REPUBLIC OF IRAQ

MINISTRY OF HIGHER EDUCATION AND SCIENTIFIC RESEARCH

AL-FURAT AL-AWSAT TECHNICAL UNIVERSITY

ENGINEERING TECHNICAL COLLEGE- NAJAF

INVESTIGATION THE EFFECT OF ENHANCING EVAPORATION – CONDENSATION PROCESS ON A CONVENTIONAL SOLAR STILL PERFORMANCE

ZAHRAA ABDULKAREEM JAAFAR

M.TECH.

IN MECHANICAL ENGINEERING TECHNIQUES OF POWER

2021

INVESTIGATION THE EFFECT OF ENHANCING EVAPORATION – CONDENSATION PROCESS ON A CONVENTIONAL SOLAR STILL PERFORMANCE

A THESIS

SUBMITTED TO THE DEPARTMENT OF MECHANICAL ENGINEERING TECHNIQUES OF POWER

AS PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR MASTER OF THERMAL TECHNOLOGIES DEGREE IN MECHANICAL ENGINEERING TECHNIQUES OF POWER

(M.TECH.)

BY

ZAHRAA ABDULKAREEM JAAFAR

(B.Tch. Automobile. Eng.)

Supervised by

Asst. Prof.

Dr. HASSANAIN GHANI HAMEED

2021

بسم الله الرحمن الرحيم

قَالُوا سُبْحَانَكَ لاَ عِلْمَ لَنَا إِلاَّ مَا عَلَّمْتَنَا إِنَّكَ
أَنتَ الْعَلِيمُ الْحَكِيمُ

صدق الله العلي العظيم

سورة البقرة (اية 32)

Disclaimer

I confirm that the work submitted in this thesis is my own work and has not been submitted to other organization or for any other degree.

Signature :
Name : Zahraa Abdulkareem Jaafar
Date : / / 2021

Acknowledgement

All Praise Be to ALLAH for His Endless Blessings and Guidance to complete this work.

I would like to offer my profound respects and sincere gratitude to my supervisor Asst. Prof. Dr. Hasnain G. Hameed for his support during the research period and guidance to accomplish this work. Special thanks go to the head and members of the Mechanical Power Technical Engineering Department for their generous assistance.

I would like to thank all those who have supported me to conduct this work. Special thanks to my classmates for their great assistant and great encouragement.

My deepest thanks, gratitude is due to my life journey companion.

Thanks to my dear parents and brothers for their patience, support and encouragement throughout my life.

ZAHRAA ABDULKAREEM JAAFAR

2021

Supervisor Certification

I certify that this thesis titled **“ INVESTIGATION THE EFFECT OF ENHANCING EVAPORATION – CONDENSATION PROCESS ON A CONVENTIONAL SOLAR STILL PERFORMANCE ”** which is being submitted by **Zahraa Abdulkareem Jaafar** was prepared under my supervision at the Power mechanic Techniques Engineering Department, Engineering Technical College-Najaf, AL-Furat Al-Awsat Technical University, as a partial fulfilment of the requirements for the Master degree of Technical Thermal Engineering.

Signature:
Name: **Asst. Prof. Dr. Hasnain Ghani Hameed**
(Supervisor)
Date: / / 2021

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

Signature:
Name: Asst. Prof. Dr. Dafer Manea Hachim
(Head of mechanical Eng. Tech. of power)
Date: / / 2021

Linguistic Certification

This is to certify that this thesis entitled **"Investigate the effect of enhancing evaporation – condensation process on a conventional solar still performance"** was reviewed linguistically. Its language was amended to meet the style of the English language.

Signature:

Name:

Date:

Abstract

Pure water represents 1% of the water around the earth. Some remote areas and deserts from suffer a lack of drinking water there are. Many attempts for producing pure water have been done and solar distillation was one of them. Solar still considered as the proper solution due to its fabrication low cost, easy to install as well as it does not need any source of power rather than solar energy. Solar distillation has low productivity rates as compared to human daily needs. This study investigates the effect of improving the main processes that control solar still productivity. Both evaporation and condensation processes have been improved in different ways. Several experiments were also conducted to investigate those effects at the technical engineering college/ Najaf /Iraq (32.1 N˚ Lat. , 44.19 E˚ Long.). Several improvements have been presented in this study such as a galvanized iron wicks, a special design solar collecting tank, evacuated copper pipes as well as cooling water channels. The solar still thermal performance was significantly enhanced either when improving the evaporation or condensation processes. The freshwater productivity rates were also enhanced by about 44.83% when using a solar collecting tank. While it enhanced about 86.65%, 72.53% , and 151% when using wick with 25* 25 mm, 50* 50 mm grid size and combined them together respectively. Evacuated copper pipes are also used to improve the productivity in this study with 7 and 15mm diameters and 100 %, 50 % filling water ratios. The maximum pure water production recorded is 90.09% utilizing the 15 mm evacuating copper pipes filled with 50% water compared with simultaneously working conventional solar still. condensation process is also improved in this study by using water channels (N shape and U shape) on the front glass cover to reduce its temperature using three water flow rates 1 , 1.5 , and 2L/min. The solar still performance was enhanced by 56 % and

45.71 % when using N and U shapes water cooling channels respectively with a water flow rate of 2 L/min.

Table of Contents

Acknowledgement ii

Supervisor Certification iii

Linguistic Certification iv

NOMENCLATURE xv

ABBREVIATIONS xv

Chapter One 1

1.1 Background 1

1.2 Solar Energy 2

1.3 Solar Energy Application 3

1.4 Solar Desalination 3

1.4.1 Solar stills 4

1.4.1.1 Advantages 5

1.4.1.2 Disadvantages 5

1.4.2 Types of Solar Stills 5

1.4.3 Single-Slope Solar Still 6

1.5 Scope and Objectives 8

Chapter Two 10

2.1 Introduction: 10

2.2 Summery 27

Chapter Three 28

3.1. Introduction 29

3.2 Construction and Materials 29

3.2.1 Basin Liner 29

3.2.2 Glass Cover 30

3.2.3 Insulation and Sealant.......... 30
3.2.4 Distillate Channel.......... 31
3.2.5 connecting Tubes.......... 31
3.2.5.1 Distilled Water Collection Port.......... 31
3.2.6 Solar Still Frame.......... 31
3.3 Measurements.......... 31
3.3.1 Pure Water Measuring Instrument.......... 32
3.3.2 Temperatures Sensing Device.......... 32
3.3.3 Solar Radiation Measuring Device.......... 33
3.3.4 Wind Speed Measuring Device (Anemometer).......... 33
3.4 Modified Still Model.......... 34
3.4.1 Evaporation Enhancement.......... 34
3.4.1.1 Solar Collecting Water Tank.......... 34
3.4.1.2 Evacuated Copper Tubes.......... 36
3.4.1.3 Galvanized Wick.......... 37
3.4.2 Condensation Enhancement.......... 39
3.4.2.1 Water Channel.......... 39
3.5 Distilled Water Producing Mechanism.......... 40
3.6 Process of Conducting The Experiment.......... 40
4.1 introduction.......... 43
4.2 Results.......... 43
4.2.1 Evaporation Enhancement.......... 43
4.2.1.1 Solar Collecting Water Tank.......... 43
4.2.1.2 Evacuated Copper Pipes.......... 48
4.2.1.2.1 Copper Tube With 100% Filling.......... 48

4.2.1.3 Galvanized Wick 57
4.2.2 Condensation Enhancement 66
4.2.2.1 Water Channel 66
Appendix -A- 87
A.1 Introduction 87
A.2 Thermocouple Calibration 87
Appendix – B – 99
Appendix – C – 101
Appendix -D 102
Appendix -E 103

List of Figures

Figure 1.1 (A): World direct normal solar irradiation [4] 3
Figure 1.1(B): Iraqi solar irradiation[5] 4
Figure 1.2 single slope solar still 7
Figure 3.1: Pictorial and schematic view for the solar still 30
Figure 3.2 data logger 32
Figure 3.3 Solar radiation measuring device 33
Figure 3.4 Wind speed measuring device (anemometer) 34
Figure 3.5 Pictorial views for A: Modified solar still and B: Solar collecting tank 35
Figure 3.6 Schematic view of A: tank and control valves and B: tank feeding mechanism 36
Figure 3.7 Evacuated copper tube 37
Figure 3.8 Types of galvanized wicks 38
Figure 3.9 Pictorial view of the tested wicks 38
Figure 3.10 cooling water channels 39
Figure 3.11 Glass cooling water channel 40
Figure 4.1*:* variation of temperature and solar radiation with measurement time for conventional solar still 44
Figure 4.2: variation of temperature and solar radiation with measurement time for modified solar still 44
Figure 4.3: variation of input water temperature with the time of the experiment 45
Figure 4.4: variation of basin water temperature with the time of the experiment 46
Figure 4.5: variation of vapor temperature with time of the experiment 46
Figure 4.6 variation of glass cover temperature with the time of the experiment 47

Figure 4.7 productivity variation with time for conventional and modified solar stills 47
Figure 4.8: variation of temperature and solar radiation with time for conventional solar still 49
Figure 4.9: variation of temperature and solar radiation with time for solar still with 15 mm diameter copper pipe 49
Figure 4.10: variation of temperature and solar radiation with time for solar still with 7 mm diameter copper pipe 50
Figure 4.11: variation of basin water temperature with the time of the experiments 50
Figure 4.12: variation of vapor temperature with the time of the experiment 51
Figure 4.13 variation of glass cover temperature with the time of the experiment 51
Figure 4.14 productivity variation with time for the three types of stills 52
Figure 4.15: variation of temperature and solar radiation with measurement time for conventional solar still 53
Figure 4.16: variation of temperature and solar radiation with measurement time for solar still with 15 mm diameter copper pipe 54
Figure 4.17: variation of temperature and solar radiation with measurement time for solar still with 7 mm diameter copper pipe 54
Figure 4.18: variation of basin water temperature with the time of the experiment 55
Figure 4.19: variation of basin water temperature with the time of the experiment 55
Figure 4.20: variation of basin water temperature with the time of the experiment 56
Figure 4.21 productivity variation with time for the three types of stills 57
Figure 4.22: variation of temperature and solar radiation with measurement time for conventional solar still 58

