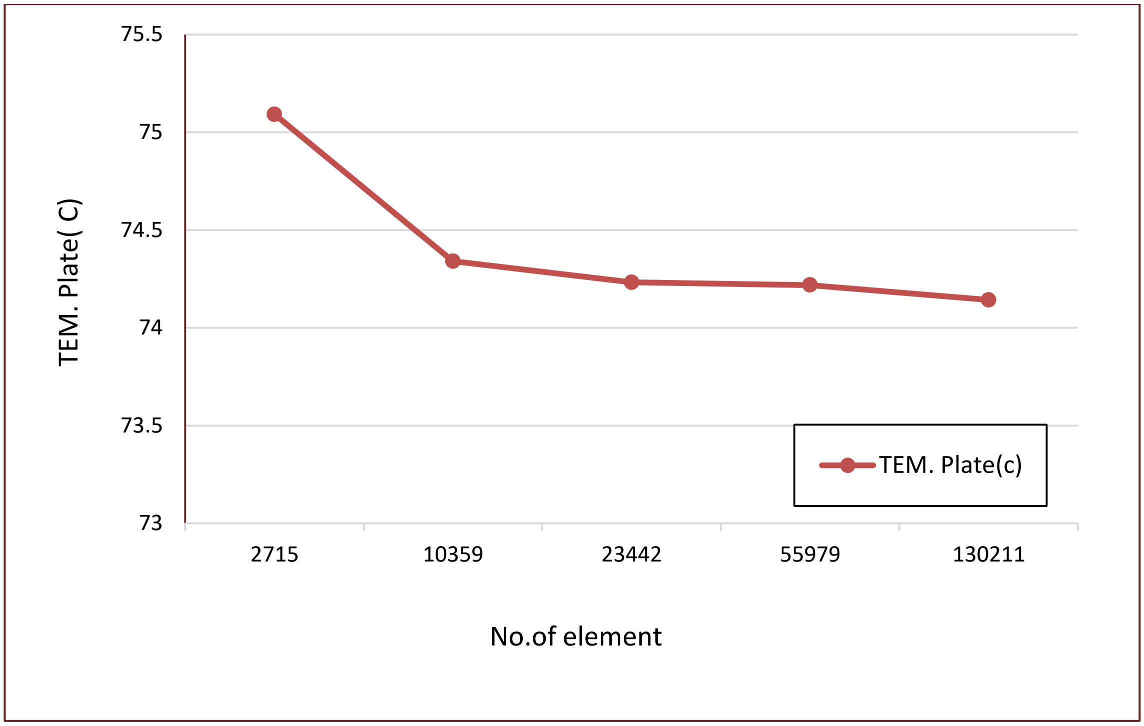


Figure 3-4. Mesh Convergence Study Based On The Resultant Temperature Plate.

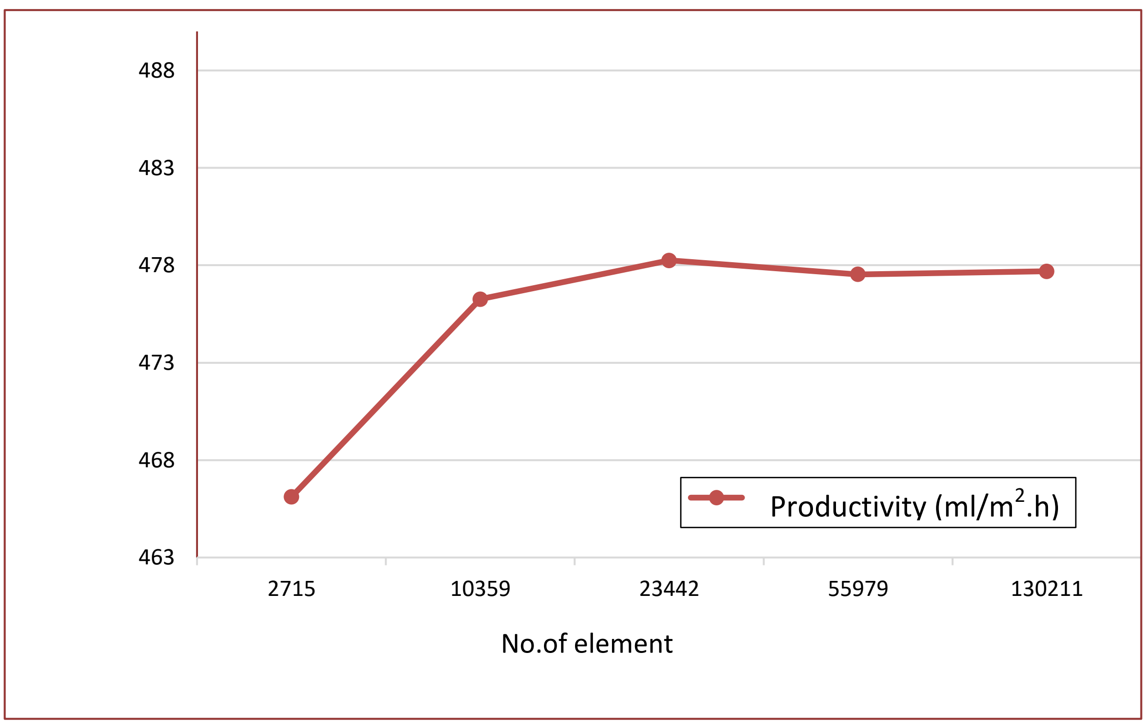


Figure 3-5. Mesh Convergence Study According To The Estimated Daily Productivity.

3.7Assumptions of Simulation

The following assumptions have been made to assist the Comsol analysis of single slope solar in this study.

1. The generated model is a three-dimensional SSSS.
2. The flow is considered laminar inside the still enclosure.
3. There is no water or vapor leakage in the system.
4. The air velocity is insignificant within the still cavity.
5. The rates of evaporation and condensation are the same.
6. The water level in the basin remains constant.

3.8 Boundary and Initial Conditions

Because boundary and initial conditions are required for any numerical simulation, partial differential equations would be solvable. Table 3-1 shows the boundary and beginning circumstances for the current case study.

Table 3-1. Boundary and initial conditions

Zone name	Condition	Thickness
Front wall	Conductive heat flux ($U=K_{ins}/t_{ins}$)	5 cm
Back wall	Conductive heat flux ($U=K_{ins}/t_{ins}$)	5 cm
Sidewall (Right)	Conductive heat flux ($U=K_{ins}/t_{ins}$)	5 cm
Sidewall (left)	Conductive heat flux ($U=K_{ins}/t_{ins}$)	5 cm
Bottom wall	Conductive heat flux ($U=K_{ins}/t_{ins}$)	5 cm
Glass cover	convective heat flux Radiative heat flux	4 mm
Initial Temperature		$T_{amb.}$ at the time (t=0)
Initial Velocity		V=0 m/s

3.9 Numerical Analysis of Single Slope Solar Still

As previously stated, it is essential to establish the governing and balance equations of the model. Figure 3-6 depicts the energy flow via the different domains of SSSS. The quantity of incident radiation on the glass cover does not totally reach the basin water.

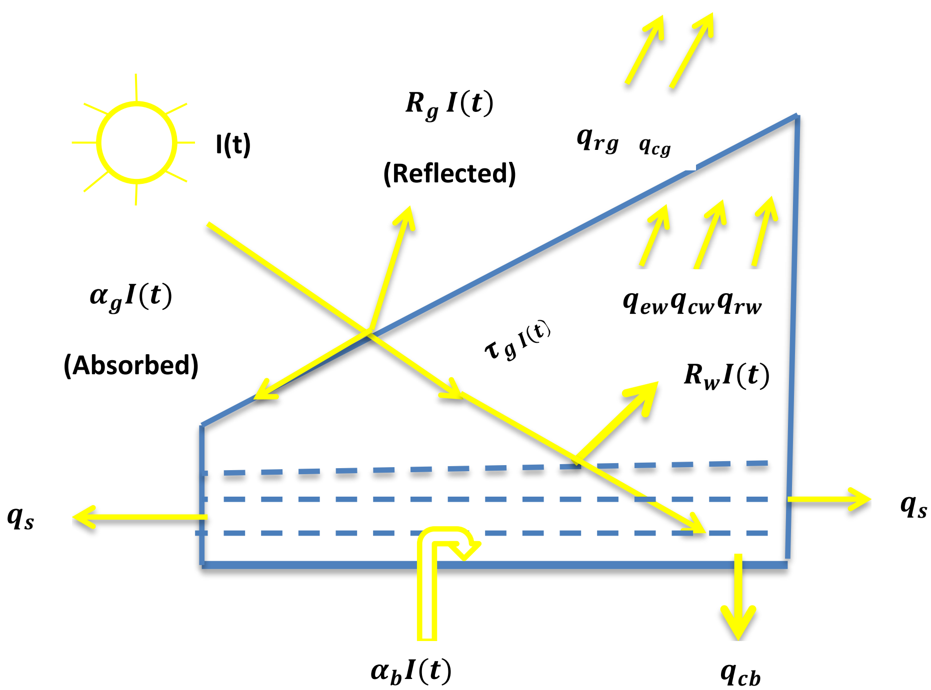


Figure 3-6 Energy distribution of the Single Slope Solar Still

A portion of this radiation is absorbed by the 4 mm glass, another portion is reflected in the atmosphere, and the remainder passes through the glass cover and into the basin water. The material coefficients of absorption (α), reflection (R), and transmittance (τ) are used to calculate the quantities of these fractions. When radiation strikes a surface, three processes occur the glass surface, the water surface, and the bottom plate surface. Nonetheless, Table 3-2 shows the geometrical and boundary characteristics necessary to undertake the numerical study.

Table 3-2 The Required Parameters For Numerical Investigation

Parameter	Value	Parameter	Value[53]
Right height (Hr)	36 cm	α_G	0.05
Left height (Hl)	9 cm	A_b	0.9
Basin Length	٦2cm	A_w	0.05
Basin width	41 cm	ε_G	0.88
Glass thickness	4 mm	ε_w	0.96
Lower plate thickness	2 mm	R_G	0.05
Water level	1 cm	R_w	0.05
Insulation thickness	5 cm	R_b	0
Inclined angle (Based on Al-diwanyah Latitude)	31.99˚	σ	$5.669*10^{-8}$
		Lev	2454 [kJ/kg]
Basin area	0.٢٥ m^2	ρ_{water}	1000 [kg/m^3]

Based on the assumptions used and heat transport processes related with incident radiation on the SSSS. Daily productivity may be expected. Because it combines fluid dynamics and heat transport, the created 3D model is a Multiphysics model. The energy equation is used to estimate temperatures, whereas the Navier-Stokes equation is used to solve the velocity field and pressures. However, in order for the simulation to run effectively, several parameters must be defined in the software tool. These parameters include solar radiation, ambient temperature, and wind speed. Thus, the general governing equations relevant to the case study of the current inquiry are as follows [51, 54]:

The Continuity Equation (The mass conservation equation): -

$$\frac{\partial \rho}{\partial t} + \nabla . (\rho u) = 0 \qquad (3-1)$$

The Navier-Stokes Equation (The conservation of momentum Equation): -

$$\rho \left(\frac{\partial u}{\partial t} + u . \nabla u\right) = -\nabla P + \nabla . (\mu(\nabla u + (\nabla u)^T)) + F + \rho g \qquad (3-2)$$

Energy Conservation Equation:-

$$\rho CP\frac{\partial T}{\partial t}+\rho C_P u.\nabla T = \nabla.(k\nabla T) + Q \qquad (3-3)$$

Concentration Equation:-

$$\frac{\partial c}{\partial t}+\nabla cu = D_{ab}(\nabla^2 c) \qquad (3-4)$$

D_{ab}: Mass diffusivity of water vapor.

C: Concentration of water vapor.

The model various regions governing equations can be summarized as follows [55,56]:

3.9.1 Glass Cover

The energy equation governs the situation of the glass cover, which is exposed to solar radiation and hence induces heat convection. As a result, the numerical simulation makes use of the following heat and energy terms:

$$m_g\, c_p\left(\frac{dT_g}{dt}\right) = Q° - Qr,_{g\_a} - Qc,_{g\_a} + Q_{ev} + Qc,_{w\_g} + Qr,_{w\_g} \qquad (3-5)$$

Main heat source (Solar radiation):-

$$Q° = A_G \dot{\alpha}_g\ I \qquad (3-6)$$

Where

$$\acute{\alpha}_g = (1-R_G)\,\alpha_G \qquad (3-7)$$

The heat radiation from glass to ambient.

$$Q_{r,g_a} = \varepsilon_G \sigma\,(T^4{}_{amb} - T^4{}_G) \qquad (3-8)$$

The heat convection from glass to ambient.

$$Q_{c,g\_a} = h\,(T_{amb} - T_G) \qquad (3-9)$$

$$h = 2.8 + 3v \quad if\, v \leq 5\ (m/s) \qquad (3-10)$$

$$h = 2.8 + 3.8v \quad if\ v > 5\ (m/s) \qquad (3-11)$$

Water vapor condensation (on glass inner surface)

$$Q_{cond} = L_{ev}.M_{ev} \qquad (3-12)$$

M_{ev}: mass flow rate of water (kg/s)

3.9.2 Basin Water

The governing energy equation of basin water relies on the following term:-

$$m_w\, C_{pw}\, \left(\frac{dT_w}{dt}\right) = Q^{\circ} - Qr,_{w\_g} - Q_{ev} + Qc,_{b\_w} - Qc,_{w\_g} \qquad (3-13)$$

Heat source

$$Q^{\circ} = A_w\, \grave{\alpha}_w\, I \qquad (3-14)$$

$$\acute{\alpha}_w = (1 - R_G)(1 - \alpha_G)(1 - R_w)\,\alpha_w \qquad (3-15)$$

Heat radiation from water to glass.

$$Qr,_{w\_g} = \varepsilon\sigma(T_{Gi}{}^4 - T_w{}^4) \qquad (3-16)$$

$$\varepsilon = \frac{1}{\frac{1}{\varepsilon_G} + \frac{1}{\varepsilon_w}} \qquad (3-17)$$

Heat evaporation from water to the glass

$$Q_{ev} = -L_{ev}\, .\, M_{ev} \qquad (3-18)$$

3.9.3 Absorber Plate

$$m_b\, c_{pb}\, \left(\frac{dT_b}{dt}\right) = Q^{\circ} - Qc,_{b\_w} - Qsides \qquad (3-19)$$

Heat source

$$Q^{\circ} = A_b \acute{\alpha}_b I \quad (3-20)$$

$$\acute{\alpha}_b = (1 - R_G)(1 - \alpha_G)(1 - R_w)(1 - \alpha_w)(1 - R_b)\, \alpha_b \quad (3-21)$$

Heat transfer from the bottom and sides of the enclosure to the surrounding.

$$Qsides = U\,(T_{amb} - T_b) \quad (3-22)$$

$$U = \frac{k_{ins}}{t_{ins}} \quad (3-23)$$

t_{ins} : the thickness of insulation material.

3.10 Productivity Enhancement Techniques:-

To perform the required improvement process on the traditional single slope solar still, procedures were carried out that included the process of upgrading the daily productivity of the traditional solar still through the use of metal plates of different shapes (corrugated, arc) and with different numbers of ripples as shown in figure (3-7) and (3-8). The use of these ripples leads to an increase in the surface area the heat exchange, which would raise the required productivity. The table 3-3 shows the details of ripples which are used, where the symbols (a) and (b) for the corrugated shape represent the dimensions of the two sides of the corrugation shape, which takes the form of a triangle, while the corrugation that takes the form of arc is defined by the length of the arc. This is discussed in Chapter Five, which compares all of the suggested arrangements, including water temperatures and daily yield. Enhancement in single slope solar still productivity can be calculated by[57]:

$$ph = \frac{(-3600 * D_{ab})}{L} \int_0^x \frac{dc}{dy} |\text{water} \quad dx \quad (3-24)$$

ph: hourly productivity

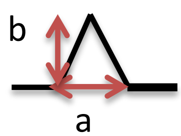
$$pd = \sum hr \ \ ph \qquad (3-25)$$

pd: daily productivity

$$Enh.\% = \left(\frac{pro.heat\ genrator - pro.classic}{pro.classic}\right) * 100 \qquad (3-26)$$

Enh : $Enhancement\ ratio$

Table 3-3 Dimensions Of Absorber Shape

<table>
<tr><th>Absorber forms</th><th>Number of ripples</th><th>a(cm)</th><th>b(cm)</th></tr>
<tr><td rowspan="5"></td><td>40</td><td>0.125</td><td>0.25</td></tr>
<tr><td>20</td><td>0.25</td><td>0.25</td></tr>
<tr><td rowspan="3">10</td><td>0.5</td><td>0.25</td></tr>
<tr><td>0.5</td><td>0.35</td></tr>
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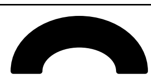
<tr><td rowspan="3"></td><td>20</td><td>0.25</td><td>0.25</td></tr>
<tr><td rowspan="2">10</td><td>0.5</td><td>0.25</td></tr>
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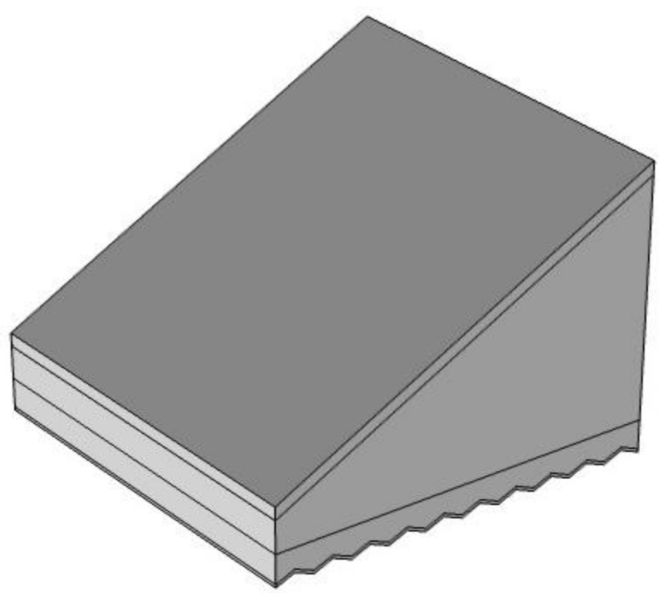


Figure3-7. The Proposed Designs Of Corrugated Plate

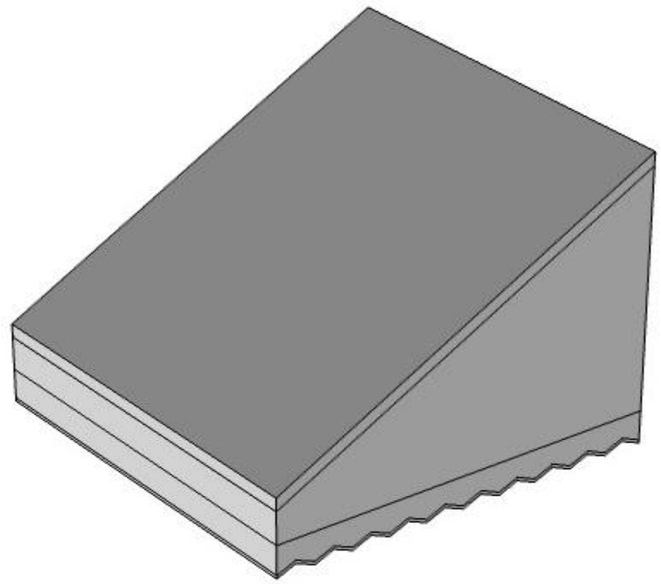


Figure 3-8 The Proposed Designs Of Arc Plate

CHAPTER FOUR

EXPERIMENTAL WORK

CHAPTER FOUR
EXPERIMENTAL WORK

4.1 Introduction

The major goal of the experiments is to determine the impact of certain operating factors and enhancing parameters on SSSS performance. It also tries to validate the numerical findings. This chapter explains the experimental setup, measuring system, experimental plan, and methodology.

4.2 Experimental Set-up

The manufactured systems were installed Al-Diwaniyah-Iraq (latitude 31.99° N, longitude 44. 93° E). The experimental setup involved the construction of conventional single slope solar still (CSSS) as well as modified SSSS (MSSSS). Several materials were used in the building procedure. These materials were chosen based on their cost and operating qualities. Figure 4-1 depicts the fabrication of single slope solar stills.