Figure 4.23: variation of temperature and solar radiation with measurement time for solar still with 25 *25 grid size wick still 59
Figure 4.24: variation of temperature and solar radiation with measurement time for still with 50 * 50 grid size wick 59
Figure 4.25 variation of basin water temperature with the time of the experiment 60
Figure 4.26 variation of vapor temperature with the time of the experiment 60
Figure 4.27 variation of glass cover temperature with the time of the experiment 61
Figure 4.28 productivity variation with the time the experiment 61
Figure 4.29: variation of temperature and solar radiation with measurement time for conventional solar still 63
Figure 4.30: variation of temperature and solar radiation with measurement time for solar still with double wicks (25 * 25 and 50 *50 grids size) 63
Figure 4.31: variation of temperature and solar radiation with measurement time for solar still with single wick (25 *25 grid size) 64
Figure 4.32 variation of basin water temperature with the time of the experiment 64
Figure 4.33 variation of vapor temperature with the time of the experiment 65
Figure 4.34 variation glass cover temperature with the time of the experiment 65
Figure 4.35 variation of productivity with the time of the experiment 66
Figure 4.36: variation of temperature and solar radiation with measurement time for conventional solar still 68
Figure 4.37: variation of temperature and solar radiation with measurement time for solar still with N shape water channel at 1 L/min 68
Figure 4.38: variation of temperature and solar radiation with measurement time for solar still with U shape water channel at 1 L/min. 69
Figure 4.39: variation of basin water temperature with the time of the experiment 69
Figure 4.40: variation of vapor temperature with the time of the experiment 70

Figure 4.41: variation of glass cover temperature with the time of the experiment 70
Figure 4.42: variation productivity with the time of the experiment 71
Figure 4.43: variation of temperature and solar radiation with measurement time for conventional solar still 72
Figure 4.44: variation of temperature and solar radiation with measurement time for solar still with N shape water channel at 1.5 L/min. 72
Figure 4.45: variation of temperature and solar radiation with measurement time for solar still with U shape water channel at 1.5 L/min. 73
Figure 4.46: variation of basin water temperature with the time of the experiment 73
Figure 4.47: variation of vapor temperature with the time of the experiment 74
Figure 4.48: variation of glass cover temperature with the time of the experiment 74
Figure 4.49: variation of productivity with the time of the experiment 75
Figure 4.50: variation of temperature and solar radiation with measurement time for conventional solar still 76
Figure 4.51: variation of temperature and solar radiation with measurement time for solar still with N shape water channel 76
Figure 4.52: variation of temperature and solar radiation with measurement time for solar still with U shape water channel 77
Figure 4.53: variation of basin water temperature with time of experiment 77
Figure 4.54: variation of vapor temperature with the time of the experiment 78
Figure 4.55: variation of glass cover temperature with the time of the experiment 78
Figure 4.56: variation of productivity with the time of the experiment 79
Figure A .1: Thermocouple (S1) calibration, ISS 1, water basin 88
Figure A .2: Thermocouple (S2) calibration, ISS 1, water basin 88
Figure A .3: Thermocouple (S3) calibration, ISS 1, vapor 89
Figure A .4: Thermocouple (S4) calibration, ISS 1, vapor 89

Figure A .5: Thermocouple (S5) calibration, ISS 1, glass cover 90
Figure A .6: Thermocouple (S6) calibration, ISS 1, glass cover 90
Figure A .7: Thermocouple (S7) calibration, ISS 2, basin water 91
Figure A .8: Thermocouple (S8) calibration, ISS 2, basin water 91
Figure A .9: Thermocouple (S9) calibration, ISS 2, vapor 92
Figure A .10: Thermocouple (S10) calibration, ISS 2, vapor 92
Figure A .11: Thermocouple (S11) calibration, ISS 2, glass cover 93
Figure A .12: Thermocouple (S12) calibration, ISS 2, glass cover 93
Figure A .13: Thermocouple (S13) calibration, CSS, basin water 94
Figure A .14: Thermocouple (S14) calibration, CSS, basin water 94
Figure A .15: Thermocouple (S15) calibration, CSS, vapor 95
Figure A .16: Thermocouple (S16) calibration, CSS, vapor 95
Figure A .17: Thermocouple (S17) calibration, CSS, glass cover 96
Figure A .18: Thermocouple (S18) calibration, CSS, glass cover 96
Figure A .19: Thermocouple (S19) calibration, ambient 97
Figure A .20: Thermocouple (S20) calibration 97
Figure A .21: Thermocouple (S21) calibration 98
Figure A .22: Thermocouple (S22) calibration 98
Figure B.1: 1 stage rotary vane vacuum pump 99
Figure B.2: low pressure gauge 100
Figure B.3 special feeding mechanism 100
C.1 Pyranometer calibration 101
D.1 Anemometer calibration 102

NOMENCLATURE

Symbol	Definition	Unit
rad	Solar radiation	w/m^2
temp	temperature	$^{\circ}C$
	productivity	$L/m^2.hr$
	time	hr

ABBREVIATIONS

Symbol	Description
mod	Modified
conv	Conventional
ISS	Improved solar still
CSS	Conventional solar still
S	Sensor

Chapter One
Introduction

Chapter One
Introduction

1.1 Background

The essential element on planet earth is water, and it what gives life. Water is necessary for life.

About seventy percent of the earth covered with water, yet only 1% of this water can be used for human consumption [1].

Many remote, desert, and conflict areas suffer the lack of pure water.
Water distillation is one of the most reliable solutions for free solar radiation to convert raw water into drinking water. The sources of water on earth are from rivers, fountains, and wells that can meet many of humanity's needs of water like industry and agriculture, but these sources of water suffer many pollutions, microorganisms, and high level of salts, due to political conflicts and desertification. Too many people cannot get enough drinking water, and according to UNESCO (2006), the number reaches one billion. Nowadays, human water demand is increasing day after day due to the increase in population and industry and agriculture needs. The limited sources, on the one hand, and the drinking water storage, on the other hand, cannot meet these demands.

Therefore, the lack of drinking water reaches the towns and villages as well. The inappropriate ways of disposal of the medical and industrial wastes cause different types of pollutions in the underground water by the rain, making most of the under-ground water not be directly consumed by humans. One of the most difficult challenges in the future is to provide the needed amount of pure water for all humans around the world [2]

Due to global warming, seawater areas are continuously expanding at the expense of the freshwater regions. Many people had to relocate to the place where they take their freshwater due to the high level of salt[3]

Many people in remote places facing the risk of having medical problems leading to the death of many of their children, according to the UNESCO in its report in 2006, about four thousand newborn babies have passed away by diarrhea only in individual third world counties[1].

1.2 Solar Energy

Solar energy is clean, sustainable, powerful, and renewable energy, generated in the sun and emitted to all the universe equally in the form of electromagnetic waves throughout the space until it reaches a body which absorbing it, causing arise in its internal energy and temperature[2]

The high potential of solar energy around the globe and especially in Iraq, see fig. 1.1 (A and B), put it in the lead of the renewable energy sources. If used to produce healthy pure water, it would be one of the most successful solutions for pure water production as the other forms of energy are retreating.

Solar distillation is not a new technology to produce pure water, but it didn't take enough attention in the past decades, and it briefly studies it could be an efficient solution to the drinking water lack in Africa and the middle east. As the solar still is easy to install barely, everyone can install and use it to produce potable water, which put it in the lead of available solutions

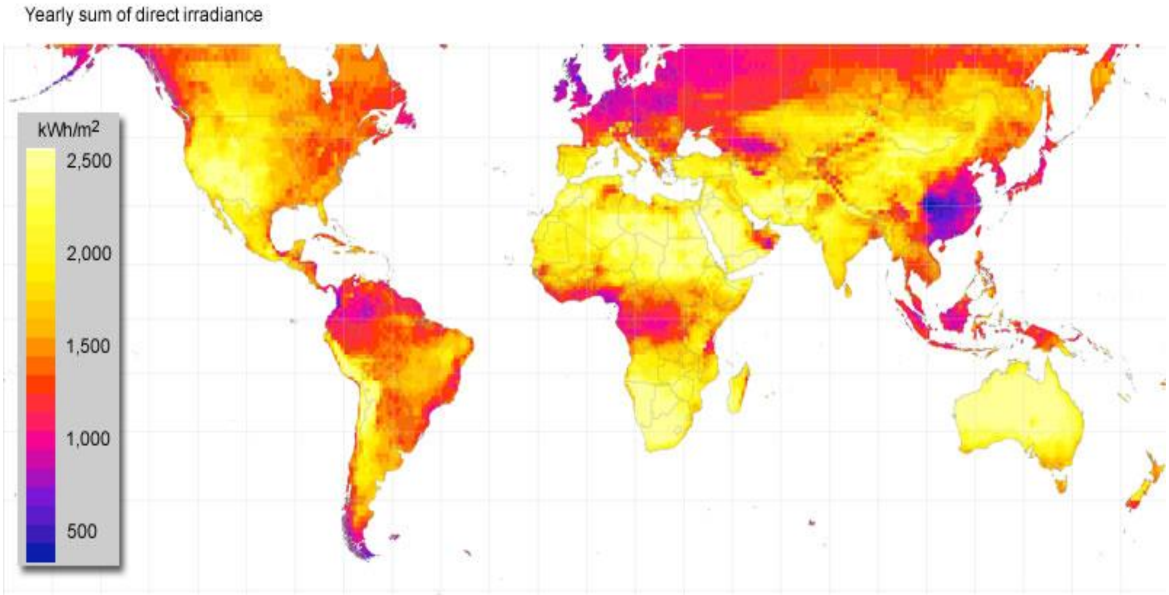


Figure 1.1 (A): World direct normal solar irradiation [4]

1.3 Solar Energy Application

The sun is the closest star to our planet and provides it with energy and life. The sun emits a tremendous amount of energy, and about 1367 Watt hits each square meter of our ionosphere. About 80% of that energy reaches the ground and could be used in different applications such as power production, water warming, solar cooking, air heating, greenhouses, and water distillation.

1.4 Solar Desalination

The main parameters that the solar distillation depends on are the evaporation and condensation processes. In the solar still, the evaporation process of the raw water in the still basin caused by the energy absorbed from the incident solar radiation through the front glass generating a decent amount of saturated water vapor that condenses on the inner side of the inclined front glass, forming a distilled water drops that collected in a particular collector. As with all production devices, the main important parameter is the manufacturing cost

. In solar stills, it is just for the initial building cost as it needs no energy for the operation process except the free solar radiation.

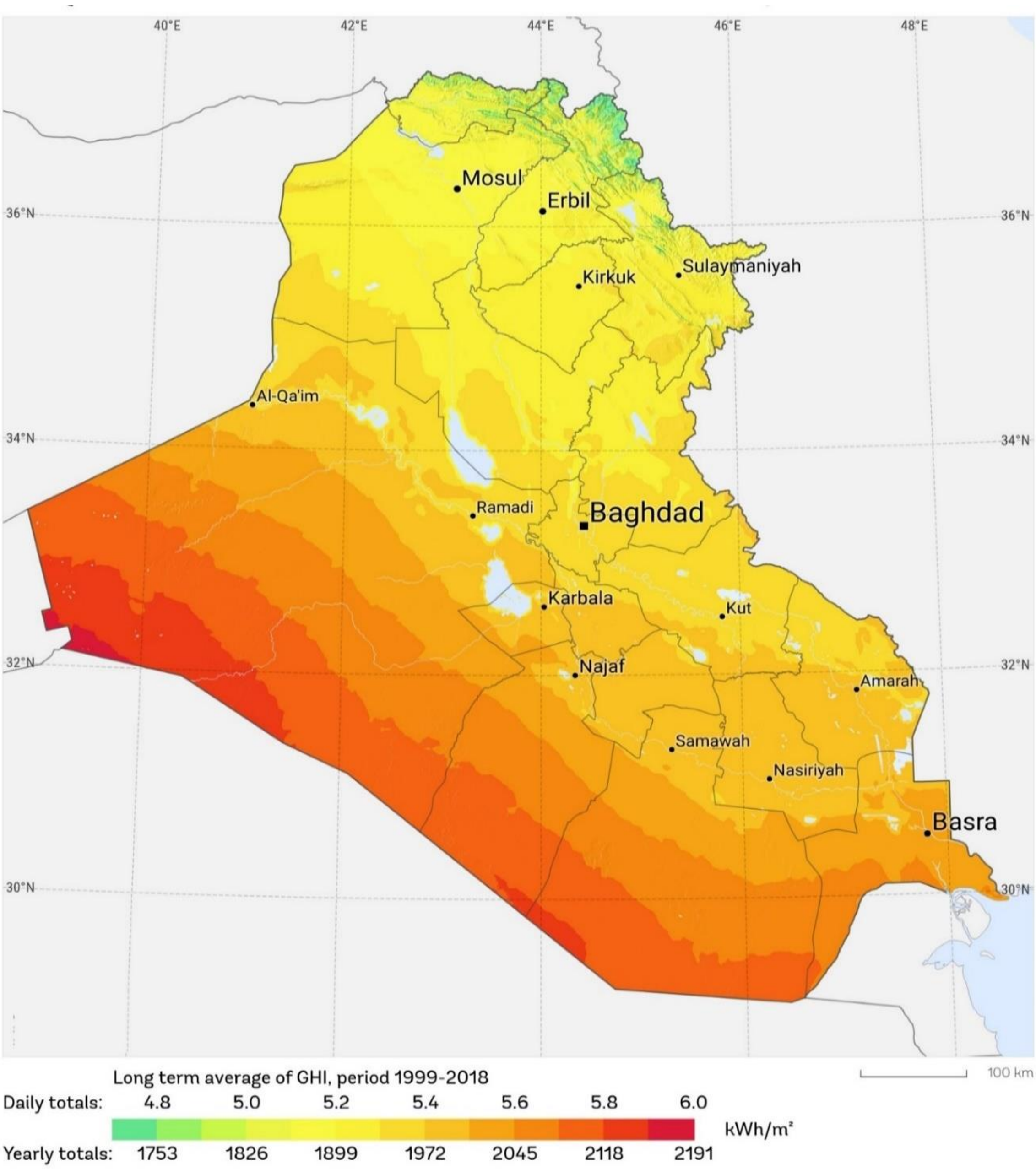


Figure 1.1(B): Iraqi solar irradiation[5]

1.4.1 Solar stills

The main challenge for solar stills is the amount of productivity, the researchers try to enhance the daily production by developing the evaporation, condensation, or both by using deferent types of nanofluids, nano with PCM, perforated plate, wicks, stepped designed, pyramid design or adding fin to the basin of still [6],[7], [8], [9], [10],[11].

Some of these still work in a multi-effect method by recycling the wasted energy when others work in single-use energy.

1.4.1.1 Advantages

The solar stills have many advantages that present it in the lead of the water distillation devices such as the free energy used, no pollution, easy and low cost to manufacture, simple to operate, no moving parts, therefore, no maintenance needed, and the water produced was tasted good due to no boiling for the raw water.

1.4.1.2 Disadvantages

Along with the many advantages of a solar still, there are also some disadvantages such as low productivity and weather dependent.

1.4.2 Types of Solar Stills

Many enhancements have been done on the solar stills due to its low productivity, and those enhancements divide the solar stills work principle into two types passive and active. The passive solar stills are simple stills or with enhancements that not required any additional power source rather than the sun radiation, that type of passive stills has less productivity and a simple design with no movable parts and requires less maintenance. In the active solar stills, the enhancements include using an additional electrical heater or solar collector to preheat the input water. In some cases, external condensers or fans are used to optimize the condensation process [12]. In some cases, the energy wasted in some industrial facilities is used. That type of solar stills has more efficiency and as well as more productivity.

1.4.3 Single-Slope Solar Still

The single slope solar stills are the simplest design of a solar distillation system that is easy to operate and install, and used for small and medium residential uses due to its limited production. The working principle of the solar still is simple and can be described as five stages.

The solar radiation passes through the upper glass cover to the enclosed and isolated container, when the solar radiation falls on the water in the basin, little of this radiation is absorbed by the water and most of it is penetrated into the black painted basin, which in turn heats up and raises the water temperature further. As the system is isolated, thermal equilibrium happens between the base plate and the water layers. A saturated vapor start released from the water due to the increase of its temperature. The water vapor rises up and reaches the glass cover which has less low surface temperature, the water vapor starts to condense as it touches the glass-forming pure water drops on the inner side. Naturally and by the means of gravity, the water drops slide down and collected by a special collector to be used as pure water.

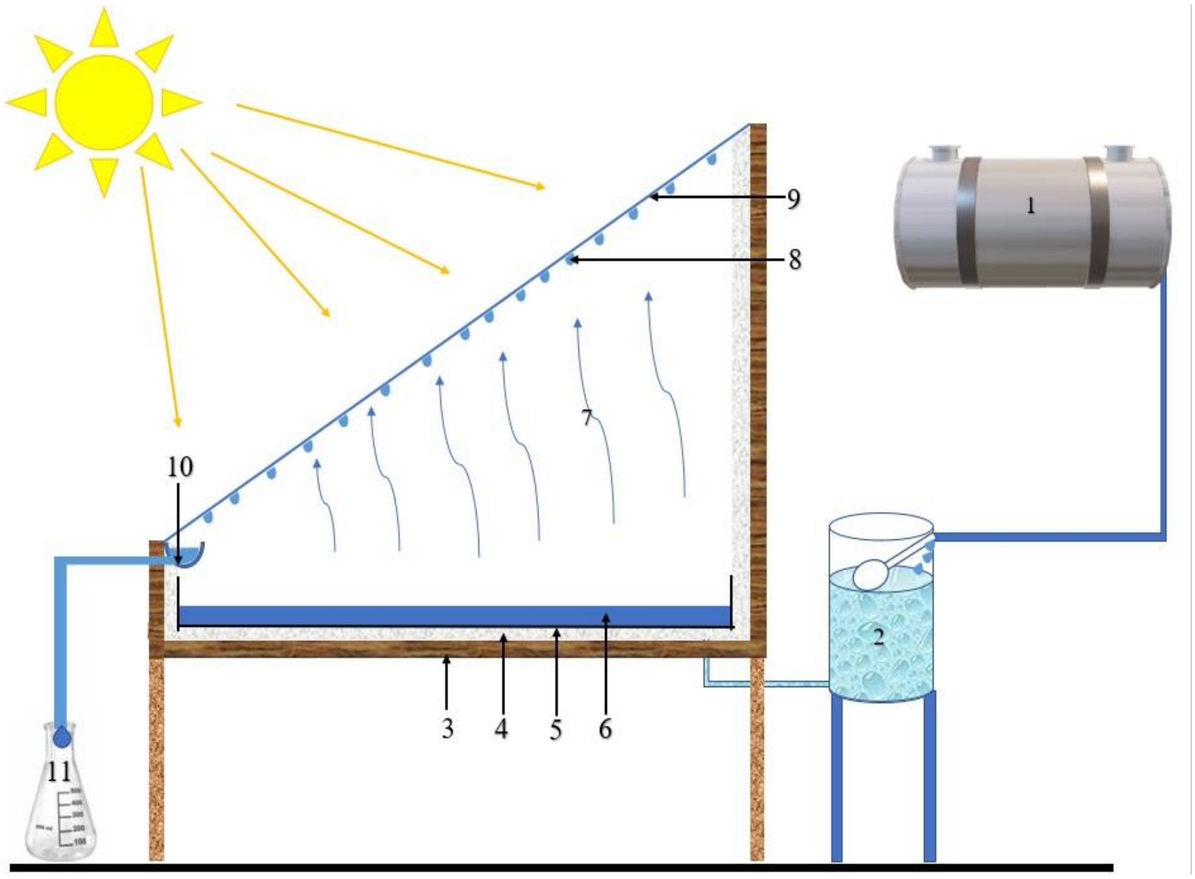


Figure 1.2 single slope solar still

1-source tank

2-level tank

3-wooden container

4-foam insulation

5-black basin

6-raw water

7-vapor

8-condensed water

9-glaas cover

10-collecter

11-pure water tank

1.5 Scope and Objectives

The main purpose of this study is to develop a small-scale solar desalination technology in Najaf city, by using local industrial materials for productivity enhancement of distilled water to face problems of electricity and shortage of purified water. Therefore, the following objectives are considered to investigate the performance of a single-slope solar still.