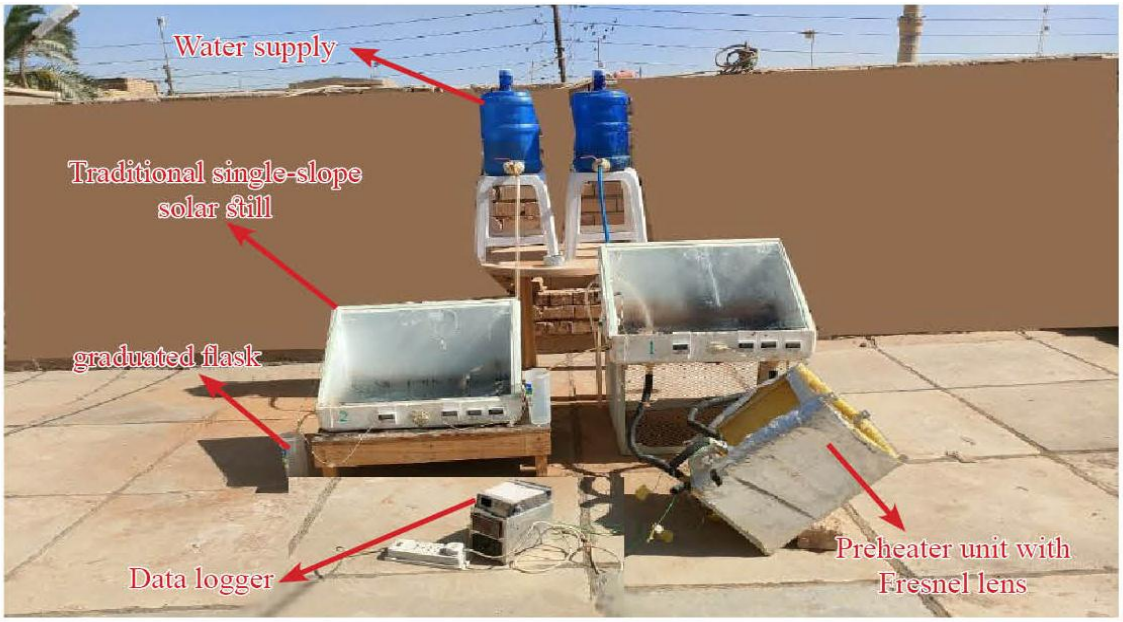


Figure 4-1. Photograph For Experimental Setup

4.2.1 Single Slope Solar Still Enclosure

The SSSS cavity was built using a Polystyrene rectangular box, and the slope was made by cutting it at an angle of 32° with a CNC machine to retain a clean finish, as illustrated in figureure 4-2. Because this box is adequately sealed and insulated, there is little probability of leaking. Furthermore, there is no need to insulate the sidewalls and bottom of the Polystyrene box since it is an insulating material in and of itself, with such a thermal conductivity of 0.030 W/m.k [54]. The box has a basin area of 0.25 m^2, a back height of ٣٦cm, a front height of 9 cm, and an insulation thickness of 5 cm (side and bottom walls)

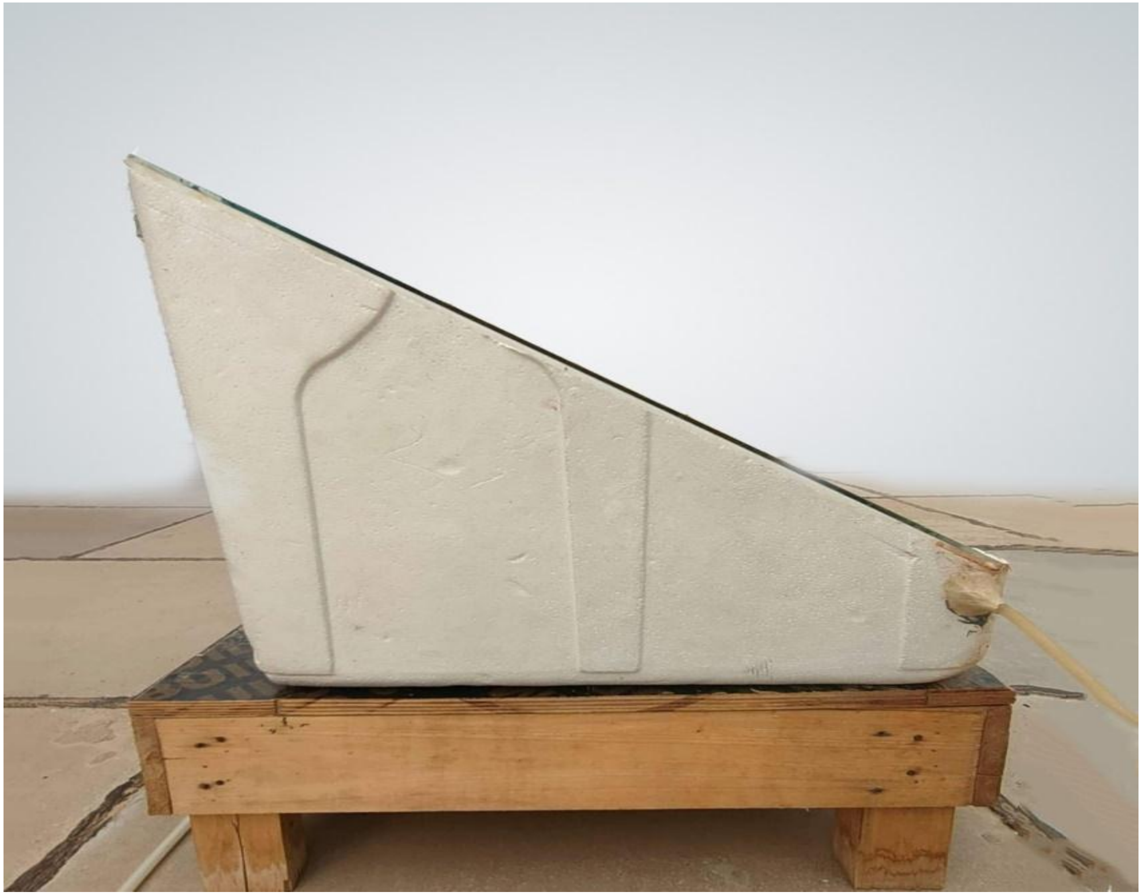


Figure 4-2 The Single Slope Solar Still Enclosure

4.2.2Basin Liner (Absorber Plate)

The basin bottom was lined with a 2 mm thick black-painted galvanized iron sheet. The sheet functions as an absorber plate, and it was sprayed with thermal black matt paint to minimize incident radiation reflectance and maximize both of corrosion resistance and absorption.

4.2.3 Solar Still Cover

Several materials can be used as cover materials, as reported in the literature, glass can be an effective choice due to its higher solar radiation transmittance and lower cost. The glass cover used was 4 mm thick and had an average transmission of 0.88. An adhesive flexible rubber band was placed between the glass cover and the inclined edges to the solar still.

4.2.4 Water Collecting Channel

On the top of lower edge of the Polystyrene enclosure, a distilled channel (collection channel) of 1 cm wide and 5° inclination from the horizontal axis is etched. Water droplets will fall into this channel as they reach the bottom end of the glass cover's surface. Consequently, collected liquid flows to a collection flask situated under the SSSS**.**

4.2.5 Water Feeding Mechanism

An inverted bottled dispenser-like device is used in this experiment's feeding mechanism. Vacuum pressure and gravity play a major role in the device's operation. Figure 4-4 demonstrate how to replace any water slipping out of the bottle with air [58, 59].

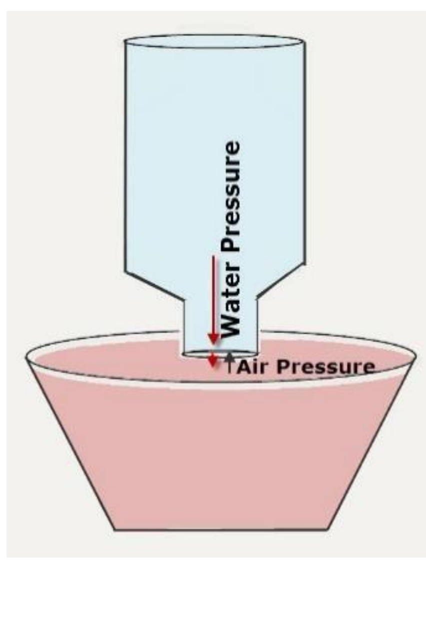


Figure4-3. Water feeding Mechanism [59]

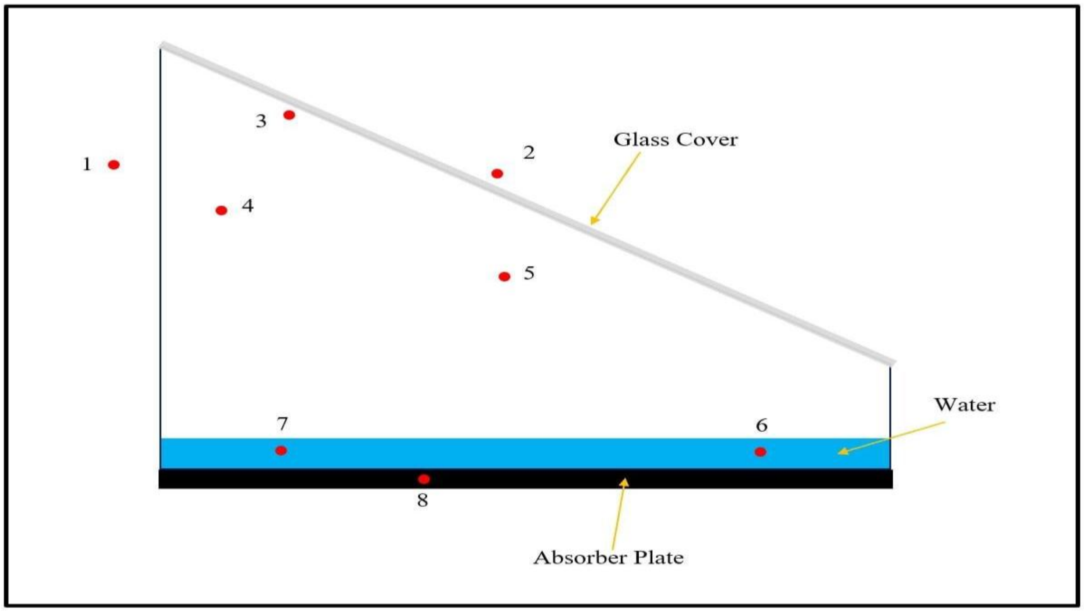
4.3 Measurement Equipment

The conducted experiments for SSSS included the utilization of different measurement instrument as follows:

4.3.1 Temperature Measurement

Measurements were made using seven calibrated K-type thermocouples with an error margin of ((0.2% ± 1°C) distributed on different points along each the CSSSS and MSSSS. Two of these thermocouples were used to measure the moist air temperature within the still, and two more were used to measure water basin temperature. The absorber plate of the basin was fitted with a thermocouple, and the glass cover's inner and outer surfaces were monitored with two more thermocouples. The temperature of the surrounding air was measured using yet another calibrated K-type thermocouple. The fifteen used thermocouples attached to 32-channel Applent digital data logger thermometer type (AT-4532x). A sample of a K-Type thermocouple and the data logger are shown in Figure 4-4. The location of each of the eight K-Type thermocouples was illustrated as in figure 4-5. Also, appendix A included the calibration findings for the thermocouples that were used.

Figure 4-4 Applents Digital Data logger Thermometer (AT-4532x) 32 Channel type



Thermocouple no.	1	2,3	4,5	6,7	8
Location	Ambient	Inner and outer glass surfaces	Moist air	Water	Galvanized Plate

Figure4-5. Distribution of Thermocouples probes across conventional SSSS.

4.3.2 Solar Radiation Measurement

Hourly measurements were made of the strength of the incident solar radiation. It is seen in figure 4-6that the TENMARS (TM-207) solar power meter is used to detect solar radiation intensities. There is an error margin of (±5%, ± 10 W /m^2) with the solar power meter. Appendix B details the process of calibrating the used solar power meter.

Figure 4-6 TENMARS (TM-207) solar power meter

4.3.3 Wind Speed Measurement

According indicated in the literature, one of the factors affecting daily solar still production is wind speed. On an hourly basis, wind speed is also recorded to see how it affects the day-to-day production of SSSS. The hourly wind speed was measured using an anemometer (AM-4206M). (0.4 - 30 m/s) with an accuracy of (1.8% N+2d). Figure 4-7 shows the anemometer that was used. The device was calibrated based on the information obtained from the Meteorological Department in Diwaniyah.

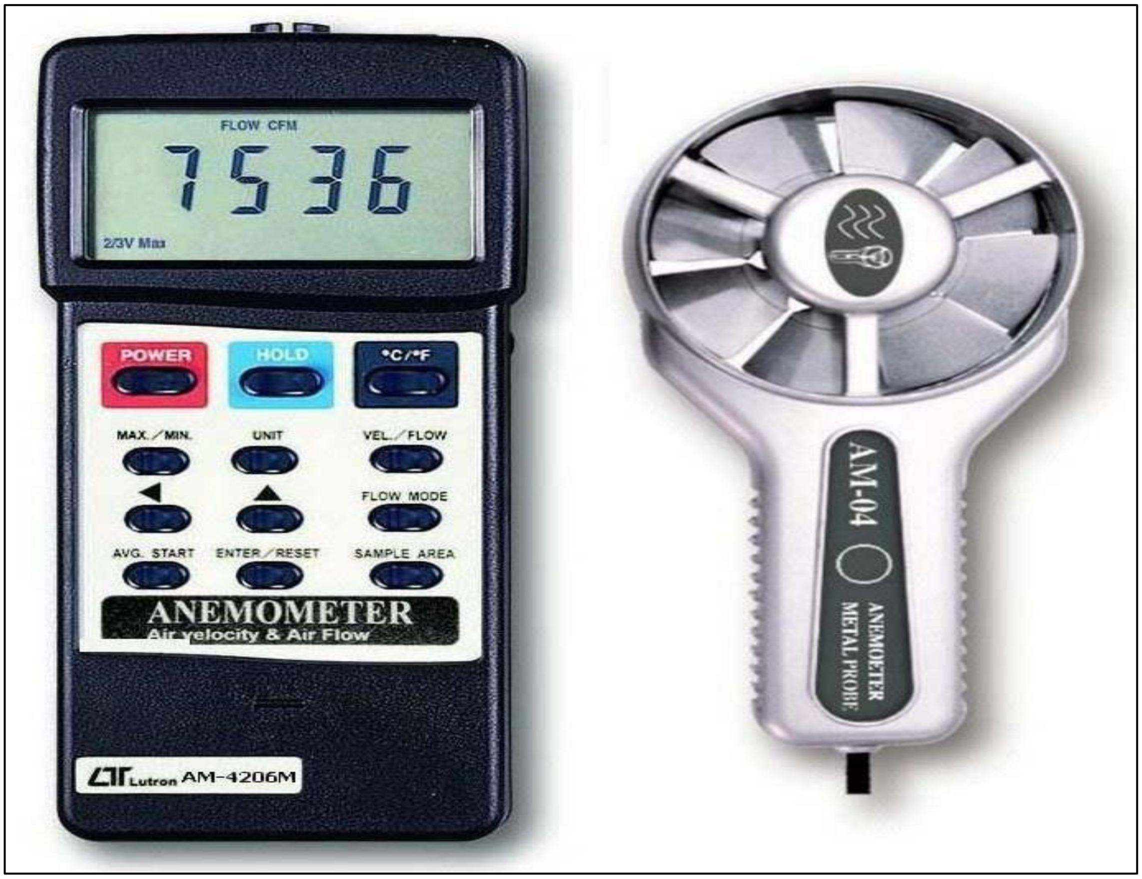


Figure 4-7. Anemometer device (AM-4206M)

4.3.4 Distilled Water Collector

A graduated flask was used to collect the distilled water to compare the hourly output of the conventional and improved solar stills. The graduated flask had a volume of 2.5 litters and a precision of (5 ml).

4.4 Fresnel Lens

A Fresnel lens is a type of composite compact lens originally. A Fresnel lens can be made much thinner than a comparable conventional lens, sometimes taking the form of a flat sheet. A Fresnel lens can capture more oblique light from a light source. A Fresnel lens is a succession of concentric rings, each consisting of elements of a simple lens, assembled in a proper relationship on a flat surface to provide a short focal length. The Fresnel lens is used particularly in lights to concentrate the light into a relatively narrow beam. The basic idea behind a Fresnel lens is simple. Imagine taking a plastic magnifying glass lens and slicing it into a hundred concentric rings. Each ring is slightly thinner than the next and focuses the light towards the center. The Fresnel lens is installed inside an aluminum box and its dimensions are (25 cm *35cm). The sun tracking, for the Fresnel lens, carried out manually.

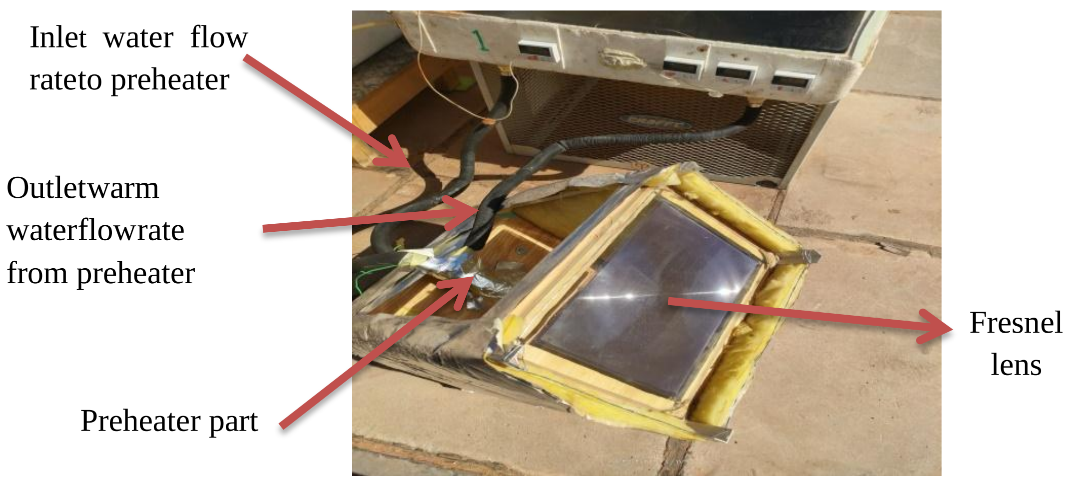


Figure4-8 Fresnel Lens

4.5 Preheated water unit

A preheater water unit, as in figure 4-9, consists of a small room, one of whose sides is exposed to the concentrated solar radiation coming through the Fresnel lens, which in turn heats the water coming from the solar still basin through the inlet pipe of the Preheater unit to raise its temperature as a result of its exposure to the hot surface of the Preheater unit. It returns as hot water or steam to the solar still basin through an outlet pipe from the Preheater. The Preheated unit was manufactured locally from the materials available in the market, which is a polypropylene tube with a diameter of 2 inches so that one of the sides is a piece of aluminum, which is the source of heat input to the water inside the tube, and the other end is converted to a pipe with a diameter of 0.75 inches to be a water entry hole The generator room, as for the exit hole, was a copper tube welded at the upper end of the surface of the aluminum piece (the radiation receiving face) from one end and the other end was connected to a copper threaded piece to represent the hot water return pipe to the distillation basin. The preheated water unit was placed, according to the measurements, in a box with dimensions (25cm * 35cm) and the surface of the generator and the outer walls of the box were insulated with glass wool to reduce the loss of heat to the surroundings

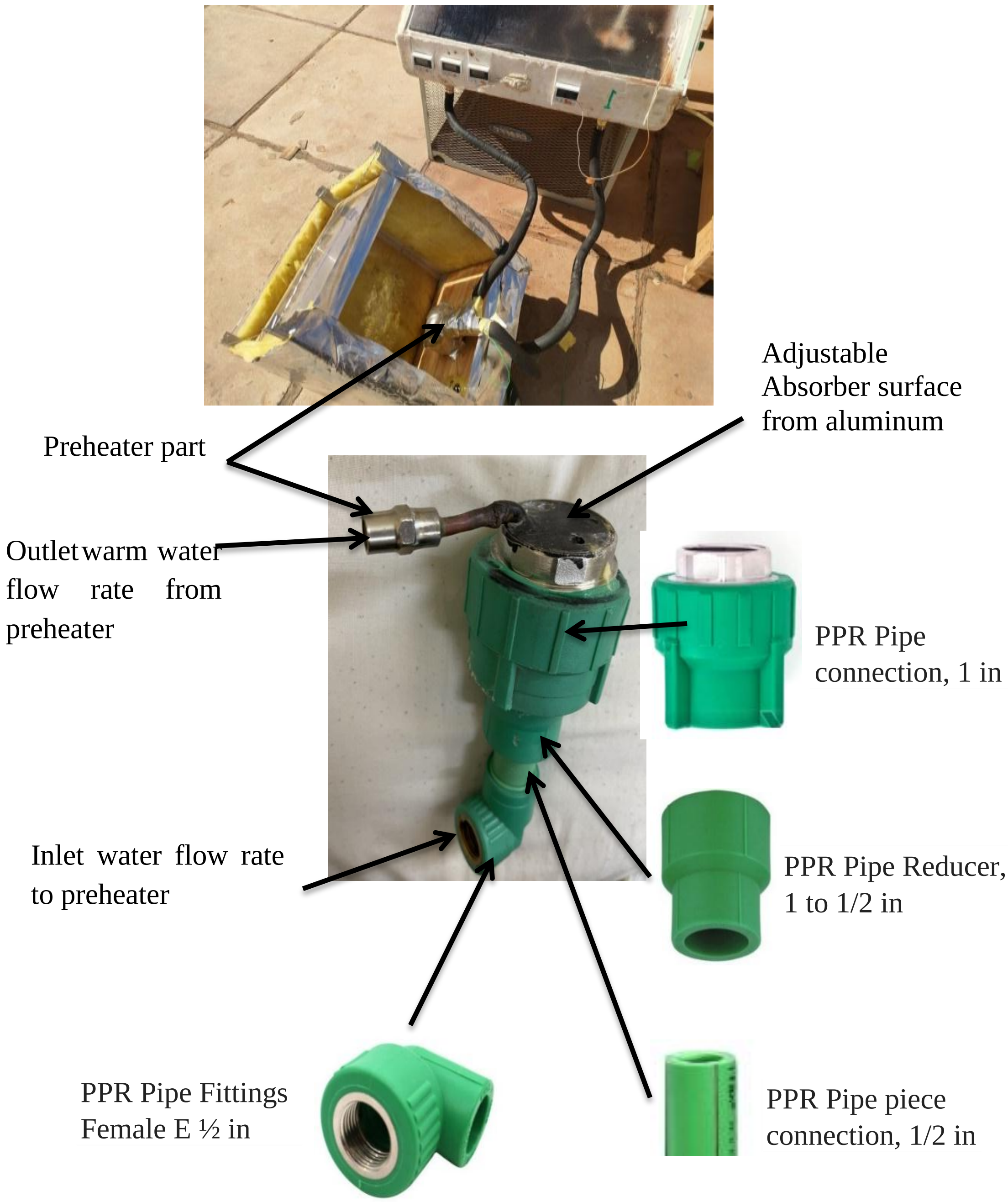


Figure 4-9: Preheater unit with a Fresnel lens

4.6 Experimental Procedure

In July 2022, all experiments were conducted for 10 hours. The temperature, wind speed, air temperature, solar radiation intensity, and production quantity per hour were collected. The first step is to feed the solar distiller with water through the approved feeding mechanism, which is the inverted bottle method. The water flows from the feeding tank towards the basin through the end of a plastic tube at a height of 1 cm above the absorbent plate. The (SSSS) depends on the incident solar radiation through the glass cover that absorbs some particles and is reflected and penetrates the rest towards the water of the basin, and that the water of the basin also absorbs part of the radiation and the rest permeates towards the absorption plate that has been painted black to reduce the reflectivity to some extent. Once the radiation reaches the water and the absorbing plate The temperature of the water inside the basin rises and begins to evaporate and rises to the bottom surface of the glass and then condenses water droplets that flow into the collection channel at the lower end of the distiller and the width of the channel is (0.8) cm and then goes to the graduated flask concerning the traditional solar still while the solar distiller with generator Steam and the lens One side of the preheated water unit is exposed to the incoming solar radiation through the lens, and the water coming from a basin is heated through the inlet pipe of the generator to raise its temperature, as a result of its exposure to the surface of the heated generator. Naturally circulation, without the intervention of any other assistive device, depending on convection, experiments were conducted at four different heights, 24cm,30cm,34cm,38cm

Chapter Five

Results and Discussion

Chapter Five

Results and Discussion

5.1 Introduction

This chapter discusses the results of the experimental and numerical works that were conducted to improve the performance of single-slope solar stills. The numerical work included an improvement process by using different shapes of absorber plate. The proposed shapes of the plate beside the flat are corrugated and arced, to investigate the effect of plate shape on the solar still productivity. The study comprised eight cases for the different plate shapes. Also, four experimental cases relied on the use of a preheated water unit- Fresnel lens with different levels concerning the solar still. The experimental work for each case repeated more than one time to obtained the best and accurate results. The results of the experimental work are compared with that of numerical work and good agreements are obtained. The following sections illustrate the results obtained from the studies that were conducted.