1- Enhance the evaporation process by increasing the input water temperature using solar collecting tank

2- Enhance the evaporation process using copper pipes (evacuated and filled with a different filling ratio of water)

3- Enhance the evaporation process using different types of wicks

4- Enhance the condensation process by cooling solar still glass cover (by water) with two different construction.

Chapter Two

Literature Review

Chapter Two

Literature Review

2.1 Introduction:

Along with the pure water need around the world, the solar radiation might be the solution for this problem, using the sun energy to evaporate and re-condensate salty, impure or even contaminated water called the distillation process. Exposing impure water to sunlight in a certain mechanism will rise it energy content and by so its temperature which generate water vapor. Collecting that saturated vapor on a lower temperature surface will leads to liquefy that water vapor into pure water.

Distillation in single slope solar still has been noted that is the easiest, lowest cost yet has a low productivity rates among deferent methods of water distillation. So, enhancing its productivity will make it a proper solution for domestic drinking water need in remote regions when it is very difficult to connect to the electrical power source.

In this review, The light will be spotted on the studies that investigate the effect of changing deferent parameters in single slop solar still to enhancing its productivity. Numerical, experimental and combined studies have been done to enhance the conventional solar still. Many of these studies focused on increase the evaporation rates, others put the focus on the condensation and some researchers investigate the effect of them both. However, In the below a table comprises a classification for these studies contain the author name, type of study and the results. Also, these studies are classified according to the chronology and type of study.

No.	Author	Type of study	Work	Type of enhancement	Results
1	**A.A El_Sebaii et al (2009)**[13]	Theoretical	using of phase change material PCM (stearic acid)	Evaporation enhancement	When using (stearic acid) as a PCM, it is found that the productivity enhanced by 85.3% in compared with the conventional still.
2	**Abdullah Bilal et al (2019)** [14]	Experimental	Different amounts of pumice stone added inside the basin and used as heat storage element	Evaporation enhancement	Productivity when using 5 kg of pumice stone was 1.748 L/m^2 and 1.618 L/m^2 when using 10 kg. While it was 1.95 L/m^2 without using the stone, this means that the productivity decreases as the amount of pumice stone increase during the day, while it enhanced during the night by about 1.32% and 3.62% when using 5 and10 kg of stone, respectively.

No.	Author	Type of study	Work	Type of enhancement	Results
3	**Mohit Bhargva (2019) et al** [15]	Experimental	Different wick materials, Bamboo cotton, jute, wool, and cotton are used. Wick is placed over rectangular shaped fins installed in still basin.	Evaporation enhancement	With using four types of materials as wicks (bamboo cotton, jute, wool and cotton), the results showed that the maximum productivity and efficiency when using bamboo cotton and found to be 3.01 L/m² and 34.5% respectively. Furthermore, these results are more than the (jute, cotton, wool, and conventional) by (16.9%, 20.7%, 37.8% and 51.9%) respectively.
4	**Gnanaraj et al (2018)**[16]	Experimental	using external mirror reflector.	Evaporation enhancement	By using mirror reflector, the results showed that an increase of 41% in the freshwater output of still compared to the conventional one.

No.	Author	Type of study	Work	Type of enhancement	Results
5	**Arun kumar et al (2018)** [17]	Experimental	using a porous absorber (carbon-impregnated foam) and bubble-wrap insulation	Evaporation enhancement	The daily productivity of the still with the bubble warp insulation was 2.3 L/m² where it was 1.9 L/m² without the same insulation, And the productivity of the still with both of porous absorber & bubble warp insulation was 3.1 L/m² and in case of wooden insolation only it was 2.2 L/m²
6	**Rashidi et al (2018)**[18]	Experimental	introducing reticular porous media (black sponge rubber)	Evaporation enhancement	Increasing the energy absorbed by using black sponge rubber in the still basin. Whereas the experiments showed that the productivity of the modified still was 17.35% higher than that of the conventional solar still.

No.	Author	Type of study	Work	Type of enhancement	Results
7	**Haddad et al (2017)**[19]	Experimental	Using vertical rotating wick	Evaporation enhancement	Using of a vertical rotating wick enhanced the evaporation process and in result the total productivity of the still to be 5.03 kg/m² in winter and 7.17kg/m² in summer, whereas the percentage increase in compared with the conventional still productivity was 51.1% and 14.72% respectively
8	**Sellami et al (2017)**[20]	Experimental	using blackened sponge sheets with different thicknesses pasted over the basin liner (heat-absorbing surface)	Evaporation enhancement	By using sponge sheets with different thicknesses solar still productivity was increased by 57.77% and 23.03% for 5 mm and 10 mm thick sponge sheets, respectively. However, for 15 mm thick sponge sheet, the productivity value was 29.95% less than that of conventional still.

No.	Author	Type of study	Work	Type of enhancement	Results
9	**Arjunan et al (2017)** [21]	experimental	placed pebbles in still basin as sensible heat storage material.	Evaporation enhancement	Using pebbles in still basin as a heat storage material increase the working time of the modified still and the fresh water productivity was increased by 9.5% as compared with that conventional.
10	**V. Ramanathan et al (2017)**[22]	experimental	Using flat plate collector	Evaporation enhancement	By combining solar still with a flat plat collector for preheating the input water to the solar still, the productivity increased by 25% compared with conventional one.
11	**El-Naggar et al (2016)** [23]	experimental	Developed a still basin equipped with straight fins.	Evaporation enhancement	utilizing straight fins lead to increasing the heat exchange between water and the basin absorbing plate. The fresh water productivity increased by 13%.
12	**Matrawy et al (2015)** [24]	experimental	Using black cloths in solar still	Evaporation enhancement	By using a corrugated black cloth on porous material, the productivity of the solar still was increased by 34% .

No.	Author	Type of study	Work	Type of enhancement	Results
13	**Rajasekhar et al (2015)**[25]	experimental	Using PCM With nanoparticles	Evaporation enhancement	Paraffin wax, as PCM, and Aluminum oxide Nanoparticles were used. The results show that the daily efficiency of the still with Nano-PCM, PCM and without any additive are 66%, 45% and 25% respectively.
14	**Eltawil et al (2014)** [26]	experimental	Using flat plat collector	Evaporation enhancement	Companioning a solar collector with solar still for preheat input water lead to increases the productivity by 36%.
15	**Omara et al (2013)** [27]	experimental	Feeding water preheat	Evaporation enhancement	By using a dish for concentrating sun energy to preheat the input water, the output freshwater productivity increased by 347%
16	**Sakthivel et al (2010)** [28]	experimental	using jute cloths	Evaporation enhancement	Placing jute cloths in the still basin and on the back wall, this increased the daily productivity by 20% .

No.	Author	Type of study	Work	Type of enhancement	Results
17	**S. Abdallaha et al (2008)** [29]	experimental	Sun tracking system	Evaporation enhancement	They found that the productivity enhancement in about 22% compared with conventional still .
18	**Pankaj Dumka (2019) et al** [30]	Theoretical and Experimental	magnetized ring of ferrite Added inside the basin	Evaporation enhancement	Internal efficiency is increased as well as the exergy by 110.26 % and 49.17% respectively and the overall water distillation was enhanced by 49.22% compared with the conventional solar still.
19	**Abhay Agrawal (2019) et al** [31]	Theoretical and Experimental	Multiple floating v-shaped wicks used inside the basin	Evaporation enhancement	Enhancing evaporation process by increasing the evaporative surface by 26% leading in a daily productivity enhancement in about 56.62% in clear summer day and 47.75% in sunny winter day compared to a conventional still, and the productivity was 6.2 and 3.23 kg/m^2 respectively.

No.	Author	Type of study	Work	Type of enhancement	Results
20	**Panchal et al (2018)** [32]	Theoretical and Experimental	Using marble pieces and sandstones as heat energy storage materials	Evaporation enhancement	Increasing working time of the solar still due to using marble pieces and sandstones as a heat storage material. They found that, as compared with conventional one, the productivity was enhanced by 30% and 14% for using marble pieces and sandstones respectively.
21	**Agrawal et al (2017)** [33]	Theoretical and Experimental	utilize two basin water depths	Evaporation enhancement	It was found that as the basin water depth increases, the distillate output decreases. Thus, for 2 cm and 10 cm water depths, the theoretical and experimental daily efficiency values were approximately 52.83% 41.75%, 41.49% and 32.42%, respectively.

No.	Author	Type of study	Work	Type of enhancement	Results
22	**D.B. Singh et al (2016)** [34]	Theoretical and Experimental	hybrid Photovoltaic-thermal collector	Evaporation enhancement	By combining a thermal collector with solar still, the daily productivity ranged from a maximum value in summer of 7.74 kg/m^2 to 1.67 kg/m^2 in winter, and thus the productivity enhancement varied between 883.55% to 120.29%. the theoretical and experimental results are in good agreement when it compared.
23	**Samuel et al (2016)** [35]	Theoretical and Experimental	Using different energy storage materials	Evaporation enhancement	By using spherical salt balls and sponge as a heat storage the maximum distilled water output was 3.7 $kg/m^2/day$, when the still with sponge was 2.7 $kg/m^2/day$, while the conventional how is without any storage material was 2.2 $kg/m^2/day$.

No.	Author	Type of study	Work	Type of enhancement	Results
24	**Estahbanati et al (2016)** [36]	Theoretical and Experimental	Develop a still with internal reflectors	Evaporation enhancement	Investigate the effect of using internal reflector on the side walls and the back wall the results show efficiency of 18% and 22% respectively. While the productivity was also investigated for summer, winter and an entire year and it found to be 65%, 22% and 34% respectively .
25	**Srivastava et al (2013)** [37]	Theoretical and Experimental	Using pieces of blackened jute cloth	Evaporation enhancement	By utilizing of blackened jute cloth to increase the absorption in still basin, the productivity in clear and cloudy days are found to be 68% and 35% respectively more than the conventional still.

No.	Author	Type of study	Work	Type of enhancement	Results
26	**Mohit Bhargva (2019) et al** [38]	Experimental	Study effects of shading and evaporative cooling on solar still glass cover	Condensation enhancement	Experimental results showed that the productivity can be increased by 16.4% and 3.8% efficiency increase when shading the front cover with half shad with front glass cooling. The maximum productivity when compounds both of them was 2.114 L/m^2 day, and it decreases as the shading increase.
27	**K. Vinoth Kumar at. al. (2008)**[39]	Experimental	Using tap water for cooling the still walls	Condensation enhancement	Circulating tap water around still walls for increase the condensation area and collect the condensed water from the three walls by special collectors. The efficiency was 30% with a maximum productivity of 1.4 L/m^2.d.

No.	Author	Type of study	Work	Type of enhancement	Results
28	**Lei Mu et. al. (2019)**[40]	Experimental	Used the refraction effect by Fresnel lens and cooling the glass cover by forced air	Evaporation and Condensation enhancement	Utilize a Fresnel lens lead to concentrate the solar radiation of a certain area on a fixed point to increase the heat transfer coefficient, also a fan for forcing air on the front glass of the still. The results showed that an increased in the productivity and efficiency by 467% and 87% respectively.
29	**Hassanain Gh. Hameed et al (2017)** [41]	Experimental	Study the effect of forced air cooling for the glass cover and using wire screen mesh at basin liner.	Evaporation and Condensation enhancement	The results cleared that the productivity increased by 22.8% when using air with a speed of 4.0 m/s and 36.6% when using both wire screen mesh and air with a speed of 2.5 m/s.

No.	Author	Type of study	Work	Type of enhancement	Results
30	**Kaushal et al. (2017)**[42]	Experimental	Using floating wick and heat recovery system	Evaporation and Condensation enhancement	For enhancing the evaporation process, a floating cotton cloth wick is used. Also, water circulation channels with a vertical wick at the still back wall for condensing more vapor using a water pump and external heat exchanger for west heat recovery. The productivity enhancement was about 21% comparing with the conventional still.
31	**S.W.Sharshir et al.(2017)** [43]	Experimental	By using graphite and copper oxide micro flakes and cooling the glass cover with water film	Evaporation and Condensation enhancement	The use of Nanoparticles and film water enhanced the evaporation and condensation processes in the still, respectively. The productivity increased by 44.9% when using graphite and 53.9% when using copper oxide micro flakes. Also, the productivity increased by 47.8% and 57.6 % when the cover is cooled .

No.	Author	Type of study	Work	Type of enhancement	Results
32	**Meysam Faegh et al. (2017)** [44]	Experimental	Study the effects of using a PCM (Paraffin wax) and evacuated tube solar collector on still performance	Evaporation and Condensation enhancement	It is appearing from the experiments that Using PCM extended the working time of the still. And using evacuated solar collector preheated the input water. Thus, for using these additives, the productivity and efficiency were enhanced by 86% and 50%, respectively.
33	**R. Arun Kumar et al. (2016)** [45]	Experimental	Investigate the effect of using a rotating shaft and DC fan	Evaporation and Condensation enhancement	The experiments stated that the effect of agitation on water inside the still basin by DC motor and using DC fan to circulate the water vapor to an external condenser increased the productivity by 39.49%.

No.	Author	Type of study	Work	Type of enhancement	Results
34	**A. E. Kabeel et al. (2014)** [46]	Experimental	Study the effects of using Nanoparticles (Al_2O_3) and external condenser on still productivity	Evaporation and Condensation enhancement	Using an external condenser improves the productivity of the still by 53.2%. Also, the use of aluminum oxide as a Nanoparticles increases evaporation rates. Thus, the results show that productivity increased by 116% when using both Nanofluid and external condenser.
35	**Syed Noman Danish et al. (2019)** [47]	Theoretical and Experimental	Using a vacuum pump with shell and tube heat exchanger	Evaporation and Condensation enhancement	Using a fan to transmit vapor produced inside a still enclosure to a shell and tube heat exchanger, cooled by water circulated with another underground pump for using the geothermal energy to reduce its temperature by 15-25 °C below ambient, led to increased daily productivity by 305%. Also, there was good agreement between the analytical simulation and the experimental results.

No.	Author	Type of study	Work	Type of enhancement	Results
36	**Saeed Nazari et al. (2018)** [48]	Theoretical and Experimental	Using Cu_2O as a Nanoparticles and using of external condenser	Evaporation and Condensation enhancement	Using a suction fan for reducing the partial pressure over the water surface for increasing the evaporation rates and circulate the vapor to an external condenser equipped with a thermoelectric module on the condensing channel to enhance the condensation process. Also, adding Cu_2O nanoparticles for further enhancing the evaporation process. The experimental results show that the productivity increased by 26.9% when the nanoparticle concentration was 0.04% and 43.9% at 0.08 Nanoparticles consternation with a vapor flow rate fixed at 180 LPM.

2.2 Summery

From the literature review, the most prominent conclusions can be identified as follows:

1-Through research, it is found that the water distillation technique of using solar energy is one of the most important ways to provide drinking water as it depended on free energy available and also that solar distillers are not complex devices to build as well as have a low cost. despite the fact that solar stills are not modern technology, the need It is urgent to continue research and develop in order of improving the performance of solar distillers

2-As still work depends mainly on the evaporation and condensation processes, so the researchers worked to improve these two processes, analytically and experimentally. Some researchers did not give the desired results with a high difference in productivity when compared to conventional still distillates, and some of them gave opposite results that reduced productivity, and some researchers baptized adding external auxiliary factors it relied on other energies like electrical energy.

Therefore, the main objective of this study was to research and develop the factors that affect evaporation and condensation processes in a positive way, with the aim of increasing productivity. As well as avoid previous researches problems.

Chapter Three

Experimental Study

CHAPTER THREE

EXPERIMENTAL STUDY

3.1. Introduction

The main purpose of the experimental study is to evaluate the effect of the parameters that have a direct effect on the still performance like solar radiation, wind speed, and ambient temperature as well as the effect of some proposed parameters that have an effect on either the evaporation process like (solar collecting tank, different types of galvanized wicks and evacuated copper tubes) or the condensation process like front glass water channel cooling. All the experiments have been done during full day time for accurate results.

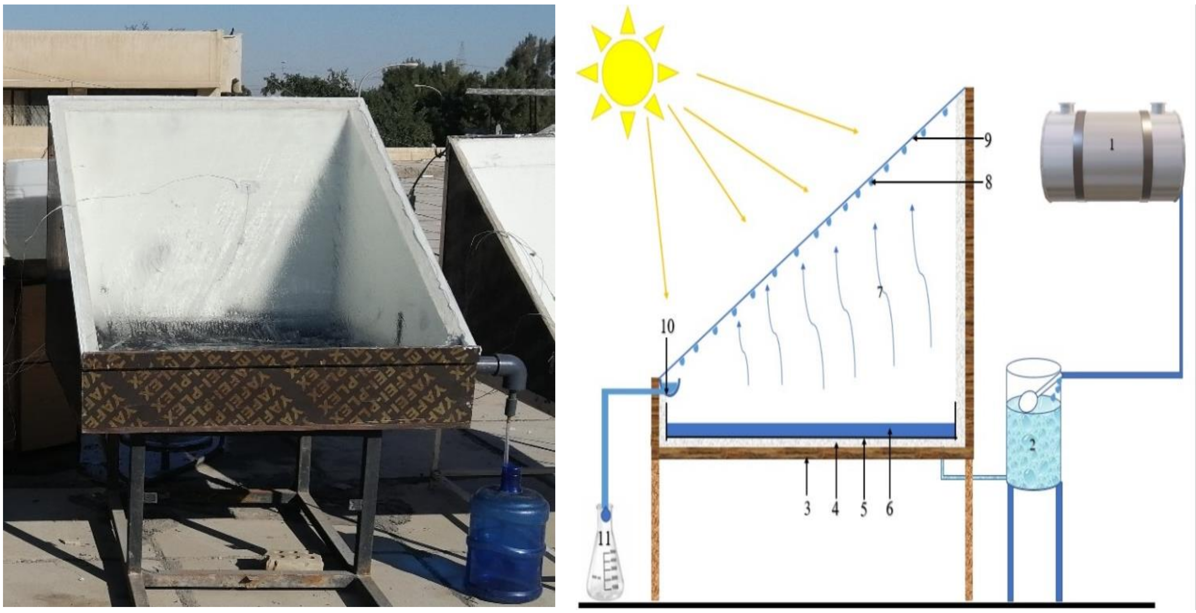
3.2 Construction and Materials

A single slop solar still has been developed for experiments using materials that give the optimum operation and the lower cost. The frame manufactured in the site and all the materials are from the local market within the specified material properties. The pictorial and Schematic views for conventional still are illustrated in figures 3.1 A and B.

All the parts dimensions and properties are illustrated below.

3.2.1 Basin Liner

As a standard solar still, A 1m² basin has been manufactured with 10 cm edge height for containing the water. A 1.5 mm thick galvanized iron is used for avoiding corrosion and painted with high thermal resistance black paint for optimum absorption for fallen solar energy radiation and withstand the operating temperature.



A B

Figure 3.1: Pictorial and schematic view for the solar still 1- Raw water tank. 2- Level tank. 3- Wooden frame. 4- insulation cork. 5- basin liner. 6- Raw water. 7- water vapor 8- condensed water drops. 9- Glass cover. 10- pure water collecting tray. 11.pure water collecting tank

3.2.2 Glass Cover

The front face of the solar still is covered by a clear transparent window type class of 6 mm thick for allowing the maximum amount of energy to pass through to the absorbing basin lining plate. The glass has an average transmissivity of 0.88 and tilted with a 32° as based on the attitude and longitude of the city of Najaf. Also, different materials are used for fixing the glass on the still frame, such as rubber and silicone, for ensuring a sealed system operation for optimum working conditions.