5.2 Numerical Analysis Results

In this work, COMSOL 5.5 program used to create a 3-D model. This model helped examine parameters and the numerical modeling is time- and cost-efficient.

5.2.1 Model Validation

In order to validate the developed model, the findings generated using the COMSOL 5.5 program were compared with those obtained by Elango et al [60]. They presented practical experiments that included the use of traditional single slope solar still. This still is made up of a galvanized iron basin that has an area of 0.25 m^2 and is insulated with a thermally layer that is 0.05 m thick and a glass cover tilted with 30 degrees with horizon and 0.004 m thickness. The results showed that there was a good agreement between them, as can be shown in figure 5-1 and5-2. When it comes to productivity the error does not surpass 4 % , and for water temperature the error does not exceed 7 % .

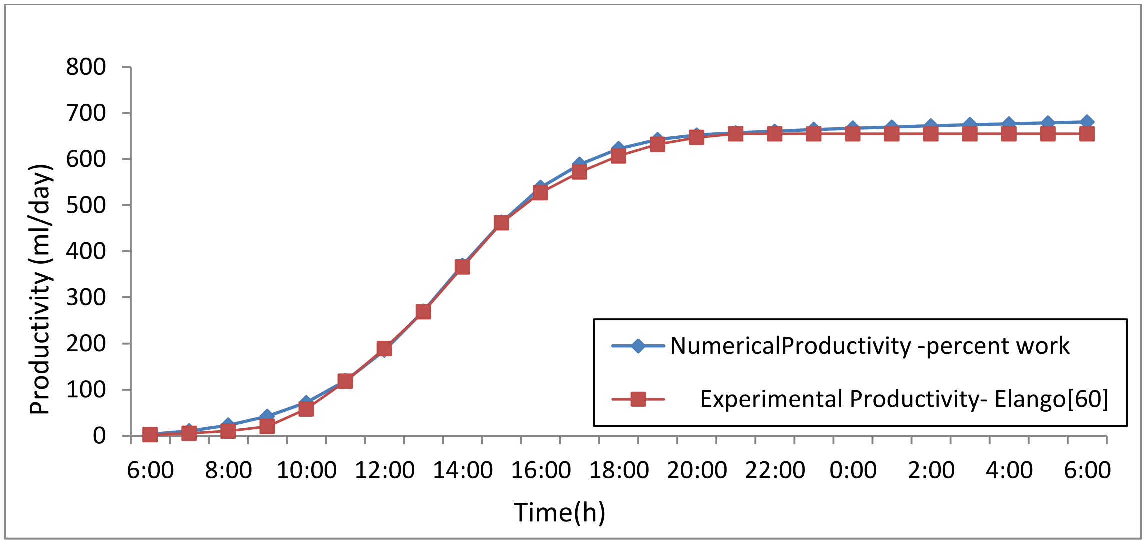


Figure. 5-1 Productivity validation of the developed model and Elango et al [60]

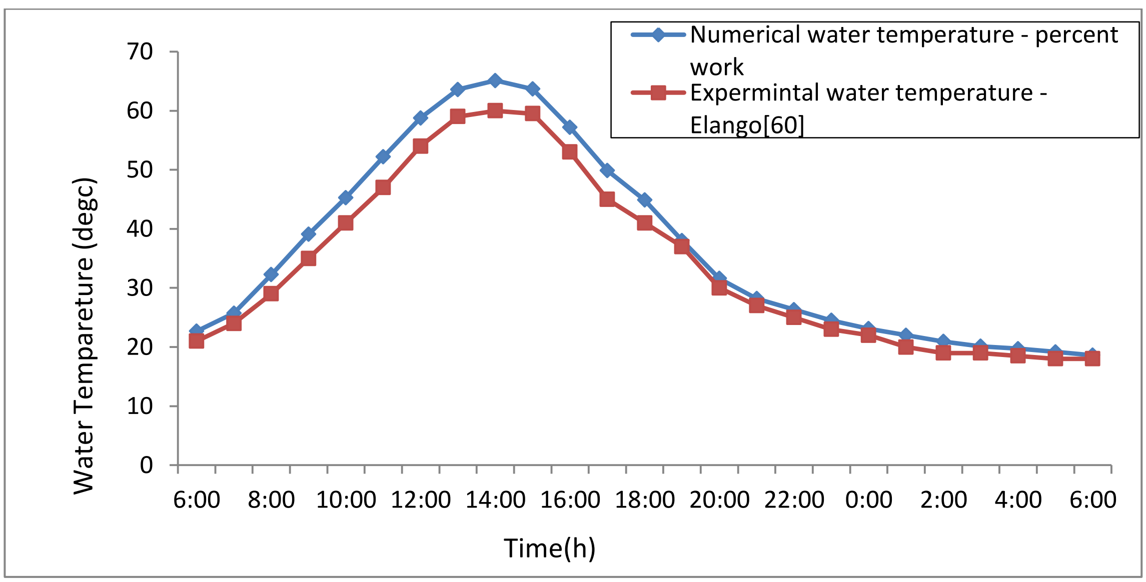


Figure5-2 Water temperature validation of the developed and Elango et al. [60].

However, it is necessary to consider more than one case to ensure a reliable numerical model. Thus, other work was taken into account to validate the developed 3D model. Zahraa Abbas [61] reported experimental investigation of SSSS using Comsol software. The basin examined still had an area of 0.39 m^2 made of cork, and the top cover was 0.004 m glass with 32^o as horizontal inclination angle. The daily yield gained from experimental examination reported by Zahraa and this work are shown in figure 5-3 Also, figure 5-4 shows the basin surface water temperatures for both works. The developed model and Zahraa findings are in good agreement, and the maximum error not excess 11% and 8% for productivity and water temperature respectively.

well. Throughput and temperature errors were does not excess 8% and 11% respectively.

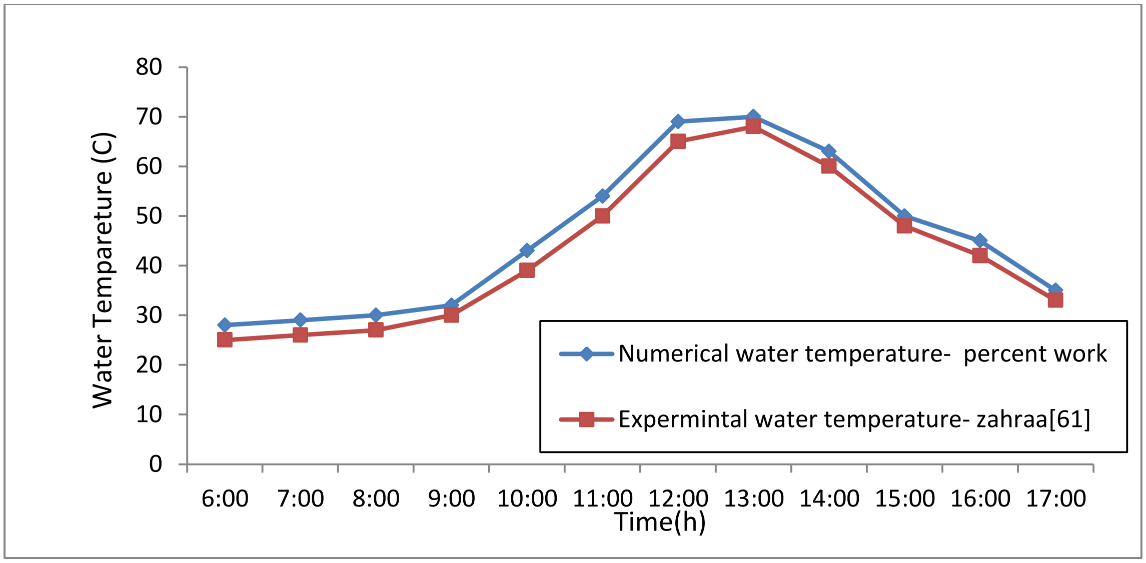


Figure. 5-3 Water Temperature Validation Of The Developed Zharaa [61]

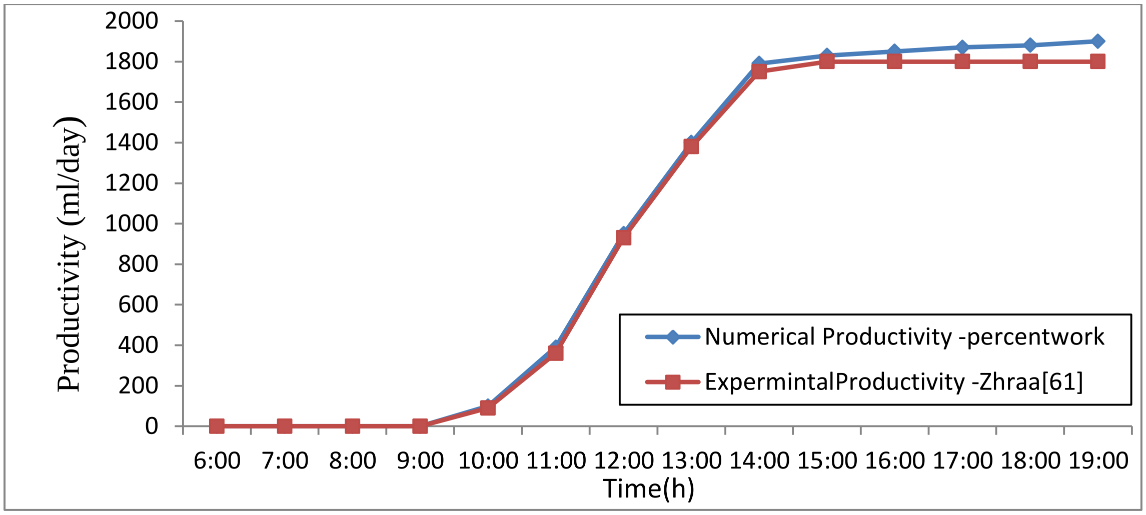


Figure. 5-4 Productivity Validation Of The Developed Model Zahraa[61]

5.2.2 Absorbent Plate Shape

To adopt the improvement of solar water desalination techniques, it developed a certain design with different absorption configureurations to choose the appropriate geometry for productivity enhancement. Flat, corrugated, and arc absorbent shapes were chosen. Environmental data were considered the same for all numerical cases performed on the day (8/5/2022) and taken from the Meteorological Department in Al-Diwaniyah city.

5.2.2.1 The Effect Of Flat plate

In solar distillation, the temperatures of inner glass cover, absorption plate, and surface water play a key role in the distillation of salt water in general. The amount of distillate yield by solar still depends on the temperature difference between surfaces of water and inner glass cover. Figure 5-5. shows the temperature distribution along the still at simulation period with defined hours as 8:30 am, 1and 4 pm for water depth of 1 cm. It is clear from the figure, that the temperature increased with time progress until reaches its maximum value at 1 pm, and then decreases according to the solar radiation amount. The total productivity of the solar still reaches up to 2.8436 kg/m^2.

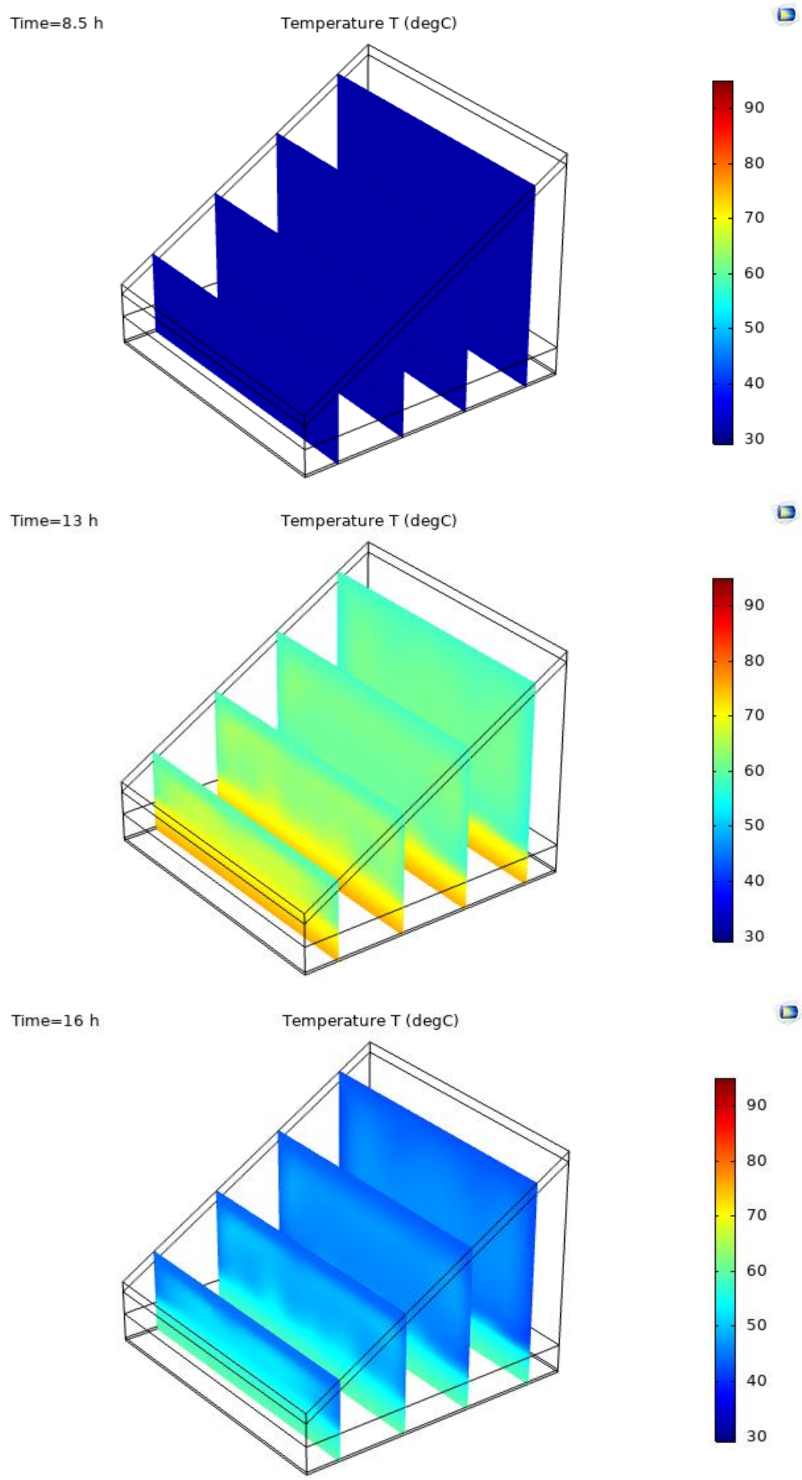


Figure. 5-5 Temperature Distribution Along Flat Plate Of Single Slope Solar Still.

The pressure distribution of the moist air inside the solar still is shown in the figure5-6. From the figure it is shown that the pressure of moist air increases with the time due to increasing the velocity magnitude inside the still.

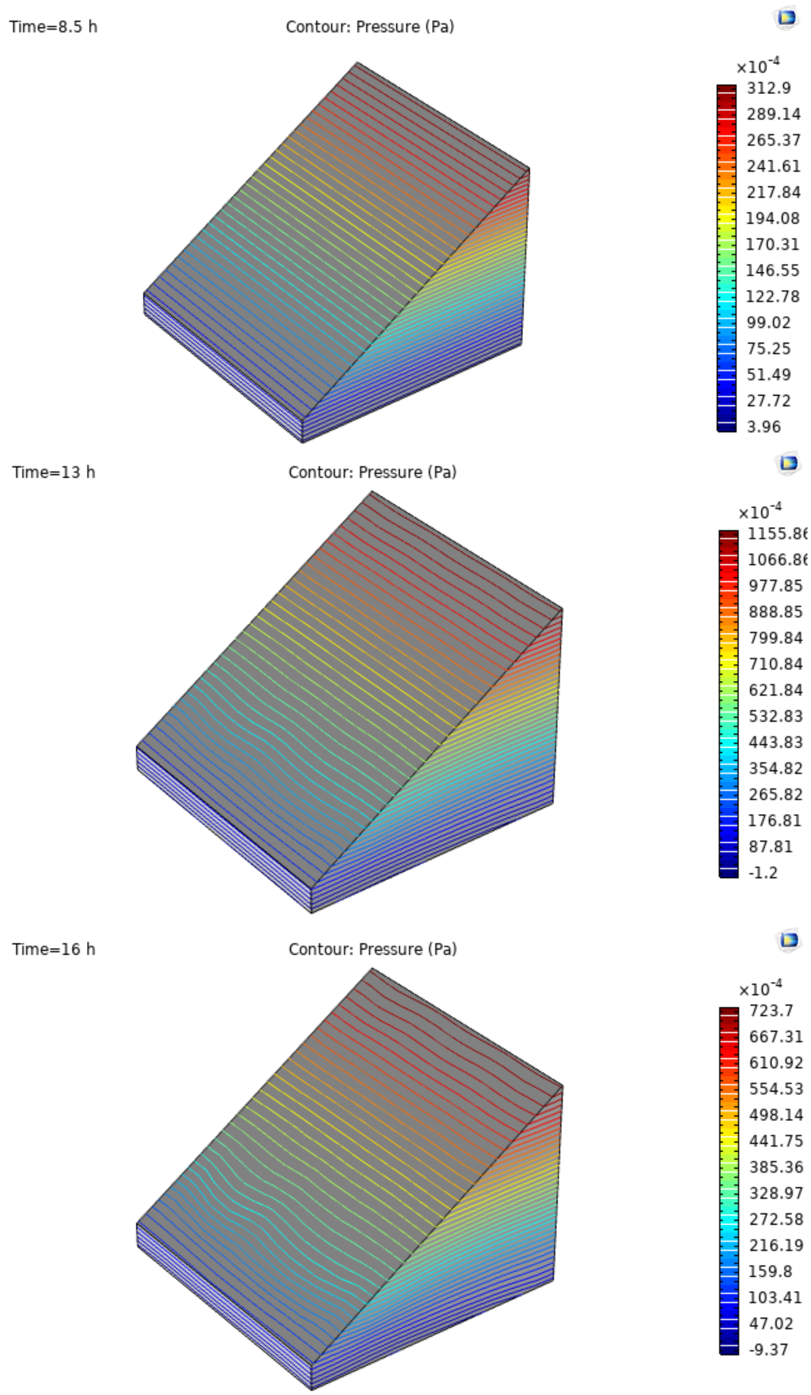


Figure 5-6 The Non-Uniform Pressure Distribution Along Flat Plate Of Single Slope Solar Still

The concentration of water vapor along the still is affected directly by the temperature inside the solar still. Whereas, the increase and decrease of the flow lines coincide with the increase and decrease of the temperature with time. It can be seen in figure 5-7.