3.2.3 Insulation and Sealant

For optimum operation, all the absorbed energy must be conserved inside the solar still. All four sides and the basin bottom are insulated with a 3 cm thick white cork which has a low thermal conductivity of 0.045 W/m. ℃. Also, rubber straps and silicon are used to prevent any vapor leakage from the solar still.

3.2.4 Distillate Channel

For collecting pure condensed water from the inner side of the glass cover a 5 cm diameter PVC pipe sliced into half, with a 110cm long and fixed with a slope angle of 6° from the horizon for a natural flow of water, and the pipe diameter reduced to a 1.25 cm pipe outside the still for collecting the pure water into a PVC container and then measured by the graduated flask.

3.2.5 connecting Tubes

A set of transparent tubes are used for connecting the main water source to the supply level tanks for continuously supplying the still with constant raw water level for all time of experiments. Also, the same tubes are used for the drain hole for the salt removing process. Another transparent tube is used to connect the collector to the pure water storage PVC tank.

3.2.5.1 Distilled Water Collection Port

For collecting the distilled yield, a 1.25 cm diameter transparent tube is used to connect the collector to the measuring jar for precise measuring after each experiment completion.

3.2.6 Solar Still Frame

The frame body is made basically from compressed 1.8 cm thick wood panels constricted together, forming the mainframe of the solar still, which contains all the still parts inside. All the wooden frame is supported with an iron frame from the bottom.

3.3 Measurements

All the tests of this work are done on the roof of the communication department building of Najaf Engineering Technical College, which located in

Iraq/Najaf city (32. 1° N and 44.19° E). The raw water that used in all tests was tap water has a salinity ranging from 2600 – 3000 ppm. All experiments are done in January, March, May, and June and by the help of four main measurement devices. All and each one of these devices will be explained Briefly as below.

3.3.1 Pure Water Measuring Instrument

Through the solar Still working along day time, the pure water flows from the glass cover to the collecting channel and then to the measuring gar drop by drop. The collecting measuring jar is insulated to ensure that the produced water will not evaporate. The total capacity of the measuring jar has a volume capacity of 5 litters.

3.3.2 Temperatures Sensing Device

The temperature was measured by a K-type thermocouple inside and outside the still with a measuring accuracy of (0.2 % ± 1° C). An 8 sensor was implanted in each still to give an accurate reading for the basin water, vapor, inside and outside of the glass cover, input water, and the environment ambient temperature. Some extra sensors are used for some experiments, which include some modified parts. all these sensors are connected to a 64 channel Applent (AT-4532x) data logger as shown in figure 3.2. All these thermocouples are calibrated as in Appendix A.

Figure 3.2 data logger

3.3.3 Solar Radiation Measuring Device

For measuring an accurate amount of incidence solar radiation, the measuring device must be tilted with the same angle of the still glass cover, with an angle of 32^o. The direct radiation was measured with the TENMARS (TM-207) radiation meter, as shown in fig. 3.3. it is with an accuracy of (± 5%, ± 10 W /m^2)

Figure 3.3 Solar radiation measuring device

3.3.4 Wind Speed Measuring Device (Anemometer)

As the air passing over the glass cover has a magnificent effect on the still condensation, thus the airspeed must be measured. An anemometer type (AM-4206M), as shown in figure 3.4, was used to measure the wind speed for each hour with measuring range of (0.4 - 30m/s) and accuracy of (±1.8% N+2d).

Beside the above measuring instruments, and for more accurate environmental condition measurements the data from Davis weather station installed in the Engineering Technical College in Najaf /Iraq 10 meters above the ground are considered.

Figure 3.4 Wind speed measuring device (anemometer)

3.4 Modified Still Model

As known the conventional solar still has low productivity; therefore, many studies suggest different types of enhancements to increase its production. In this study, adding some parameters were suggested to achieve that purpose. For enhancing the evaporation process such as preheat the input water, adding different types of wicks and evacuated copper pipes and also some condensation enhancements are suggested such as cooling the glass cover with two different types water channel. Each one of these additions explained briefly below.

3.4.1 Evaporation Enhancement

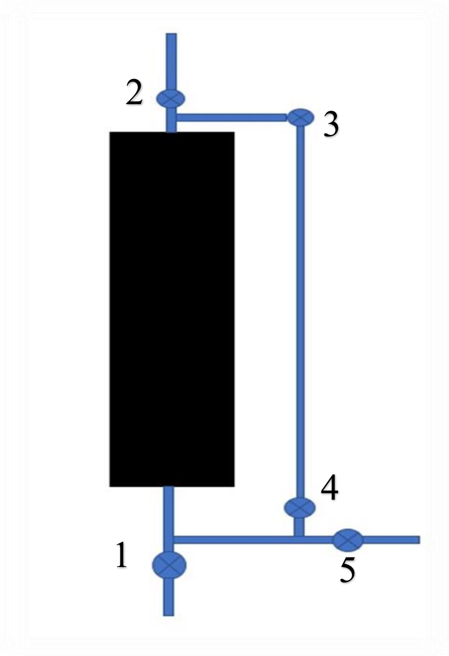
3.4.1.1 Solar Collecting Water Tank

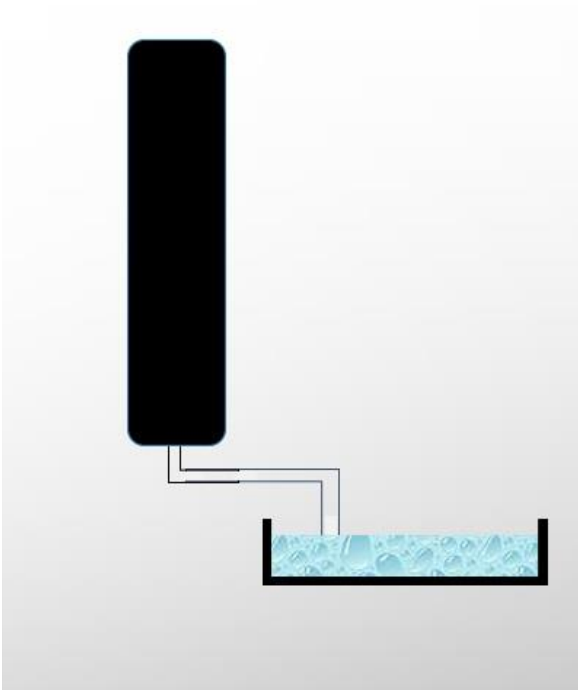
One of the main parameters that directly affect the raw water evaporation is its temperature. Increasing the input water temperature will speed up the evaporation time needed as the solar radiation received by the solar still is constant. Using metal tank, black painted and inclined with the same tilt angle of the still glass cover, as shown in figure 3.5 A and B, will increase the amount of the energy absorbed by the tank itself rising the inside water temperature. A (16x4x116 cm) galvanized iron tank manufactured locally is used, covered by 4 mm glass window with 4 mm gap from all sides to avoid heat loss by convection (as shown in fig. 3.5 B), tilted with 32° for absorbing as much energy as possible.

Also, the tank provided with site glass for showing the inside water level as well as it is designed with five valves in different locations (as shown in fig. 3.6 A). Valve (no.1) used for tank input raw water, valve (2) used for release inside air during tank refill, valves (3) and (4) are to control the water inside the glass and valve (5) controls the raw water flow from the tank to the still.
The level in the still is adjusted automatically by the tank operation mechanism, as the tank is sealed and the only way the air comes in is the same way that the water goes out. The tank output pipe is designed to touch the basin water surface barely and when the water level goes down a decent portion of air inters the tank. An amount of the same volume of water inters the still until the water surface closes the airway to the tank. Then the water is stopped flowing (as shown in fig.3.6 B).

A B

Figure 3.5 Pictorial views for A: Modified solar still and B: Solar collecting tank





A B

Figure 3.6 Schematic view of A: tank and control valves and B: tank feeding mechanism

3.4.1.2 Evacuated Copper Tubes

For enhancing solar still performance evacuated water-filled copper tubes (filling with different ratios) are suggested for increasing the evaporation rates by rising basin water temperature. A 15 mm and 7 mm inner diameter with 5.9 m length copper tubes shaped in a certain pattern and painted with black paint for absorbing more energy, as shown in fig. 3.7. By evacuating the tubes and filling it with different water ratios that will lead the water inside the tubes boils faster and in low temperature than the water subjected to the normal pressure. 100% and 50% filling water ratios are taken.

The tubes were evacuated with a double stage evacuation pump until the pressure reaches almost absolute zero. The water inside tubes will be subjected to almost zero pressure that will be lowering its boiling point. The procedures of evacuating and filling for tubes are explained in Appendix B.

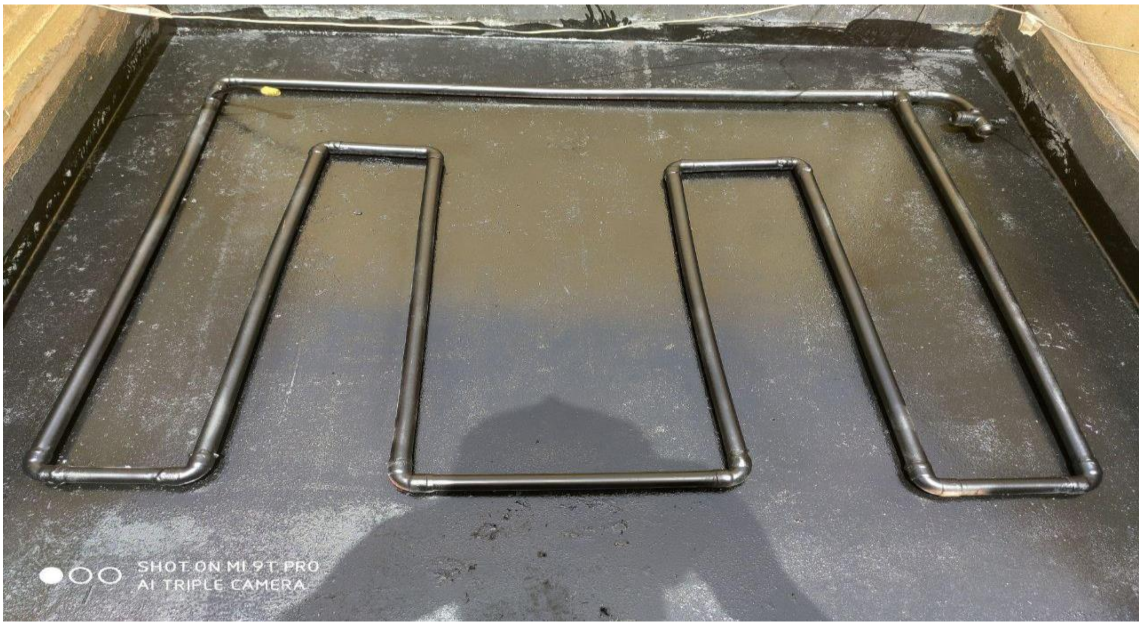


Figure 3.7 Evacuated copper tube

3.4.1.3 Galvanized Wick

For increasing absorbing surface and thermal contact area, different size of black painted galvanized iron wicks is suggested to use inside the solar basin. A 25 mm x 25mm and 50mm x 50mm grid size with the same outer dimensions of 850 mm*850 mm and 4 mm wire gauge, as shown in figures 3.8, are used. The wick material with a specific heat capacity of 0.46 kJ/kg.K and thermal conductivity of 79.5 W/m.K. Each one of the grids tested separately and computed of both small and big grid together, as in figure 3.9, tested and compared the results with the conventional still.