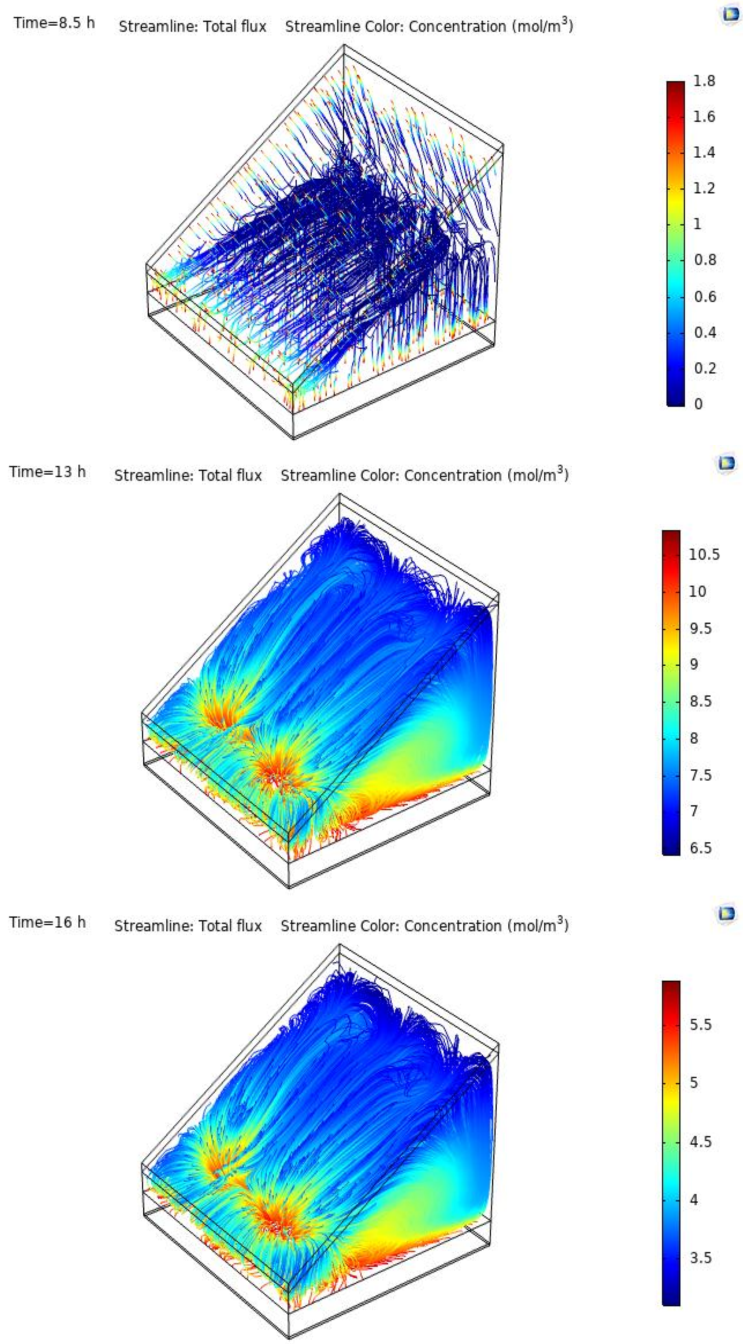


Figure. 5-7 Streamlines Of Moist Air Along Flat Plate Of Single Slope Solar Still.

5.2.2.2 The Effect Of corrugated Plate

The corrugated plates were simulated theoretically with different ripples of (10, 20 and 40). The details of each ripple dimensions (height and width) are also defined. The Figure 5-8 to 5-12 show the distribution of temperature along the still with corrugated plate at 8:30 am, 1, and 4 pm respectively. It can be noticed that there is a clear increase in temperature along the still from 8:30 am to 1 pm, and then a decrease at 4 pm, this is due to the behavior of solar radiation with time. Also, it can be noticed that there is a considered difference in the temperature distribution along the still with the corrugated plate when compared with the still of a flat plate. Whereas, the highest temperature through the still with corrugated plate reaches up (95^oC) when ($N=40$, $a=0.125$ and $b=0.25$), while that of the flat plate is (74^oC).

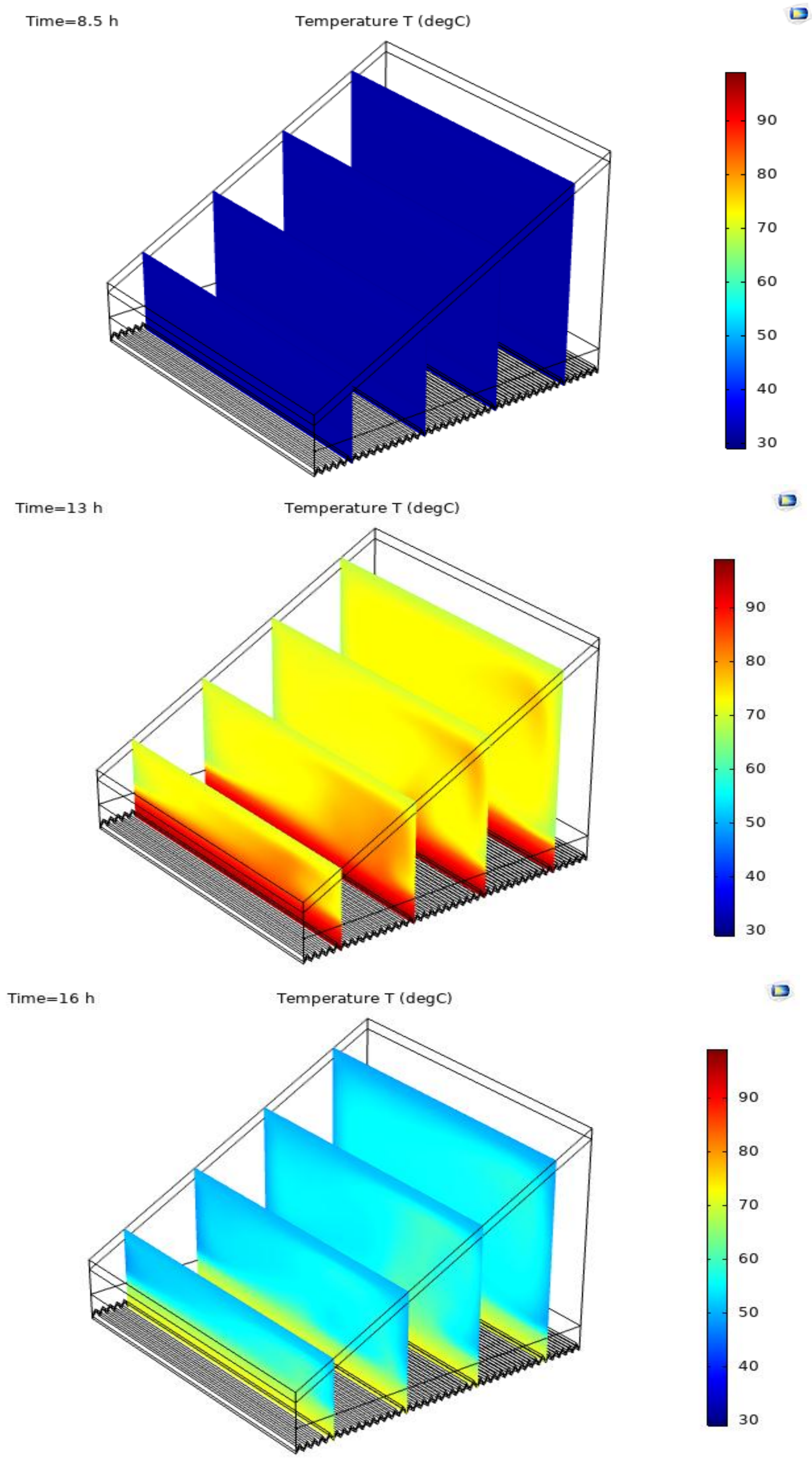


Figure .5-8 Temperature distribution along corrugated plate SSSS with (N=40, a=0.125 and b=0.25)

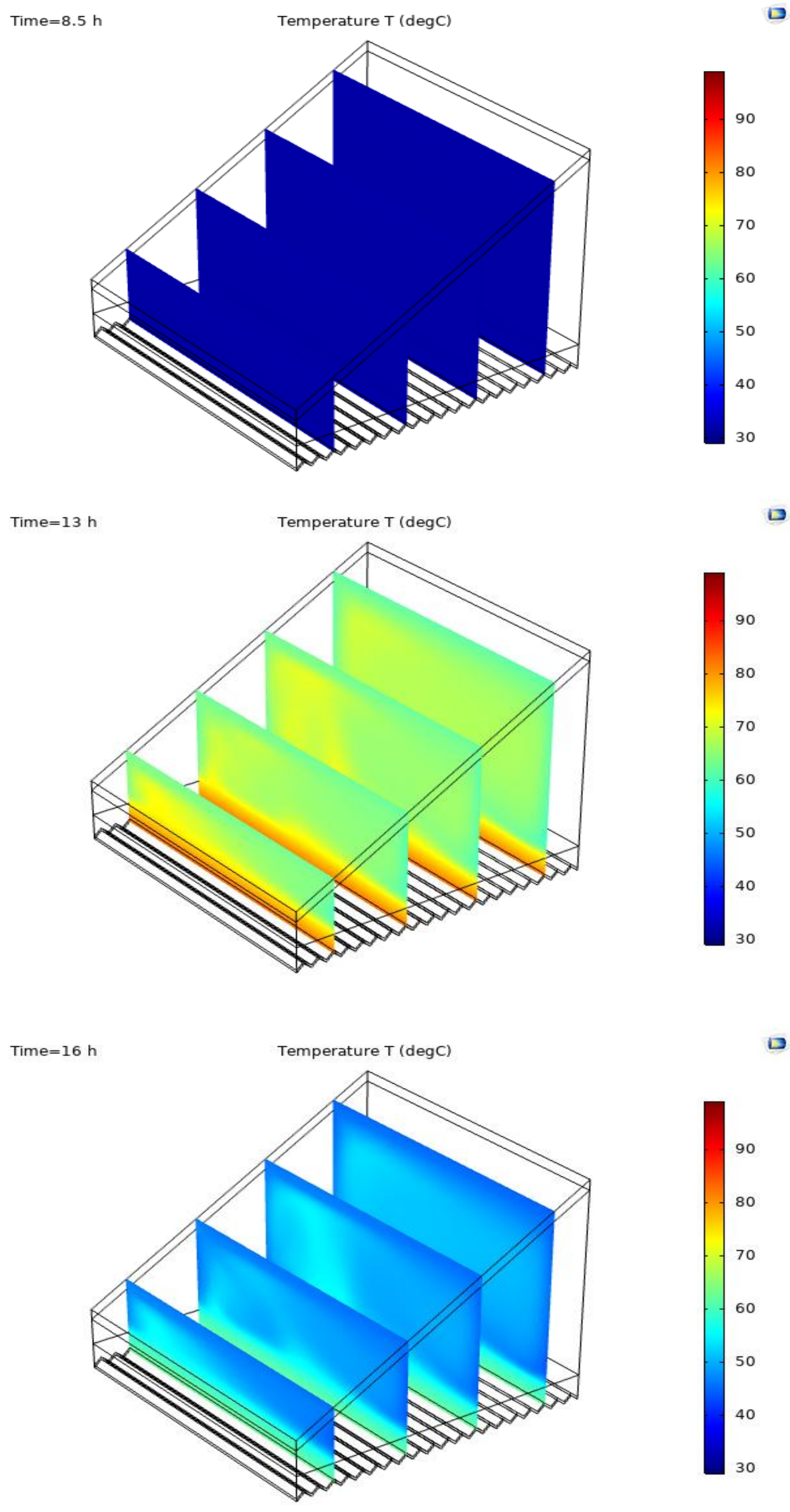


Figure. 5-9 Temperature Distribution Along Corrugated Plate Of Single Slope Solar Still With (N=20, a=0. 25 and b=0.25)

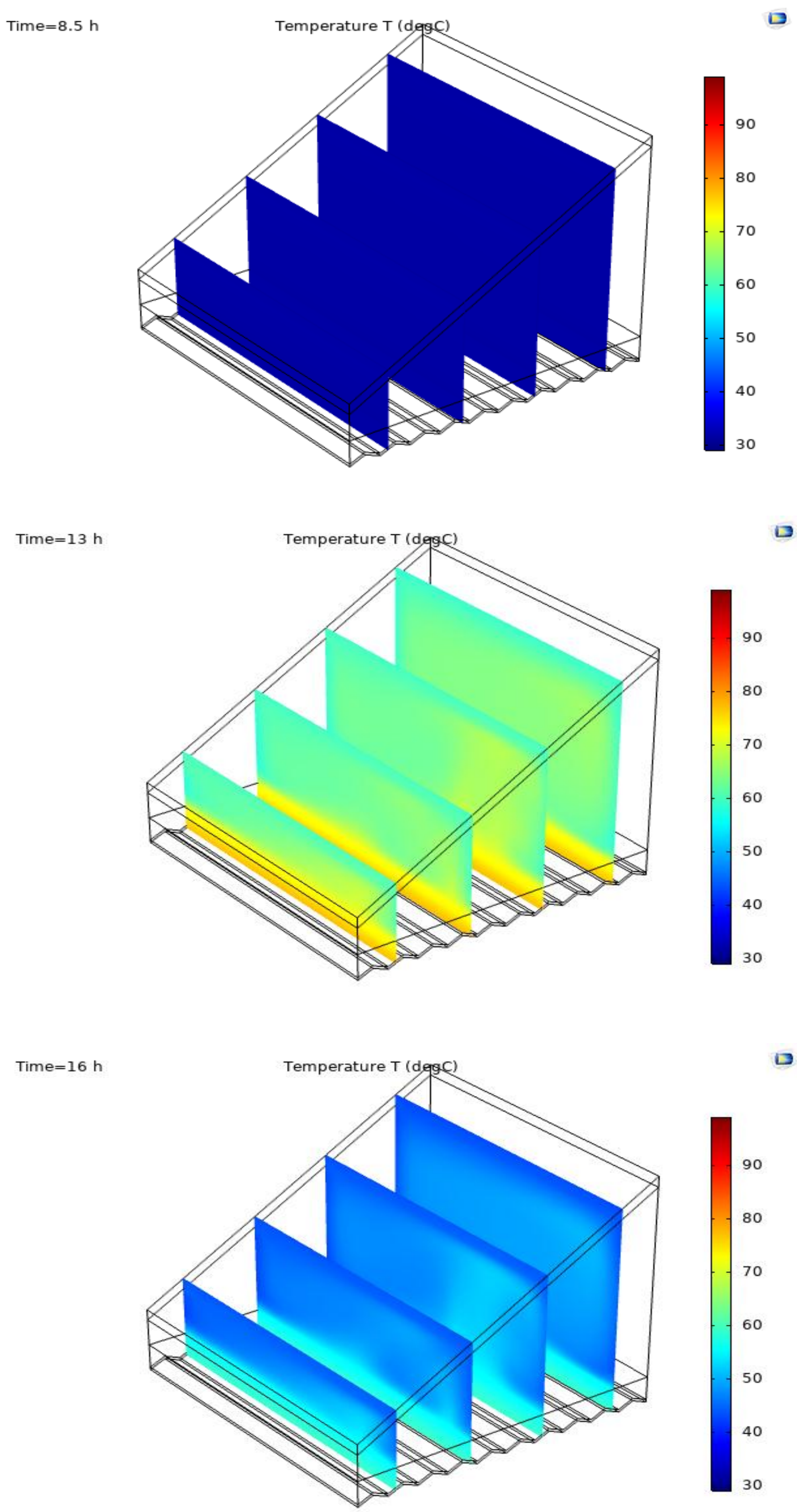


Figure. 5-10 Temperature Distribution Along Corrugated Plate Of Single Slope Solar Still With (N=10, a=0. 5 and b=0.25)

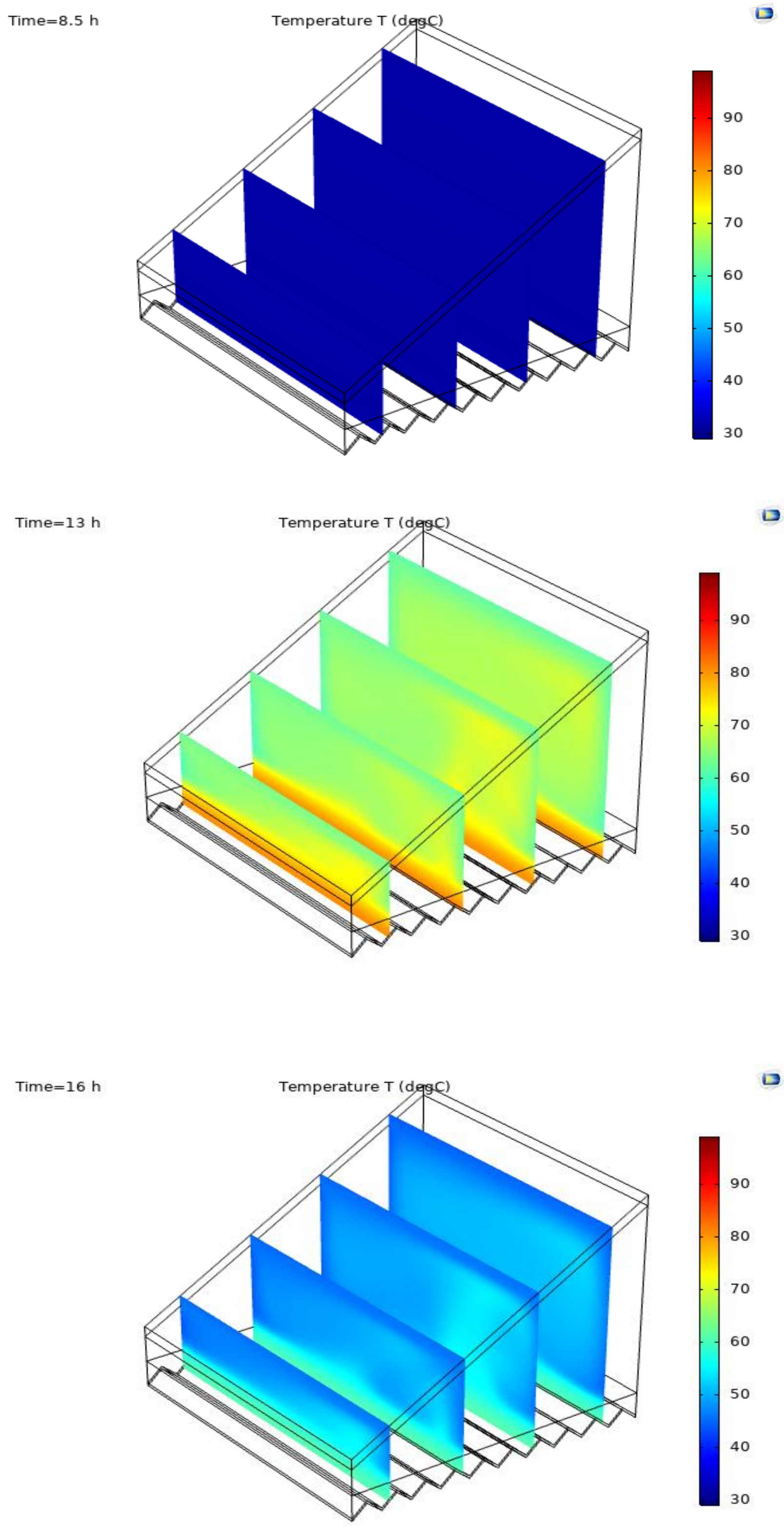


Figure. 5-11 Temperature Distribution Along Corrugated Plate Of Single Slope Solar Still with (N=10, a=0.5 and b=0. 5)

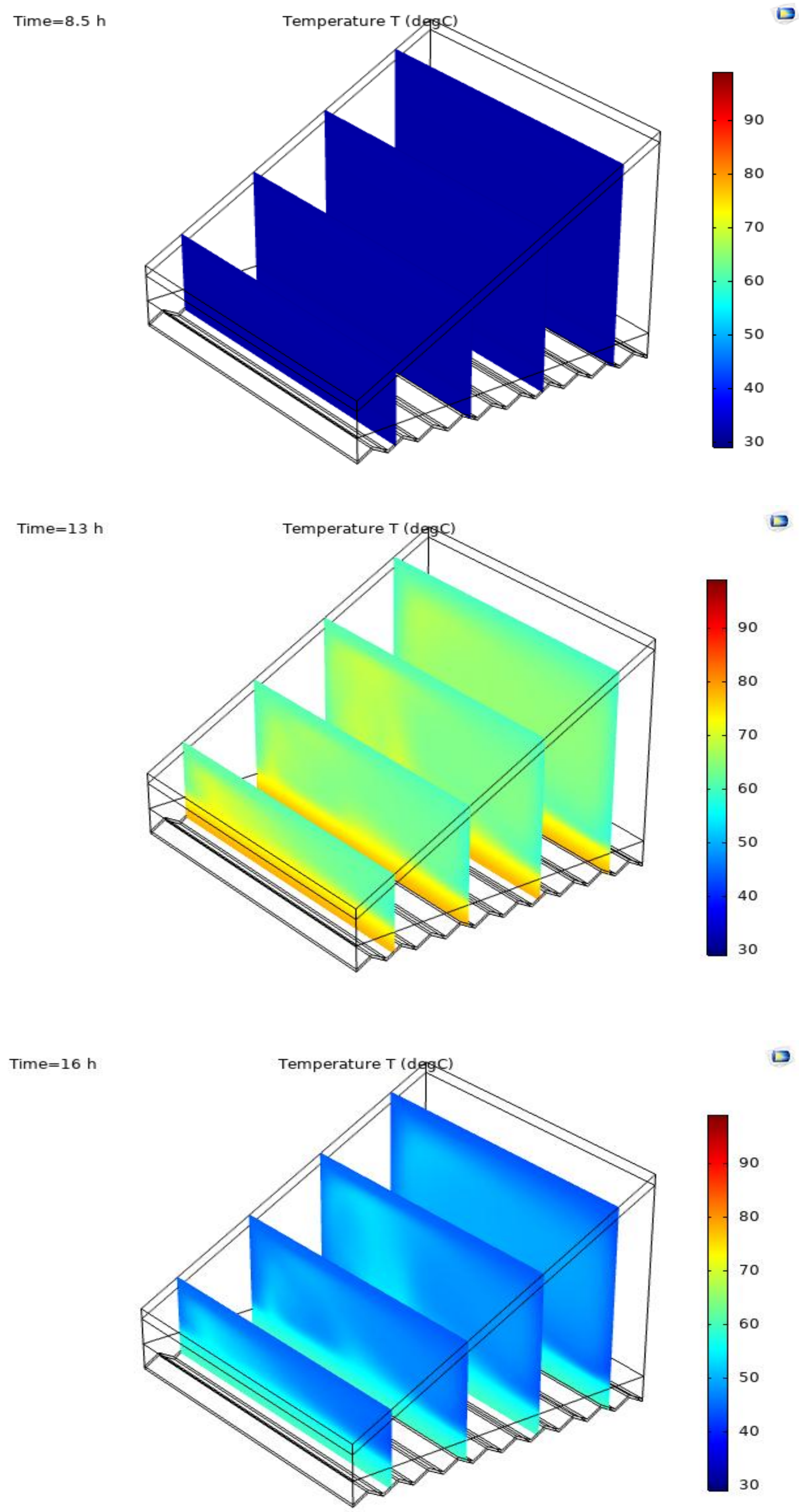


Figure. 5-12 Temperature Distribution Along Corrugated Plate Of Single Slope Solar Still with (N=10, a=0.5 and b=0. 35)

Also, it is clear from the above figures that the temperatures inside SSSS increases with the increase of plate ripples (N) due to the increase of absorbent plate area.

The concentration of water vapor through the cavity of the SSSS is affected directly by the temperature inside. Whereas, the increase and decrease of the flow lines coincide with the increase and decrease of the temperature with time. Figure 5-13 shows the distribution of streamlines of moist air inside SSSS for the specified case, and the other cases have the same trends with decreased the values due to decreasing the temperatures.

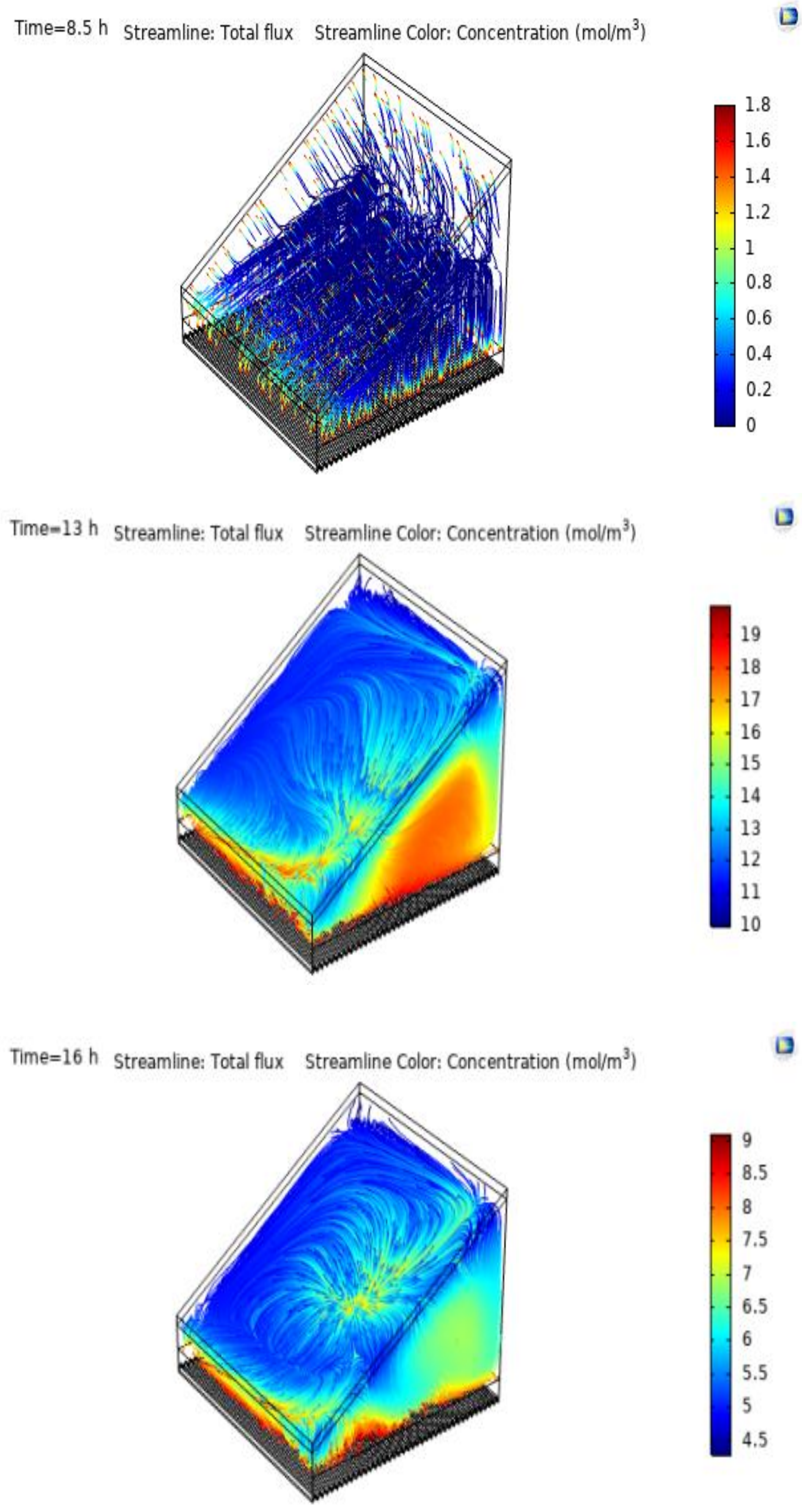


Figure. 5-13 Streamlines Of Moist Air Along Corrugated Plate Of Single Slope Solar Still with (N=40 a=0.125 b=0.25)

Thus, the productivity is directly proportional to Number of ripples (N), where the greater the number of ripples, the higher productivity. This is due to the increase in the absorbent area, as shown in the following table.

Table 5-1: The Total Productivity For Corrugated Plate Of Single Slope Solar Still.

Number of ripples (N), a and b in cm			Productivity kg/m^2
N=40	a=0.125	b=0.25	6.434
N=20	a=0.25	b= 0.25	4.315
N=10	a=0.5	b=0.5	4.221
N=10	a=0.5	b=0.35	3.6226
N=10	a=0.5	b=0.25	3.3130

The pressure distribution of the moist air inside the solar still (for N=40 ,a= 0.125 and b= 0.25) is shown in the figure 5-14. From the figure it is shown that the pressure of moist air increase with the time due to increase the velocity magnitude inside the still. All the other cases have the same trends.

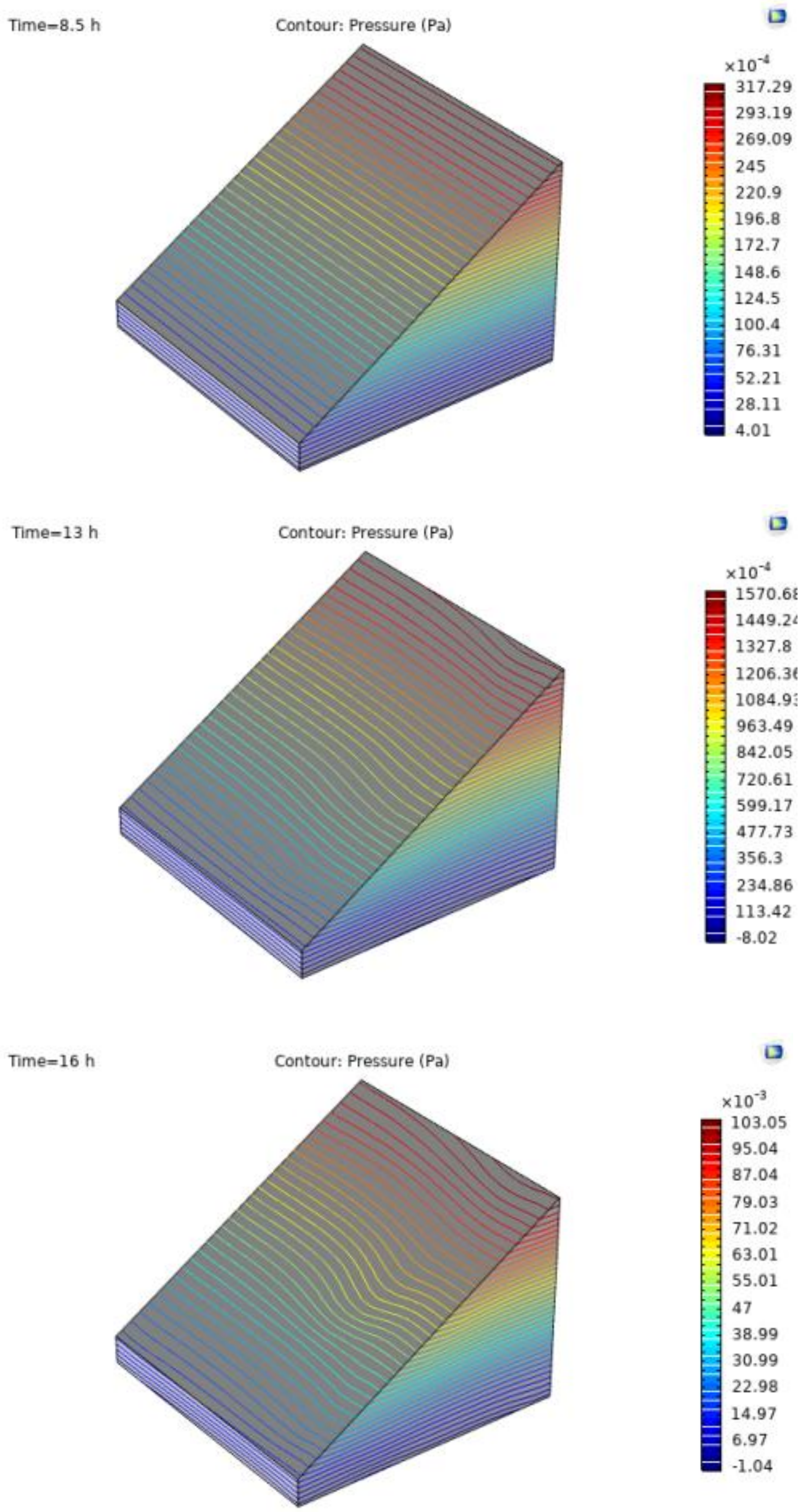


Figure. 5-14 The Non-Uniform Pressure Distribution

5.2.2.3 The Effect of Arc plate

The arced plate has been also simulated numerically under the same conditions as the flat and corrugated plates. Arced plate under consideration with two number of ripples are 20 and 10. Figures 5-15 to 5-17 show the distribution of temperature along the still at 8:30 am, 1 and 4 pm respectively. It can be seen that there is a clear increased in temperature along the still from 8:30 am to 1 pm, and then decrease at 4 pm, this due to increase and decrease of solar radiation with time. Also ,it can be seen that there is a considerable difference in the temperature distribution along the still with arced plate when compared with SSSS with corrugated and flat plates. Whereas, the highest temperature through the still with arched plate reaches up 82^{o} C for N=20, a=0.25 and b=0.25.

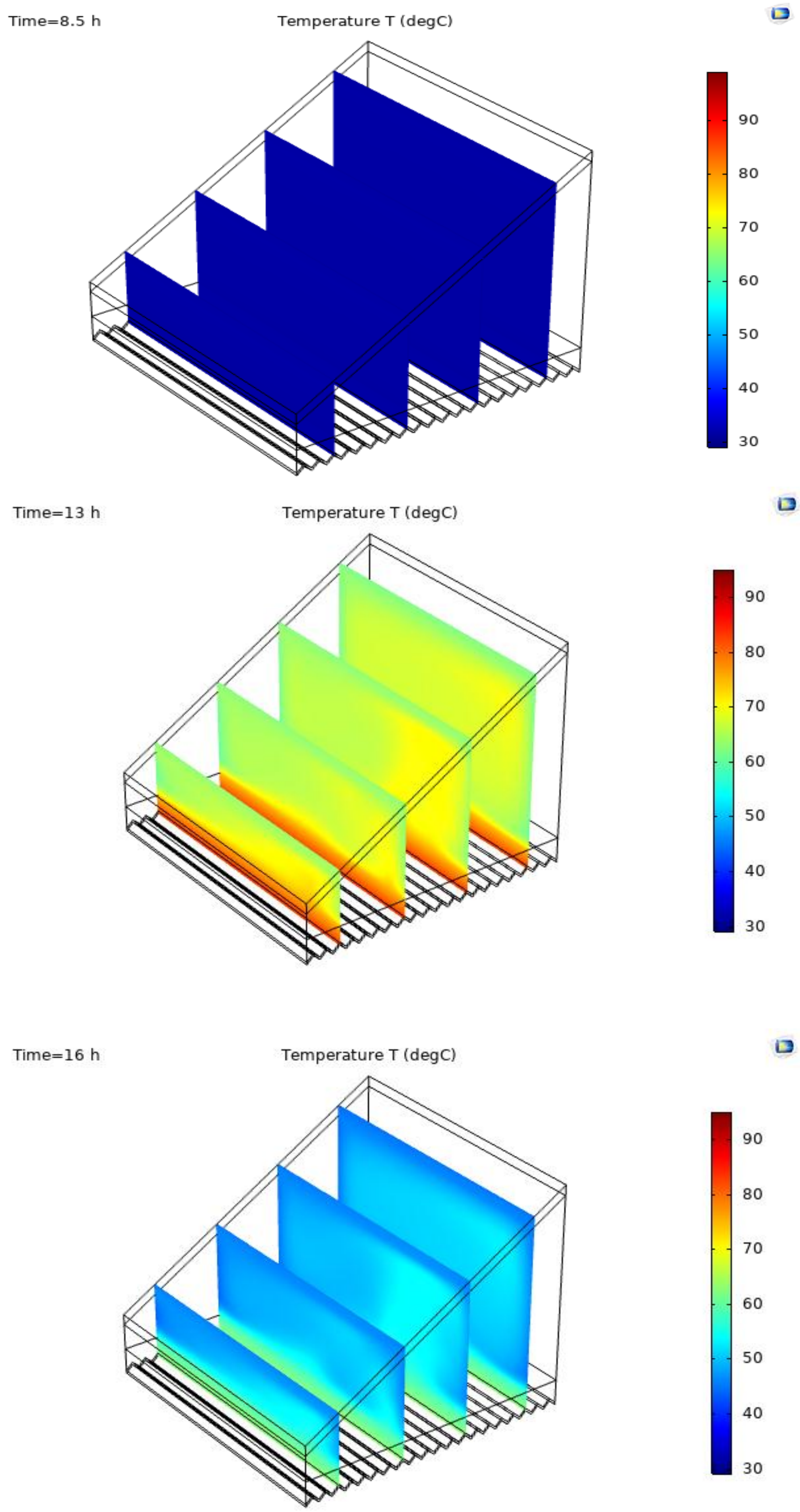


Figure. 5-15 Temperature Distribution Along Arced Plate Of Single Slope Solar Still With (N=20, a=0.25 and b=0.25)

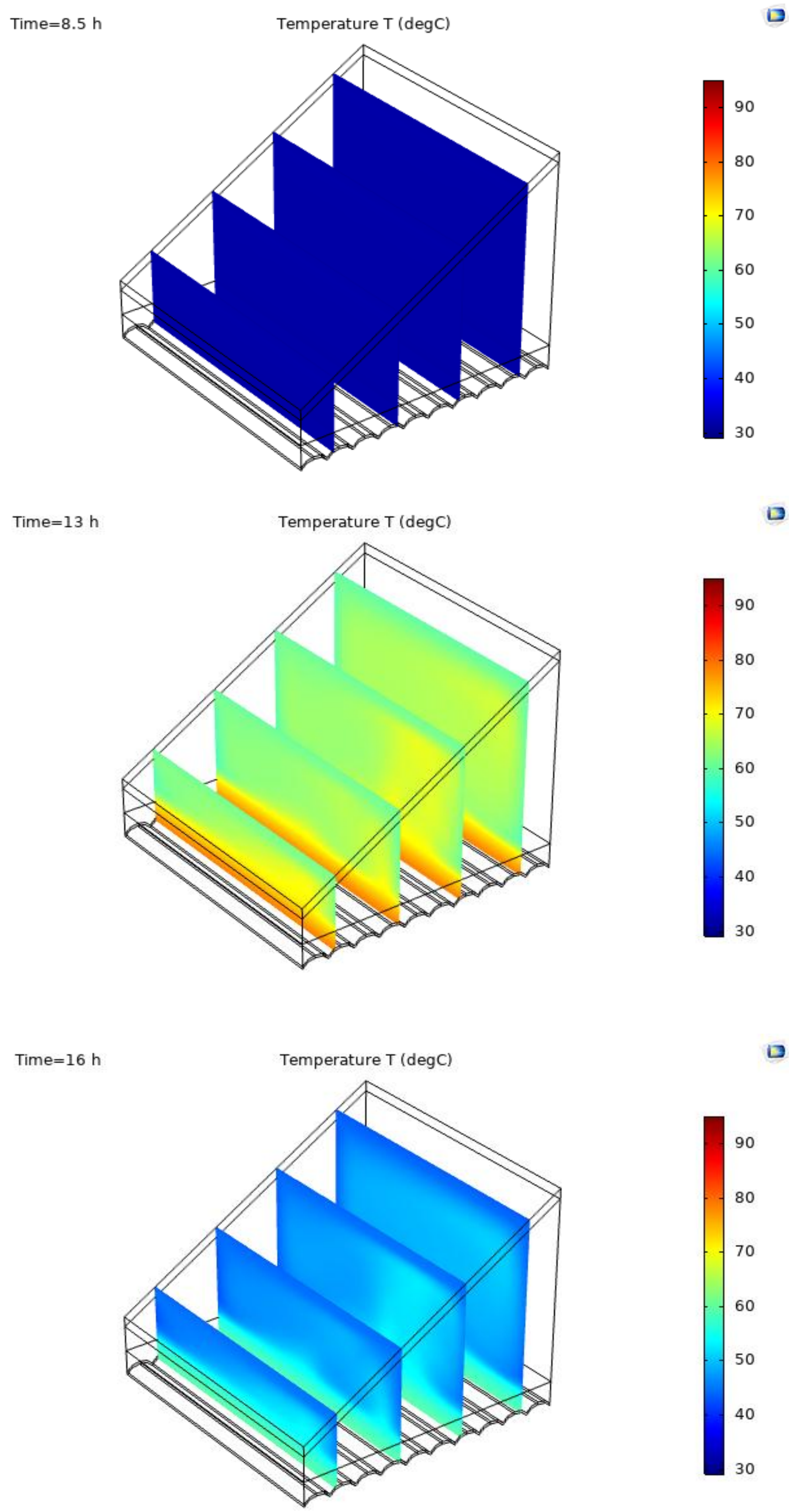
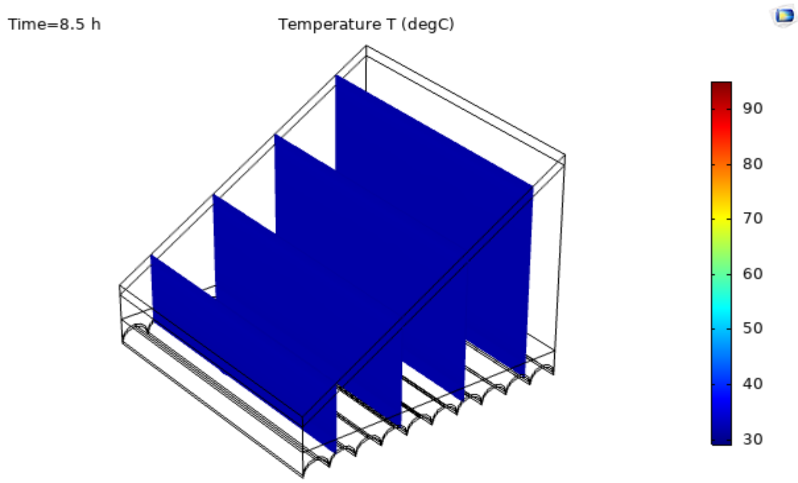
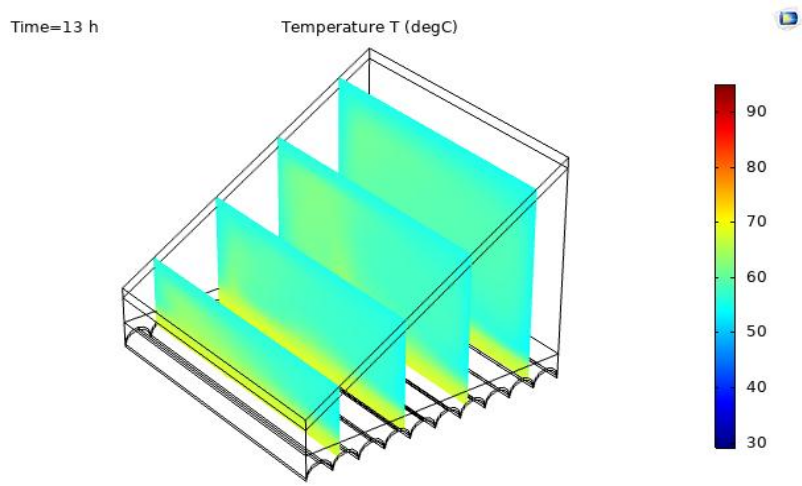


Figure. 5-16 Temperature distribution along arced plate SSSS with (N=10, a=0.5 and b=0. 25)





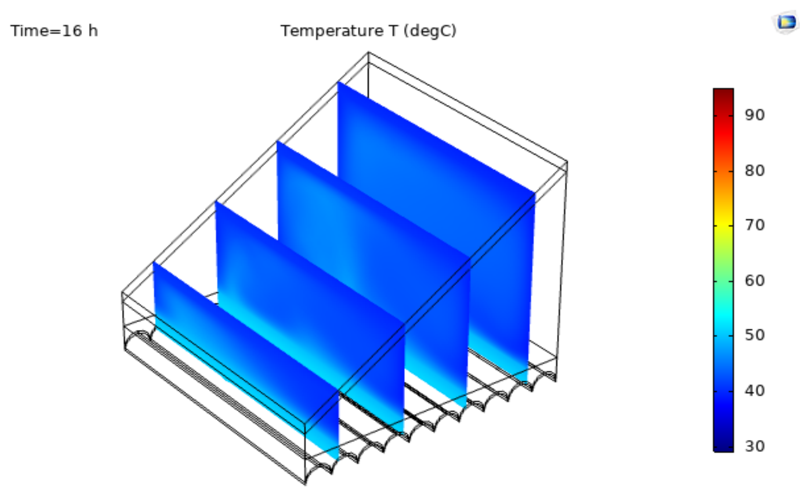


Figure. 5- 17 Temperature Distribution Along Arced Plate Of Single Slope Solar Still With (N=10, a=0.5 and b=0. 5)

Also, the concentration of water vapor along SSSS increased with the operation time progress due to the temperature increasing and then decreased with the decrease of temperature. The distribution of the flow lines, for (N=20, a=0.25 and b=0.25) can be seen in figureure5-18, whereas the other cases have the same trend as in this figure.