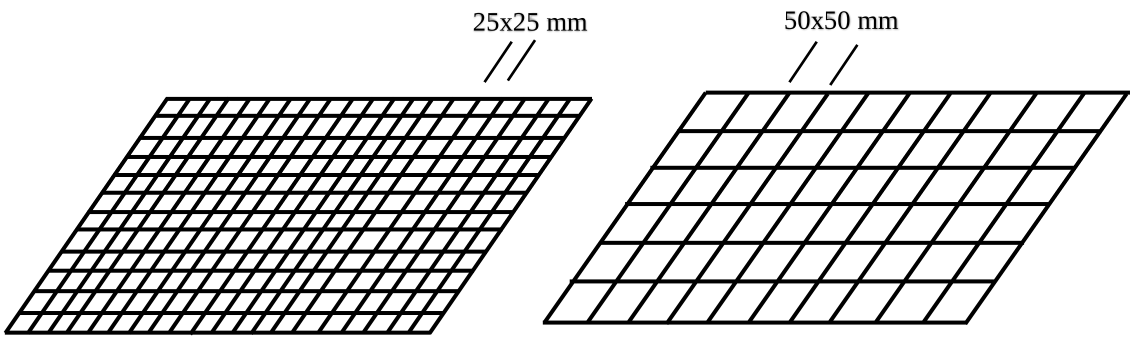


Figure 3.8 Types of galvanized wicks

Figure 3.9 Pictorial view of the tested wicks

3.4.2 Condensation Enhancement

3.4.2.1 Water Channel

Improving the condensation prosses will increase the pure water productivity, as the main parameter that controls the condensation rates is the temperature difference between the saturated vapor and the condensation surface. Using spatial designed water channels to reduce the glass cover temperature by circulating lower temperature water. Two designs have been studied, as shown in figure 3.10. To avoid radiation loss by the channel shadow, a glass with 4 mm thickness used to construct the channels with dimensions of 22 mm * 22 mm, as shown in fig. 3.11.

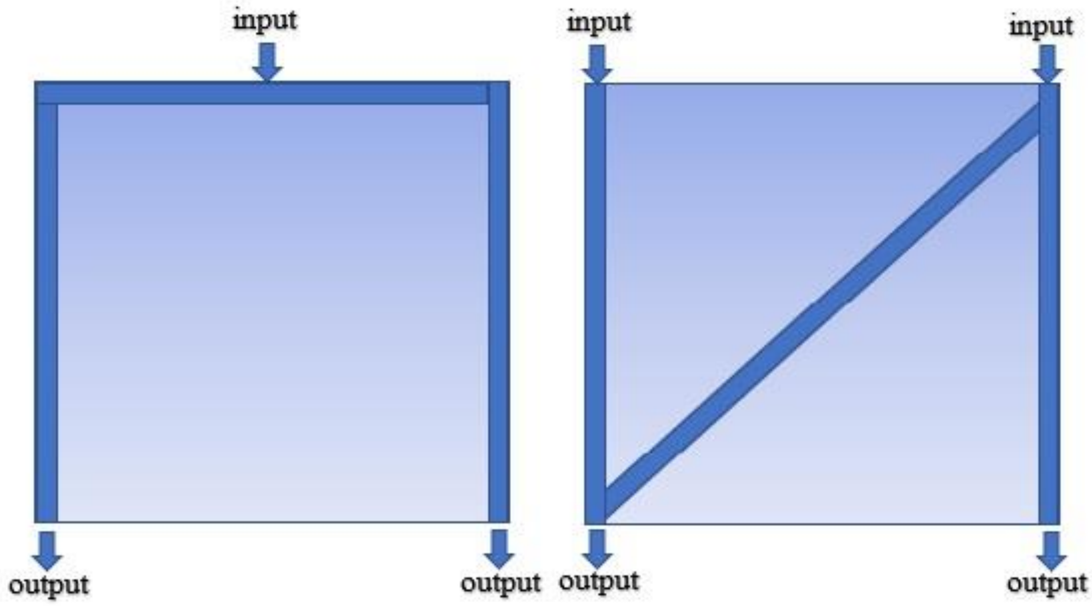


Figure 3.10 cooling water channels

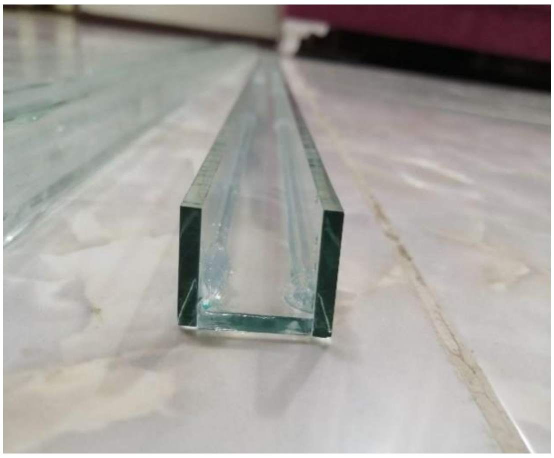


Figure 3.11 Glass cooling water channel

3.5 Distilled Water Producing Mechanism

The single slope solar still working principle mainly uses solar energy to evaporate the raw water and then re-condensate it as shown in fig. 3.1 B. When the solar radiation falls on the black painted basin plate passing through the transparent glass cover, it absorbed and rising the basin plate temperature. The heat then transfer from the plate to the water layers increasing its temperature and causing water evaporation. Due to the continuous evaporation, the inside air has a decent amount of saturated vapor, after that vapor touches the inner side of the glass cover it starts to condense due to the temperature difference. Water drops start to form on the front glass cover inner side sliding down effected by gravity until it reaches the PVC collector and then to the storing tank.

3.6 Process of Conducting The Experiment

1- After assembling all the module parts, the measuring devices must be installed and fixed in positions. The used measuring devices could be explained as below.

a- Thermocouples: for measuring the temperature in several points, a K-type thermocouple are used to measure six locations in and out the solar still. Two thermocouples are used to measure both sides of the basin raw water temperature. Also, the inside moist air is measured using two thermocouples on both sides. Another two probes used to read the glass outer and inner sides of the glass. All thermocouples are calibrated with an alcohol thermometer for insuring the maximum accuracy possible. The thermocouples are connected to a 64-channel data recorder to store the data for further analyzing

b- Solar radiation measuring: Pyranometer is mounted with the same tilt angle of the front glass cover on the solar still to read the exact amount of solar radiation fallen at that particular angle hourly. The Pyranometer is calibrated as shown in Appendix C

c- Anemometer: a wind speed turbo sensor is mounted at the same location of the solar still for reading the local wind speed for each hour, the wind speed sensor is also calibrated as shown in Appendix D.

d- Distilled water collecting vessel: for collecting and measuring the produced water a measuring cylinder is fixed under the collector tube.

2- The measuring devices are operated Concurrently with the experiment time from 8:30 am to 4:30 pm.

3- All the measured data is recorded either automatically (temperature) or manually (wind speed, solar radiation, pure water productivity) for each hour.

4- The experiments are done on the rooftop of the Communication Department at Technical Engineering College in Najaf / Iraq. The water salinity is tested, and it found to be ranging from 2600- 3000 PPM. The experiments cared out in different months and as below:

a- Solar collecting tank in January 2020.

b- Galvanized wick in march & August 2020.

c- Evacuated copper tubes in May 2020.

d- Glass cover cooling channels in May & June 2020.

Chapter Four

Results And Discussion

Chapter four

Results and discussion

4.1 introduction

In this work, all experiments are done on the communication technics department's rooftop at the technical engineering college of Najaf – Iraq (32.1 N° 44.19 E°). The experiment period was from 08:30 AM to 04:30 PM in different months to investigate the climate changes on the solar still performance. The results taken from the enhanced solar stills were compared to a conventional solar still with the same dimensions and operated at the same location and environmental conditions.

As the solar still productivity is strongly dependent upon the weather conditions, all the weather variables (wind speed, solar radiation and ambient temperature) are recorded and analyzed.

The primary purpose of this study is to enhance solar still productivity. To achieve that purpose, both evaporation and condensation processes are enhanced by considering the effects of input water pre-heating, using galvanized iron wicks and evacuation copper pipes inside the still basin, as well as cooling still glass cover with water.

4.2 Results

4.2.1 Evaporation Enhancement

4.2.1.1 Solar Collecting Water Tank

This experiment is carried out on 27th Jan. 2020. Using two single slope solar stills for study the effect of raw water pre-heating at the same climate conditions. The average wind speed is 5.4 km/hr, as states in fig. 4.1 and 4.2 solar radiation starts with 619 W/m² at the beginning of the experiment and continuously increases until the maximum value recorded at 12:30 PM with 1136 W/m². The solar radiation begins to decrease to a minimum at the end of the experiment. Due to the absorption of that radiation, the raw water's temperature, vapor and the glass cover start to increase and reach its maximum values at 01:30 PM in the conventional solar still. In contrast, the maximum values in the improved solar still were recorded at 12:30 PM due to the additional radiation absorbed by the improved tank outer.