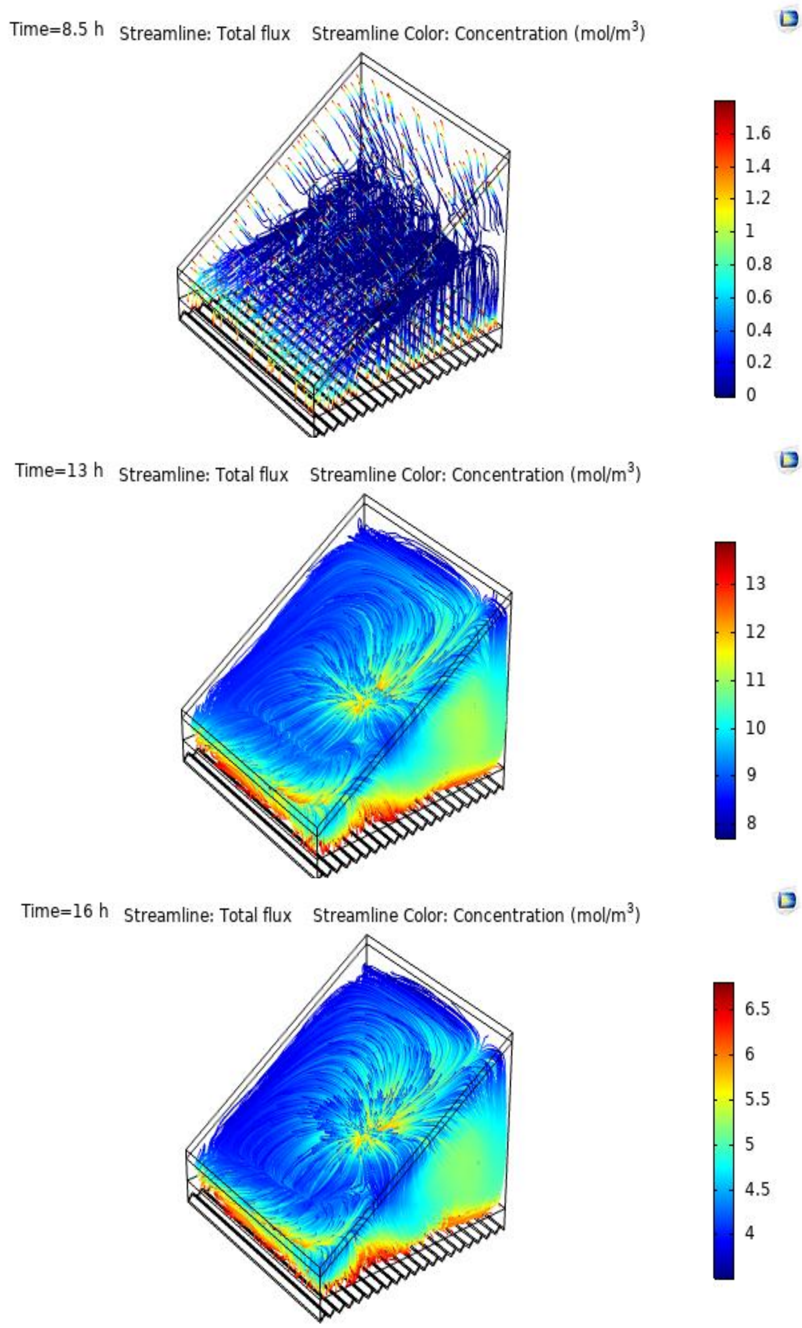


Figure. 5-18 Streamlines Of Moist Air Along Arched Plate Of Single Slope Solar Still with (N=20, a=0.25 and b=0.25)

The pressure distribution of the moist air inside the solar still is shown in the figure 5-19 for (N=10, a=0.5 and b=0.25). From the figure, as known previously, the pressure of moist air increases with the time due to increasing the velocity magnitude inside the still. The other cases have the same trend as in this case.

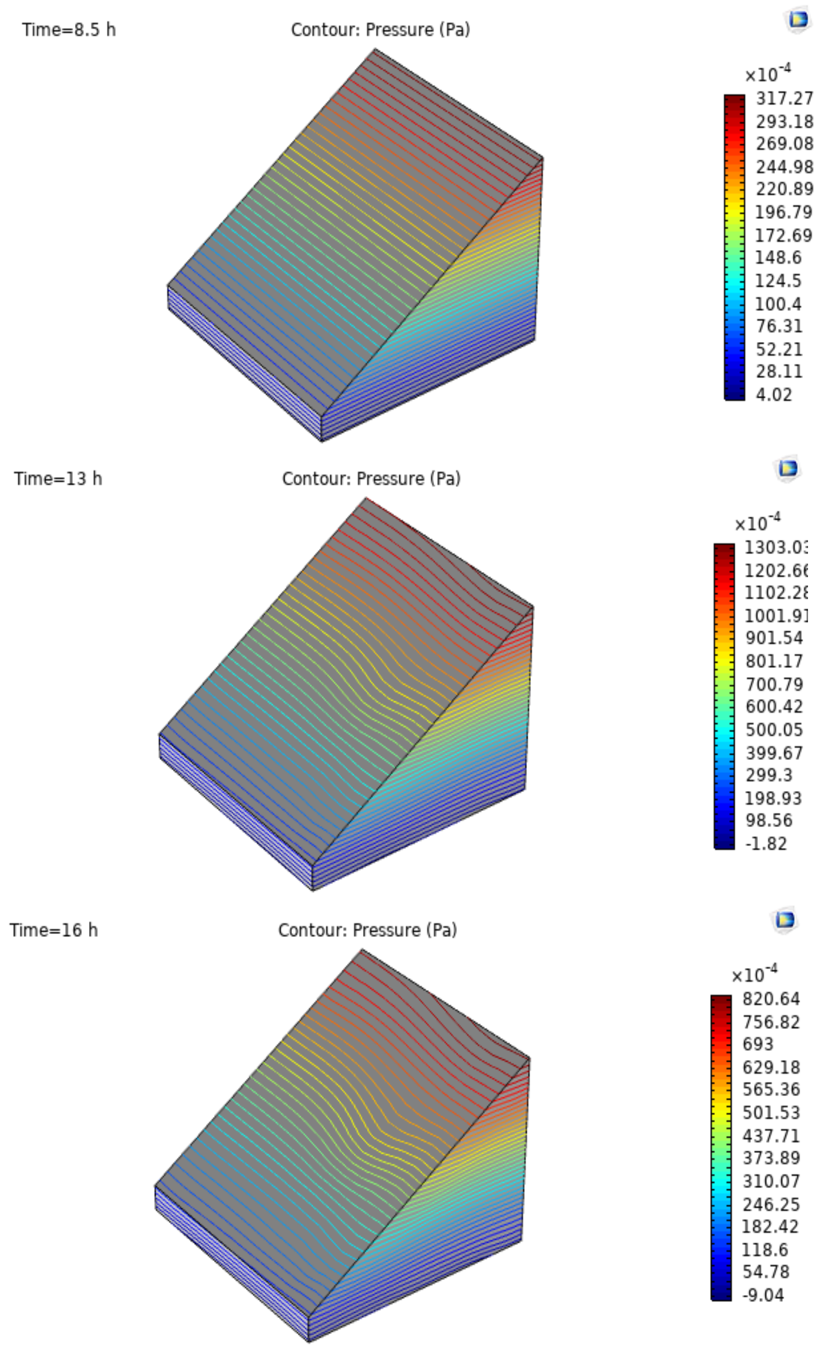


Figure. 5-19 The Non-Uniform Pressure Distribution

The productivity of the arched plate with different number of ripples (N) is shown in table 5-2 Whereas, it increases with the increase of Number of ripples (N).

Table 5-2: The Total Productivity Of Arced Plate

Number of ripples N, a and b in cm			Productivity kg/m^2
N=20	a=0.25	b=0.25	4.2354
N=10	a=0.5	b=0.25	3.5204
N=10	a=0.5	b=0.5	2.1312

It is clear from the above results, that there is a significant improvement in the SSSS productivity with using corrugated and arched plates as compared with use of the flat plate. Thus, when comparing the productivity of the three types, for the same number of ripples for the corrugated and arched plate as shown in figures 5-20 and 5-21, the solar still with the corrugated plate was considered the optimal design.

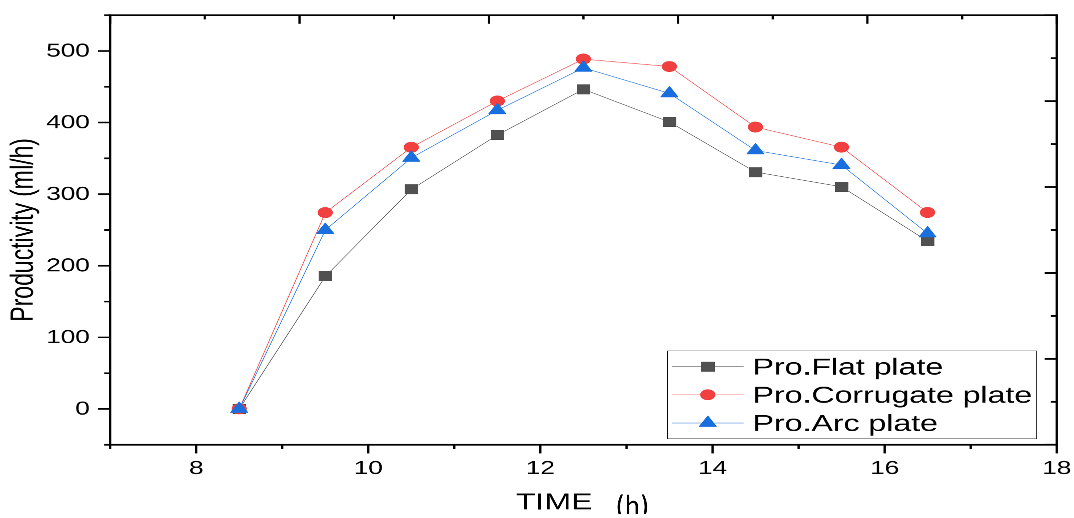


Figure. 5-20 Productivity Comparison Of SSSS With Corrugate And Arced Plates For N=10 With The Flat Plate.

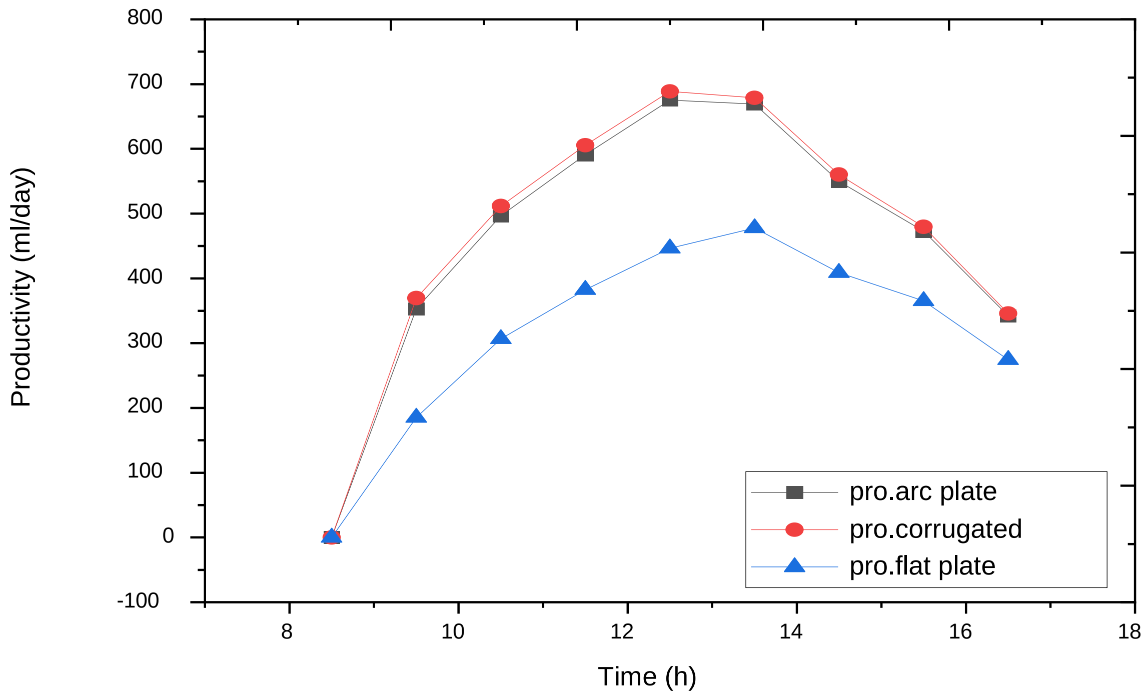


Figure. 5-21 Productivity Comparison Of Single Slope Solar Still With Corrugate And Arced Plates For N=20 With The Flat Plate.

5-3 Experimental Work Results

In this part of the chapter, all the experiments that have been done will be discussed. All experiments were conducted in Al-Diwaniyah-Iraq (latitude 31.99° N, longitude 44. 93° E). The period of the experiments were from 7 am to 5 pm. The experimental results of the improved solar still were compared with that of the conventional. The distillers are of the same dimensions, location, and environmental conditions. Because the productivity of solar stills strongly depends on the surrounding environmental conditions, all variables (wind speed, solar radiation intensity, ambient temperature) were recorded. The main purpose of this study is to enhance the productivity of solar stills. To achieve this purpose, the improvement of the evaporation process using a preheated water unit with a Fresnel lens is carried out.

5.3.1 The Effect Of water Temperature

Figure 5-22 shows the distribution of water temperature with time for all heights used during the experiments that were conducted. It is clear that the height 34 cm for preheated water unit-Fresnel lens holds the highest temperatures, The main reason is the increase in temperatures due to convection currents.

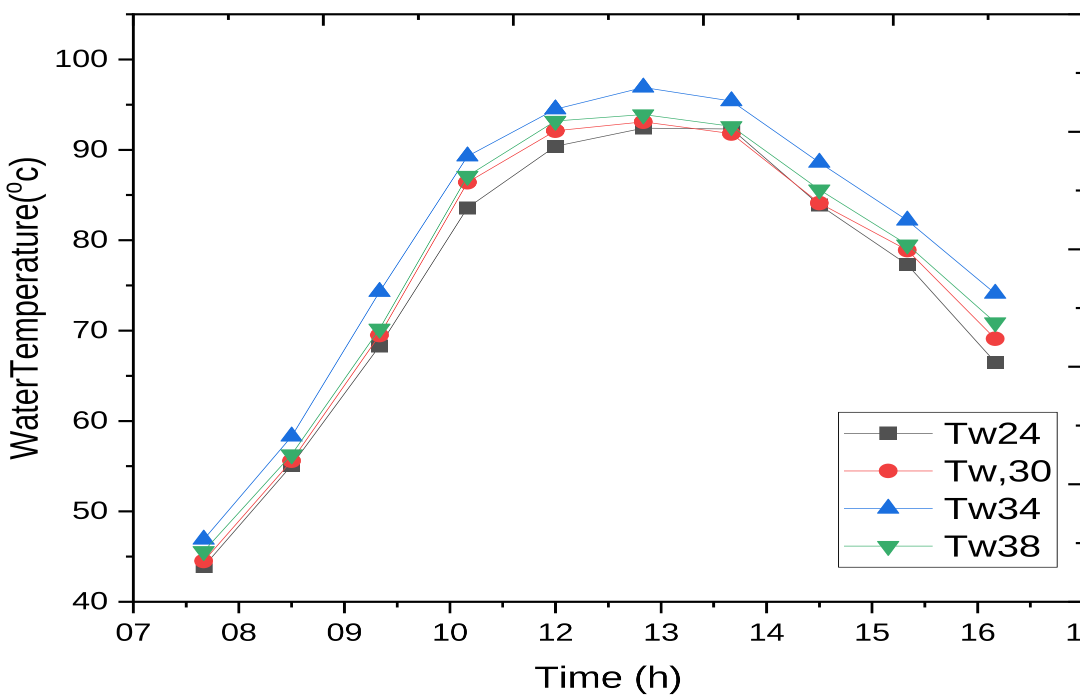
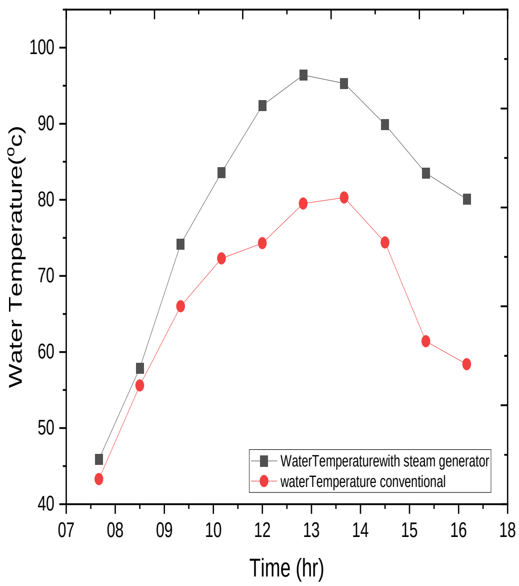
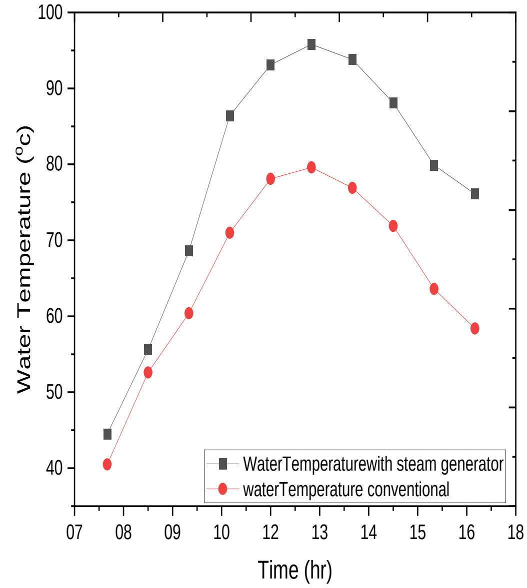


Figure. 5-22 The Distribution Of Temperatures For All Heights Of Preheated Water Unit-Fresnel Lens .

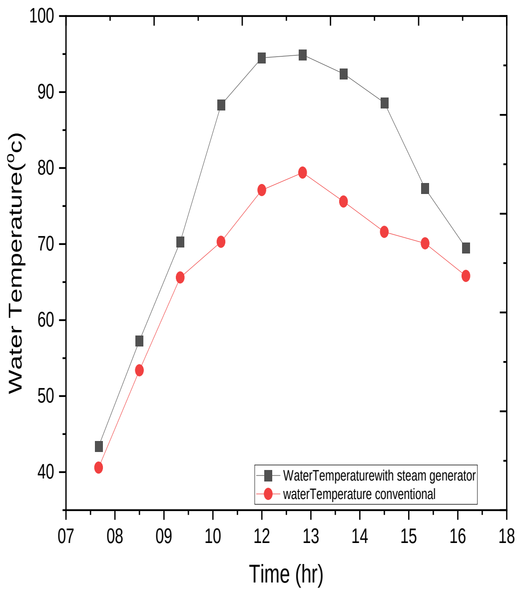
Figure 5-23 shows the water temperature behavior along the experiments time for the stills at different heights for the preheated water unit-Fresnel lens. It is clear from the figure that the maximum water temperature difference between the CSSSS and MSSSS is ($17.4^{O}C$) and occurs when the height of the preheated water unit-Fresnel lens is 34 cm.



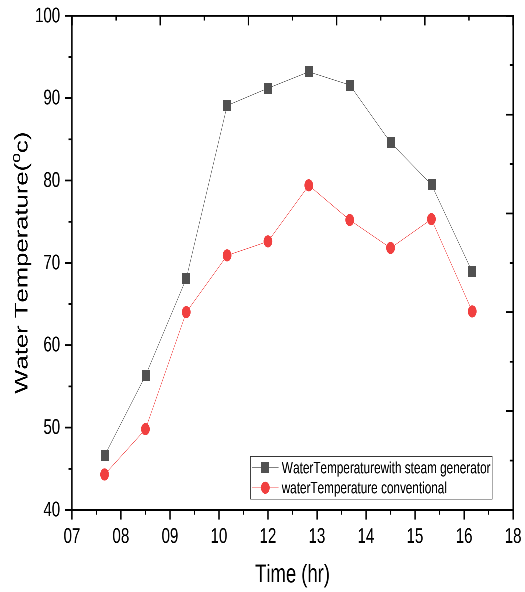
a- height of (24 cm)



b- height of (30 cm)



c- height of (34 cm)



d- height of (38 cm)

Figure. 5-23 Variation Of Water Temperature With Time Of Experiment At Different Heights Of Preheated Water Unit-Fresnel Lens

5.3.2 The Effect Of Water Productivity

Figures 5-24 and 5-25 show the behavior of solar radiation, ambient temperature, wind speed, and productivity along the time of experiment for CSSSS (H=0) and MSSSS (H=24 cm), on the day of 8/7/2022. It is clear from the figures that the most environmental parameters in addition to productivity are associated with the behavior of solar irradiation. The cumulative productivity for conventional still may reach 2110 ml/day, while for modified still is 2530 ml/day. This means that the productivity was enhanced by 19.9% with using the modified still.

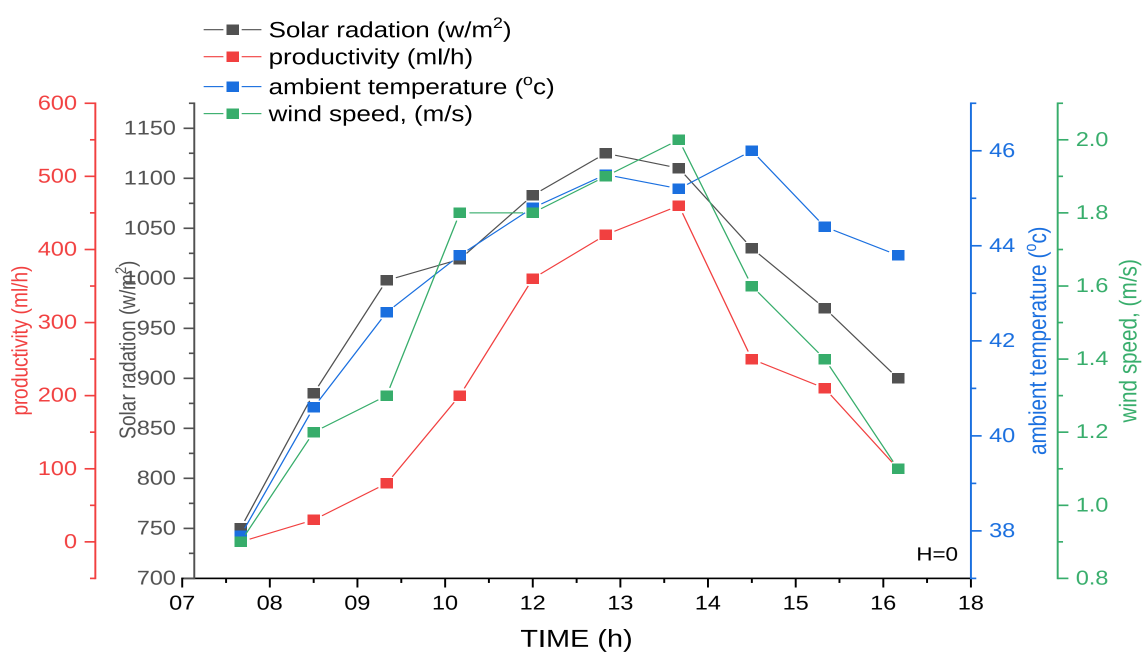


Figure 5-24 Variation Of Operating Parameters And Productivity With Time For The Conventional of Single Slope Solar Still.

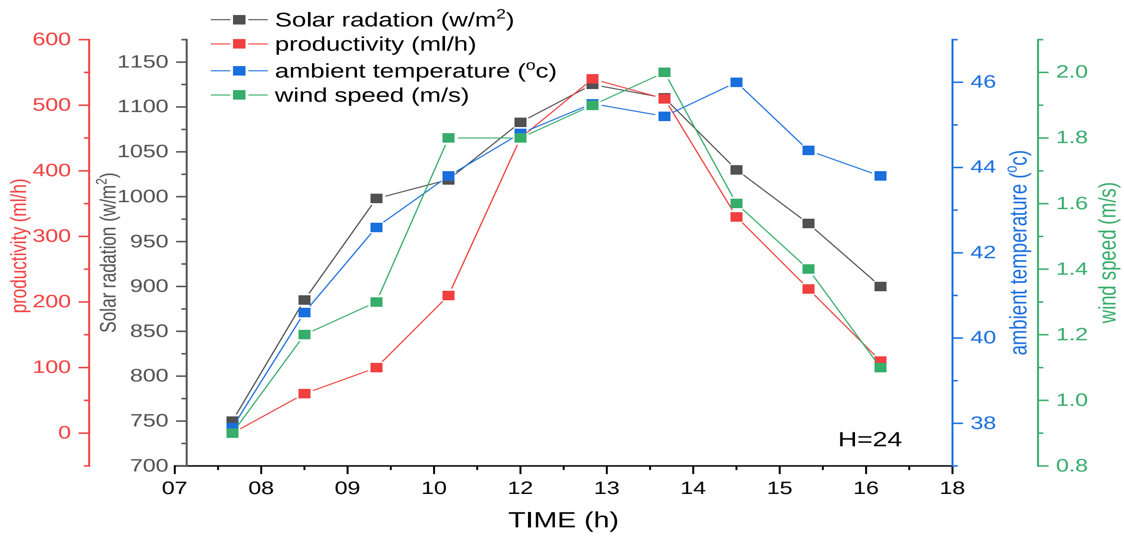


Figure. 5-25 Variation Of Operating Parameters And Productivity With Time For The MSSSS.

On the day of 9/7/2022, another experiment was conducted for CSSS and MSSSS with a height of 30 cm for the preheated water unit-Fresnel lens. The total productivity of the CSSSS was 2175 ml/day and enhanced for MSSSS by 21.8%. The variation of operation parameters and productivity with time for the two stills are shown in figures 5-26 and 5-27.

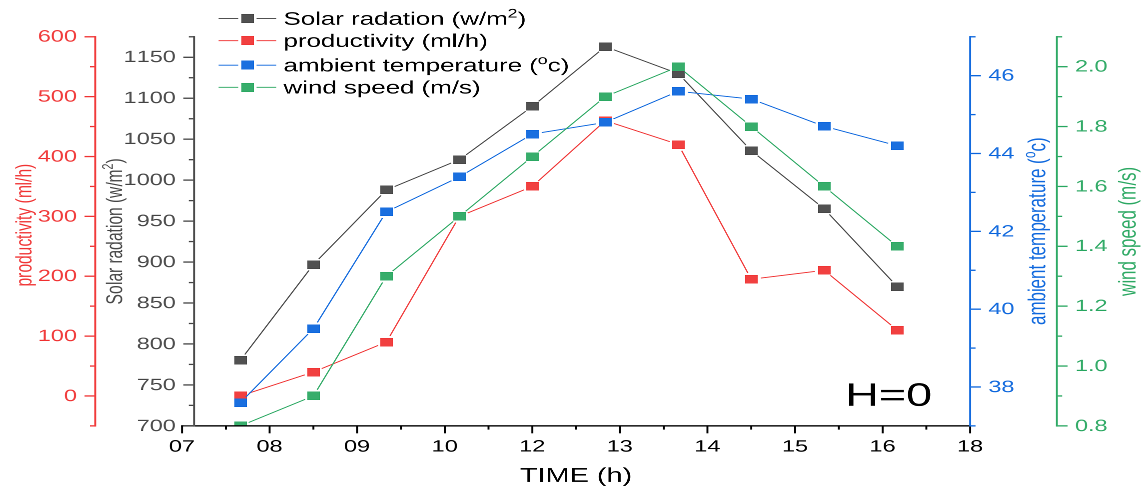


Figure. 5-26 Variation Of Operating Parameters And Productivity With Time For The Conventional Of Single Slope Solar Still

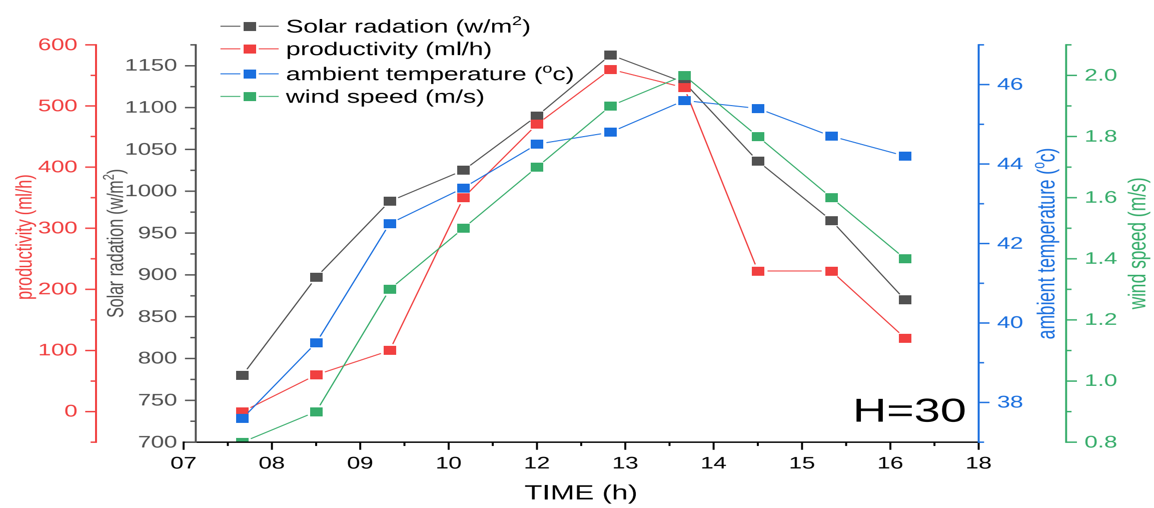


Figure 5-27 Variation Of Operating Parameters And Productivity With Time For The MSSSS.

For a preheated water unit-Fresnel lens with a height of 34 cm, an experiment performed on the day of 10/7/2022 to compare the performance of CSSSS and MSSSS. As clear from the figures 5-28 and 5-29, the hourly productivity increases with the solar intensity increase, and then it goes down after the middle of the day due to the decreasing solar intensity. Also, it is obtained from the figures that the total productivity of the CSSSS which reaches 2190 ml/day with an enhancement of 30.1% for MSSSS.

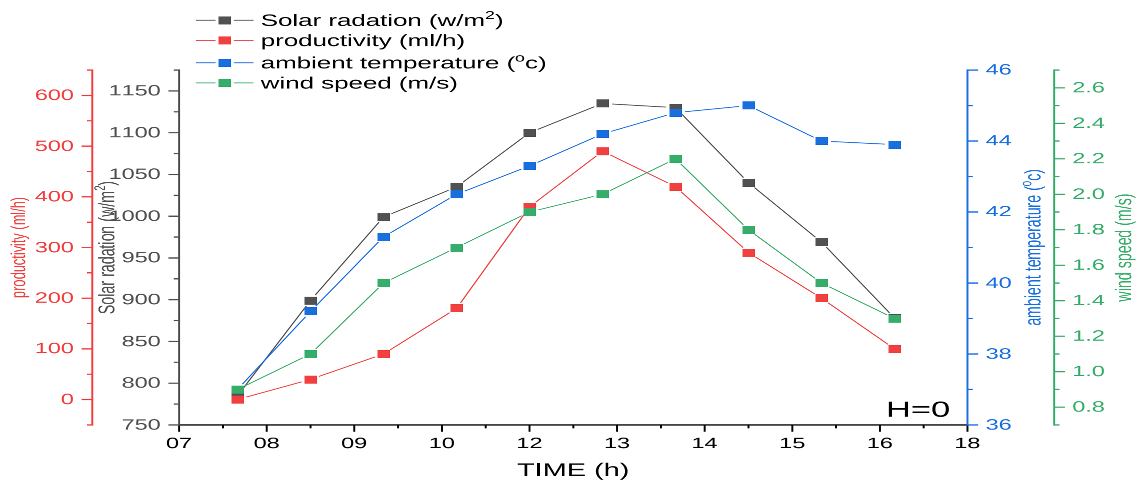


Figure. 5-28 Variation Of Operating Parameters And Productivity With Time For The Conventional of Single Slope Solar Still

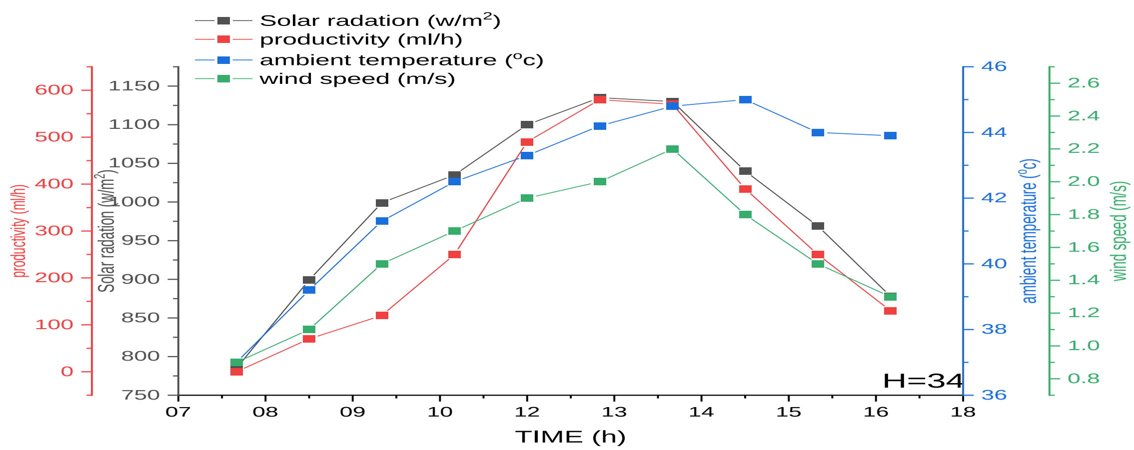


Figure 5-29 Variation Of Operating Parameters And Productivity With Time For The MSSSS.

Also, for achieved optimal water productivity, an experiment was carried out for a preheated water unit-Fresnel lens with a height of 38 cm on the day of 12/7/2022. It can be obtained from the figures 5-30 and 5-31, that the water productivity for the CSSSS is 2170 ml/day while for MSSSS is 2695 ml/day (i.e. 24.2% enhancement).

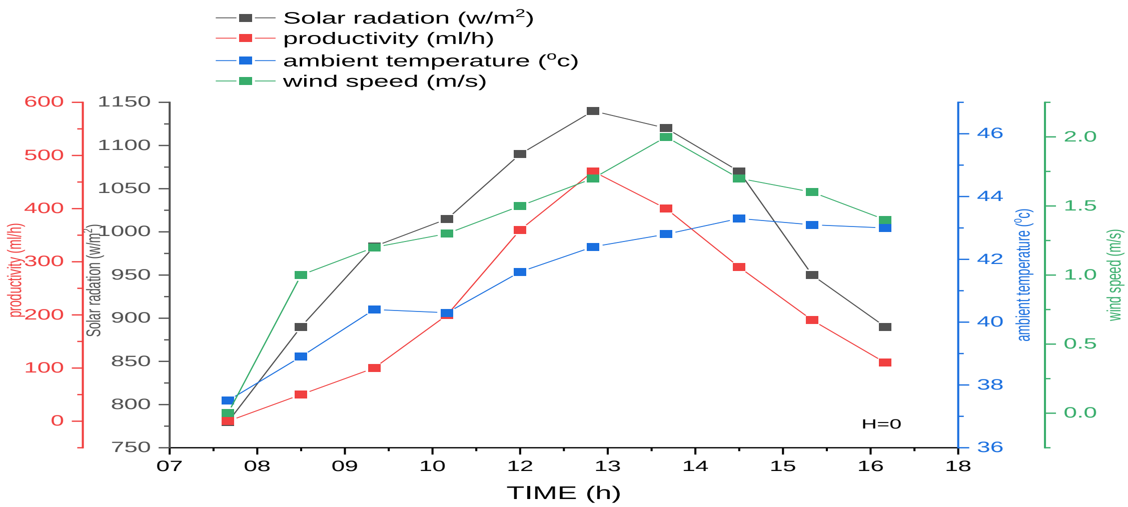


Figure. 5-30 Variation Of Operating Parameters And Productivity With Time For The Conventional of Single Slope Solar Still

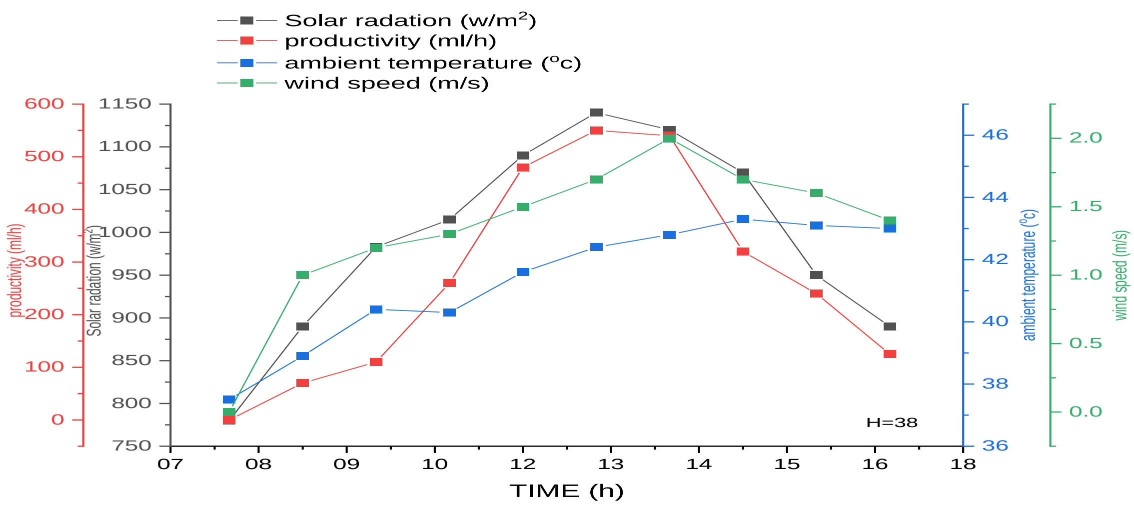


Figure. 5-31 Variation Of Operating Parameters And Productivity With Time For The MSSSS.

It is clear from the results of experiments above, that the optimal performance for MSSSS, when compared with the CSSSS performance, occurred at 34 cm height for preheated water unit-Fresnel lens, with productivity enhancement of 30.1% as shown in the figure 5-32.

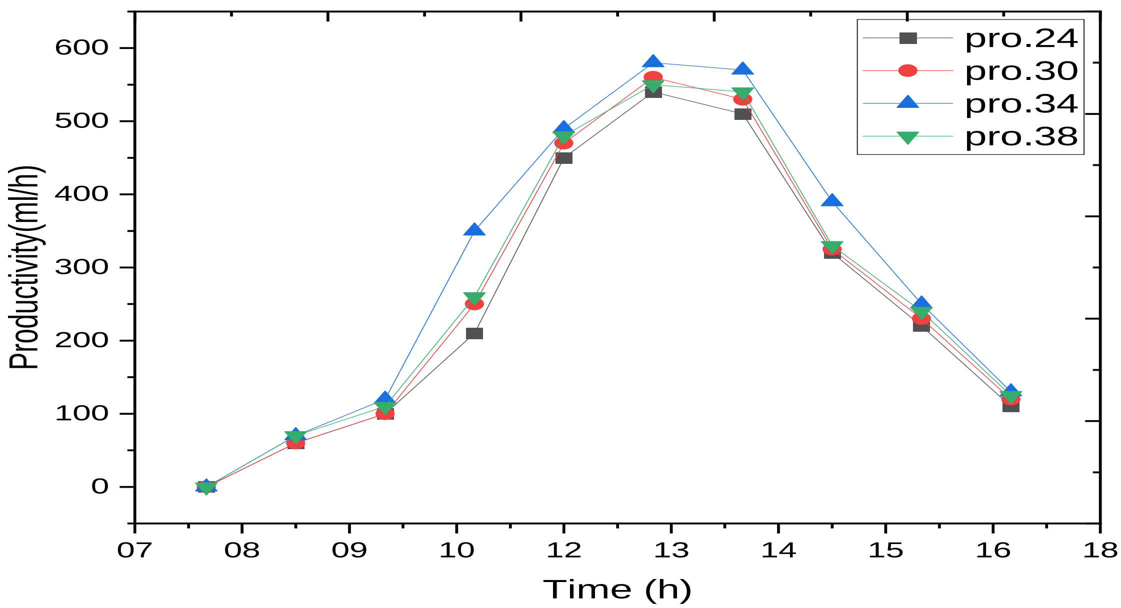


Figure. 5-32 Overall Productivity With Time For The MSSSS.

5.4 Numerical And Experimental Results Comparison Of The Conventional of Single Slope Solar Still

The results from numerical generated model (by COMSOL Multiphysics) and which obtained from the experiments for CSSSS at 10/7/2022 are carried out. The comparison process achieved for hourly productivity as shown in figure 5-33. It is clear from the figure that the numerical results are in a good agreement with that from of the experiments with maximum error not exceed 8%.

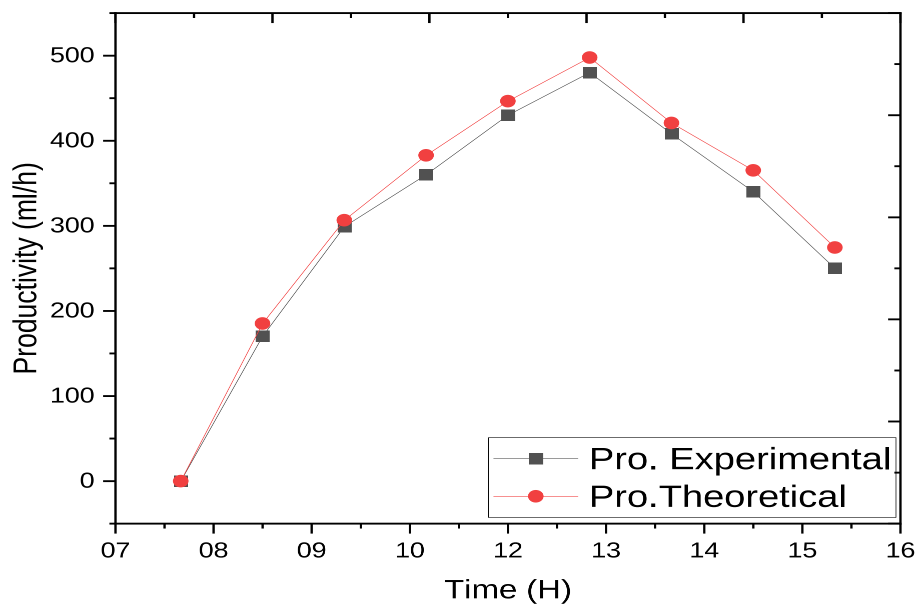


Figure. 5-33 Comparison Of Theoretical And Experimental Production Rate For The Conventional of Single Slope Solar Still (10/7/2022)

Chapter Six

Conclusions and Recommendations

Chapter Six

Conclusions and Recommendations

6.1 Conclusions

The current work studied the performance of a single-slope solar still (SSSS) to enhance its productivity. The work was in two stages: numerical and experimental. The results can be summarized as follows:

1 - In this part, the COMSOL metaphysics program was used to create a 3D model for SSSS with flat, corrugated, and arc plates. The optimization process for the corrugated and arced plates has been carried out for several cases with different dimensions to obtain the best design.

2 - The operation and environment parameters are considered throughout all the cases studied.

3 - The total productivity obtained from flat plate SSSS is 2.8436 kg/m^2.day with a maximum water temperature of 74 ^{o}C, The best results are obtained for a corrugated plate at (N=40, a= 0.125 and b=0.25) with a maximum water temperature of 95 ^{o}C, the total productivity of 6.434 kg/m^2.day and enhancement of 126 $^o/_o$ with respect to The Conventional of Single Slope Solar Still and The best results are obtained for the arc plate at (N=20, a= 0.25 and b=0.25) with a maximum water temperature of 82 ^{o}C, a total productivity of 4.2354 kg/m^2.day and enhancement of 48.94 $^o/_o$ with respect to CSSSS.

4- Experimental work focused on improving the performance of single-slope solar still using the Fresnel lens with the preheated water unit. Different heights were adopted between the base of the solar still and the surface of the preheated water unit to obtain the appropriate height that gives us the best production.

5-The total productivity obtained from flat plate SSSS is 2.190 kg/0.25m^2.day with maximum water temperature of 79 ^{o} C. And The best results are obtained for MSSS at 34cm height for preheated water unit-Fresnel lens, which are maximum water temperature of 96^{o}C, productivity of 2.850 kg/0.25 m^{2}with enhancement of 30.13$^o/_o$

6.2 Recommendations and Future Works

The suggestion for future work are as follows:

1 - Coating the absorbing plate with hybrid Nano materials to increase the productivity of their still.
2 - Utilizing solar dishes and reflectors together to receive a greater quantity of solar energy.
3 - Making different shapes of the groove in the base of the still.
4 - Using slanted bases and intermittent feeding in their still.
5 - Using automatic solar tracking system for preheated water unit-Fresnel lens.
6 - Using continuous and discontinuous cooling for glass cover together with preheated water unit-Fresnel lens

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Appendix A

A Calibration of Temperature Sensors

K-Type thermocouples were used to measure the temperatures of the constructed SSSS in this work. K-Type thermocouples are inexpensive sensors that work with a variety of electronic reading instruments. However, calibration tools are essential to assess the dependability and accuracy of these testing kits. In order to measure a set of temperatures together with a conventional mercury thermometer, the used 13 thermocouples were linked to an Applent digital data logger thermometer (AT-4532x) 32 channel type. The outcome of calibrating one of the used thermocouples is shown in Figure A-1, while table A-1 provides the results of calibrating the rest of the thermocouples.

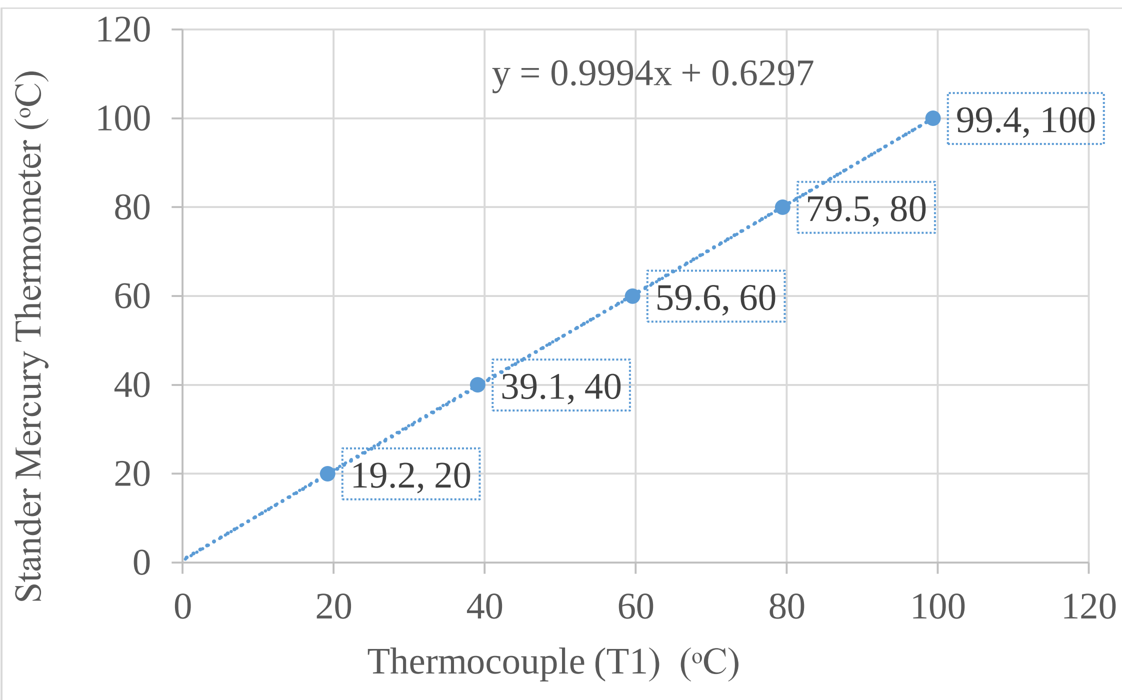


Figure A-1. Results of a K-Type thermocouple's calibration

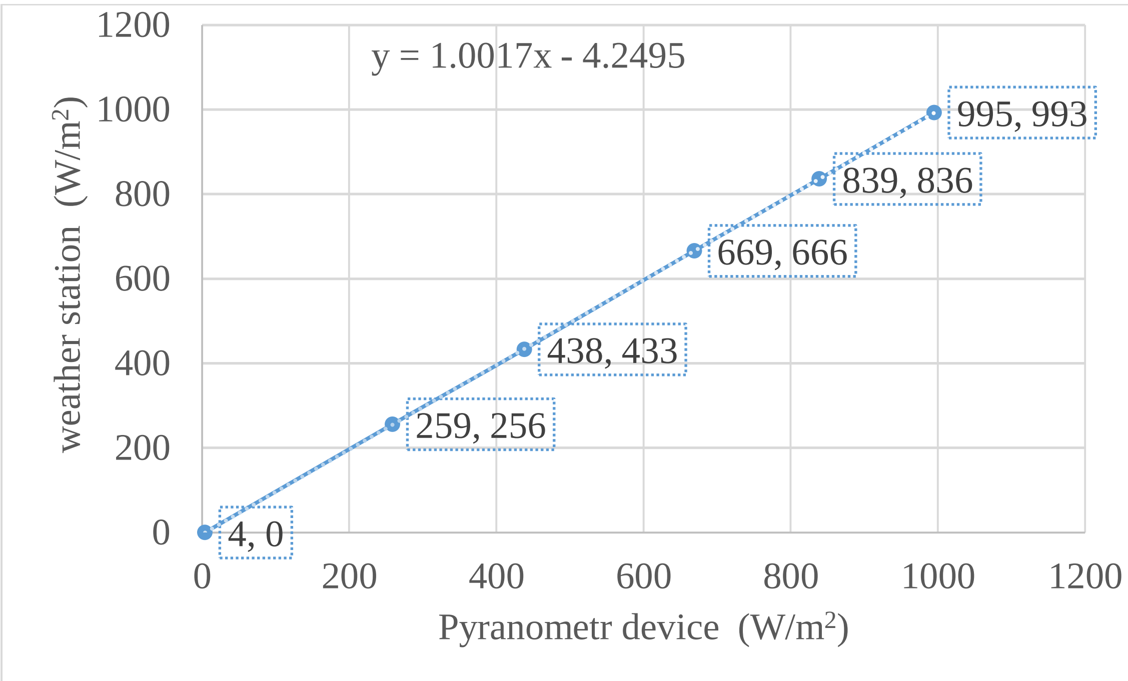
Table A-1 Calibration Results Of The K-Type Thermocouples

Sensor	Location	Correction formula
T1	Ambient	y=0.9994x+0.6297
T2	CSS- Inner glass cover	y=0.9859x+0.7394
T3	CSS- Outer glass cover	y=0.9917+.6774
T4	CSS- Most air	y=0.9964x+0.5432
T5	CSS- basin water	y=0.9991x+0.9936
T6	CSS-Galvanized plate	y=0.995x+0.8974
T7	MSS-Inner glass cover	y=0.9978x+1.0727
T8	MSS-Outer glass cover	y=0.9777x+1.2438
T9	MSS-Most air	y=1.0042x+0.6263
T10	MSS-basin water	y=1.0042x+0.6263
T11	MSS-Galvanized plate	y=0.9928x+0.7901

Appendix B

Calibration of solar intensities meter (Pyranometer)

TENMARS (TM-207) solar power meter was used to detect incident sun radiation (Pyranometer). The measurements taken by this equipment were verified against data gathered on the same experimentation dates by the Meteorological Department in Diwaniyah, Iraq. The Pyranometer's calibration findings are shown in Figure B-1.



FigureB-1. Calibration Results Of The Pyranometer

Appendix C

Calibration of Anemometer

The wind speeds were recorded utilizing an anemometer device (AM-4206M). Similar to the Anemometer the collected result was calibrated to the standard by the Meteorological Department in Diwaniyah, Iraq. Figure C-1 presents the calibration results of the AM-4206M.

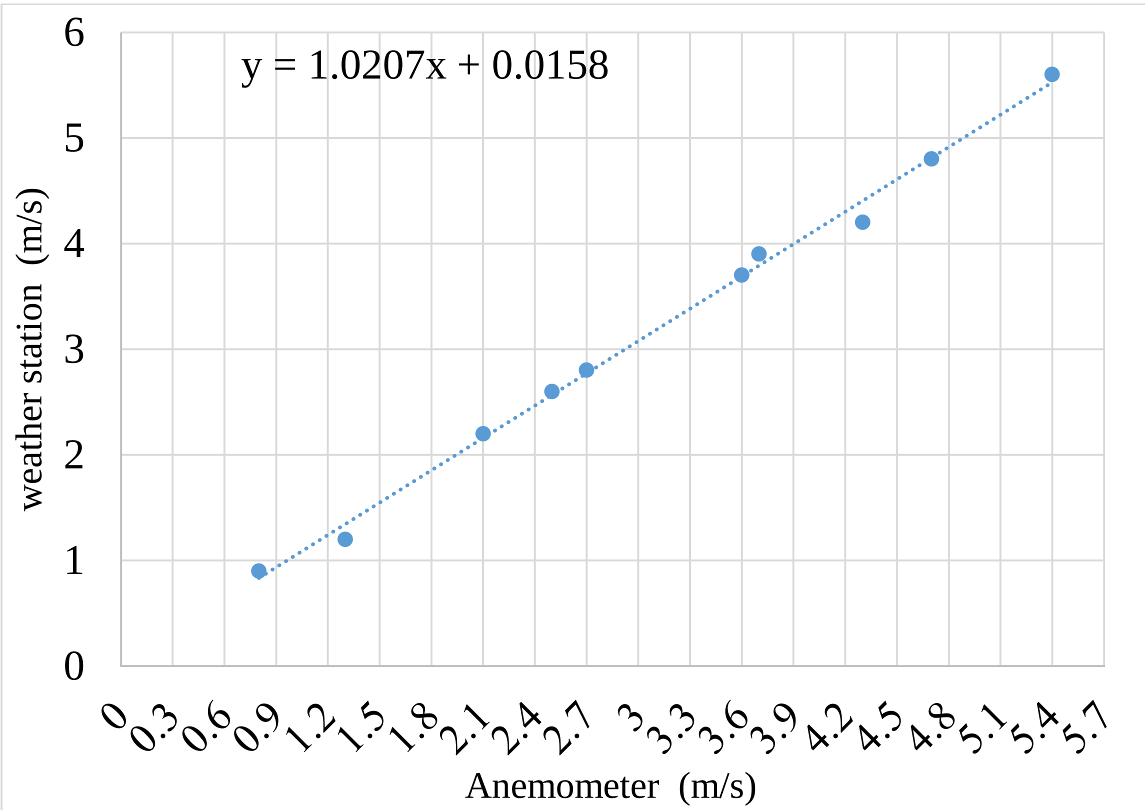


Figure C-1. Calibration Results Of The Anemometer

Appendix D

1- Doaa Chfat, Hassanain Ghani ,Ali sh.Shakir, “Modeling and experimental Study for Improving Single Slope Solar Still Performance using Different Shapes of Absorbent Plate” It has been published in

https://www.neuroquantology.com

1st International Conference on Achieving the Sustainable Development Goals

($6^{th} – 7^{th}$) June 2022 in Istanbul- Turkey

Final Acceptance Letter

Manuscript Number: 27

Dear: Duaa Chfat

Co-Authors: Hassanain Ghani Hameed and Ali Shakir Baqir

Congratulations!

It's a great pleasure to inform you that, after the peer review process, your manuscript entitled

(Productivity Enhancement of Solar Still by Solar Irradiation Collecting Techniques: Review Study)

had been **ACCEPTED** for participating in the **1st International Conference on Achieving the Sustainable Development Goals,** and considered for publication in **(AIP Conference proceeding).**

Thank you for your valuable participation in the ICASDG2022 conference.

Prof. Dr. Ahmed G. Wadday
ICASDG2022 Scientific Committee Chair | AIP Conference Proceeding Editor
$6^{th} – 7^{th}$ June 2022 | Istanbul | Turkey

الخلاصة

الماء هو أحد المتطلبات الأساسية لوجود الحياة في أي منطقة من الكون. توافر المياه ضروري لبقاء كل الحياة على الأرض. لجأ العديد من الباحثين إلى إيجاد حلول مناسبة للتخلص من ندرة المياه، وكانت أبسط هذه الحلول هي عملية التقطير الشمسي، خاصة في المناطق التي تكثر فيها ساعات شروق الشمس. اللقطات الشمسية هي أبسط الأجهزة المستخدمة للحصول على المياه المقطرة. قام العديد من الباحثين بمحاولات لتحسين أداء الطاقة الشمسية أحادية المنحدر. من بين أنواع الأحواض المختلفة من التصميمات الشمسية، لا تزال الطاقة الشمسية في الحوض الواحد هي الأكثر شهرة واختبارًا. العيب الرئيسي في اللقطات الشمسية أحادية التأثير هو انخفاض إنتاجيتها.

تم بذل العديد من المحاولات لتحسين الأداء الحراري للمقطرات الشمسية أحادية الحوض لحل هذه المشكلة. أحد هذه الأساليب هو توسيع المنطقة التي تمتص الطاقة الشمسية، ومع ذلك، فإن هذا النهج يحتاج إلى مساحة ضخمة. يتم تحقيق هذا الهدف باستخدام لوحة الامتصاص المموجة دون الحاجة إلى زيادة حجم الحوض. زيادة معدلات نقل الحرارة من الصفيحة الممتصة إلى مياه الحوض ناتجة عن زيادة مساحة امتصاص الإشعاع الشمسي، مما يزيد من الإنتاجية. فحص نظريا عملية تغيير أشكال الصفيحة الماصة لمنحدر واحد لا يزال (SSSS) باستخدام برنامج COMSOL (5.5) لتطوير والتحقق من صحة النموذج الرياضي ثلاثي الأبعاد.

تضمن التحقيق عملية تحسين للحصول على أفضل تصميم للألواح المموجة والمقوسة. أيضًا، يتم إجراء المقارنة بين نتائج الألواح الماصة المسطحة والمموجة والمقوسة. كشفت الدراسة أن درجة حرارة الماء القصوى وإنتاجية SSSS بصفيحة مسطحة يصل٧٤ درجه مئوية و ٢.٨٤٣٦ كجم/م٢ على التوالي. في حين أن SSSS مع صفيحة ماصة مموجة لها درجة حرارة وإنتاجية قصوى أعلى للمياه تصل إلى ٩٥ درجة مئوية و ٦.٤٣٤ كجم/م٢ على التوالي، عندما (N = 40 و a = 0,125 b = 0,25) وبألواح مقوسة تصل إلى ٨٢ درجة مئوية و ٤,٢٣٥٤ كغم/م٢ على التوالي عندما (N = 20 a = 0,25 b = 0,25). و مستوى المياه داخل المقطر لجميع الحالات المدروسة هو ١ سم. أما بالنسبة للتجارب التجريبية لزيادة أداء الطاقة الشمسية التقليدية ذات المنحدر الواحد، فقد تم دمج النظام التقليدي (SSSS) مع عدسة فرينل و مسخن الماء .

تم تتبع أشعة الشمس يدويًا خلال فترة التجربة وحافظت على عمق الماء داخل حوض لا يزال على ارتفاع ١ سم أثناء الدراسة. أجريت التجارب على ارتفاعات مختلفة بين سطح مولد البخار وقاعدة الطاقة الشمسية الثابتة. الارتفاعات ٢٤ و٣٠ و ٣٤ و ٣٨ سم بإنتاجية مقابلة تبلغ ٢.٥٣٠ و ٢.٦٥٠ و ٢.٨٥٠ و ٢.٦٩٥ كجم/٠.٢٥م٢ على التوالي. يتم الحصول على أفضل النتائج في ارتفاع ٣٤ سم مع درجة حرارة قصوى للمياه ٩٦درجه مئوية وتحسين الإنتاجية بنسبة ٣٠.١٣٪ مقارنه مع المقطر الشمسي التقليدي. تتم مقارنة نتائج الدراسات العددية والتجريبية للصفيحة المسطحة SSSS وكان هناك توافق جيد.

التصميم الحراري للمقطر شمسي احادي الميل مع وحده اعاده التسخين بواسطة تطبيقات عدسة فرينل

رسالة مقدمة الى

قسم هندسة تقنيات ميكانيك القوى

كجزء من متطلبات نيل درجة الماجستير في

هندسة تقنيات ميكانيك القوى / الحراريات

تقدم بها

دعاء جفات حسن العبودي

إشراف

الأستاذ المساعد الدكتور حسنين غني حميد

الأستاذ الدكتور علي شاكر باقر

٢٠٢٣