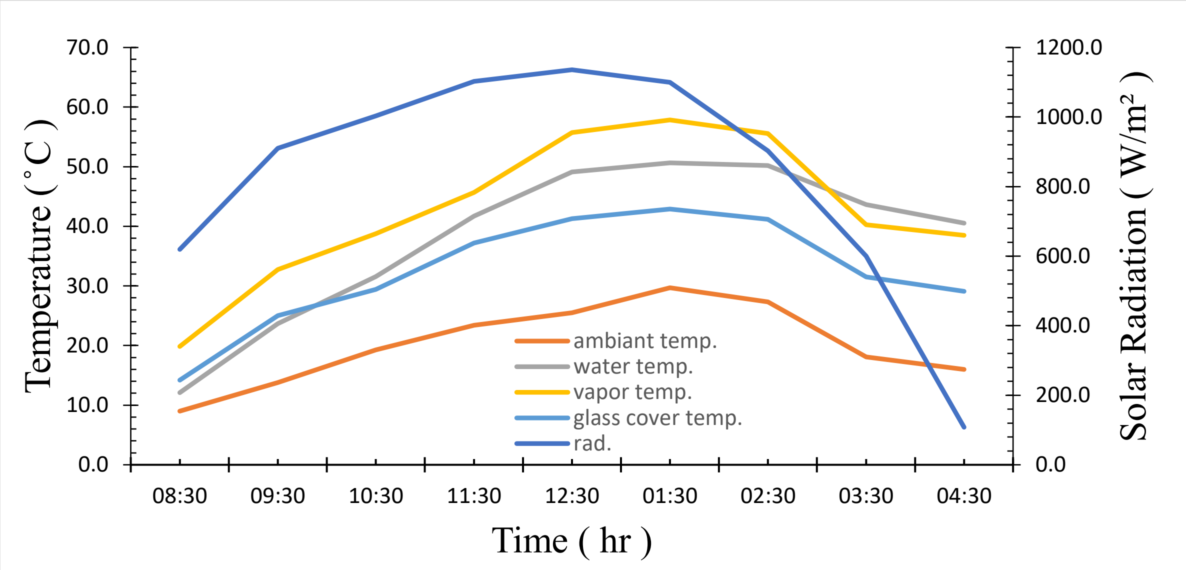


Figure 4.1: variation of temperature and solar radiation with measurement time for conventional solar still

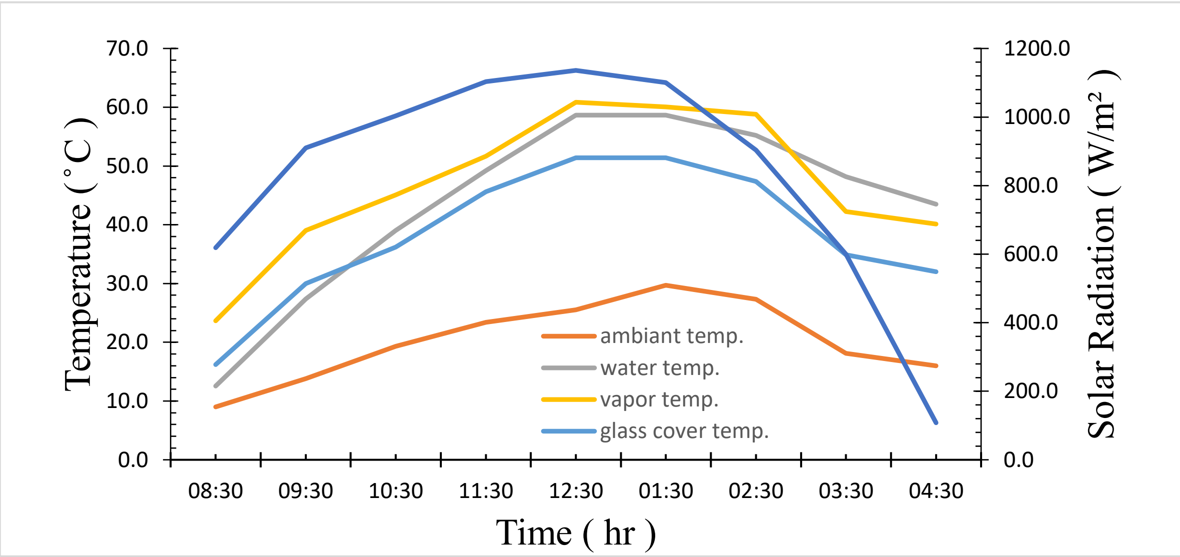


Figure 4.2: variation of temperature and solar radiation with measurement time for modified solar still

Due to the incidence of radiation and the improved design of raw water tank, the energy absorbed causes the raw water temperature to start to increase until reaching the highest value of 52.9℃ at 01:30 PM, after that, it starts to drop slowly, corresponding with the decrease of the solar radiation. While the water in the conventional solar still's tank remained at almost 15.3℃. The improved tank could increase the input water temperature by 241.8% of its original value, as shown in fig. 4.3.

That increase in the input water temperature causes an increment in the water inside the improved still basin. It records a temperature of 9.5℃ more than conventional, as shown in fig. 4.4.

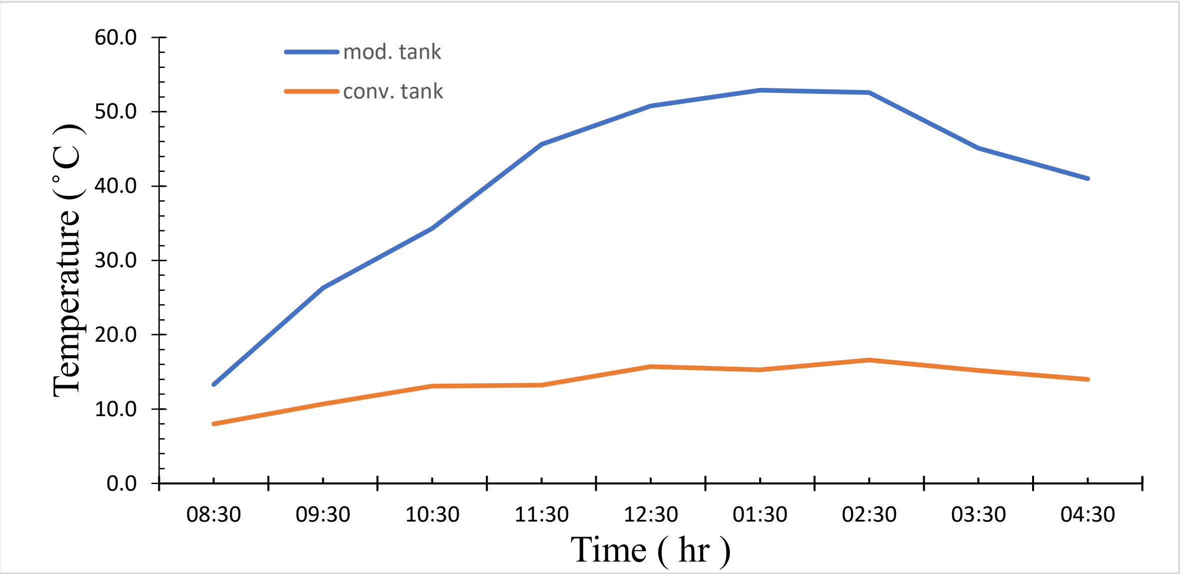


Figure 4.3*:* variation of input water temperature with the time of the experiment

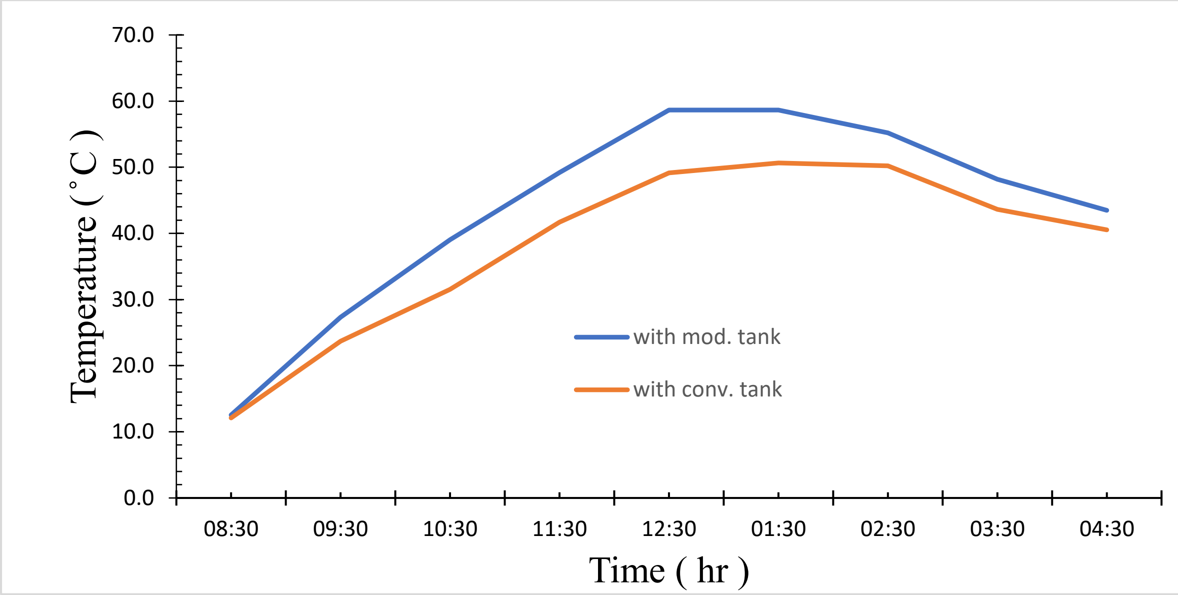


Figure 4.4*:* variation of basin water temperature with the time of the experiment

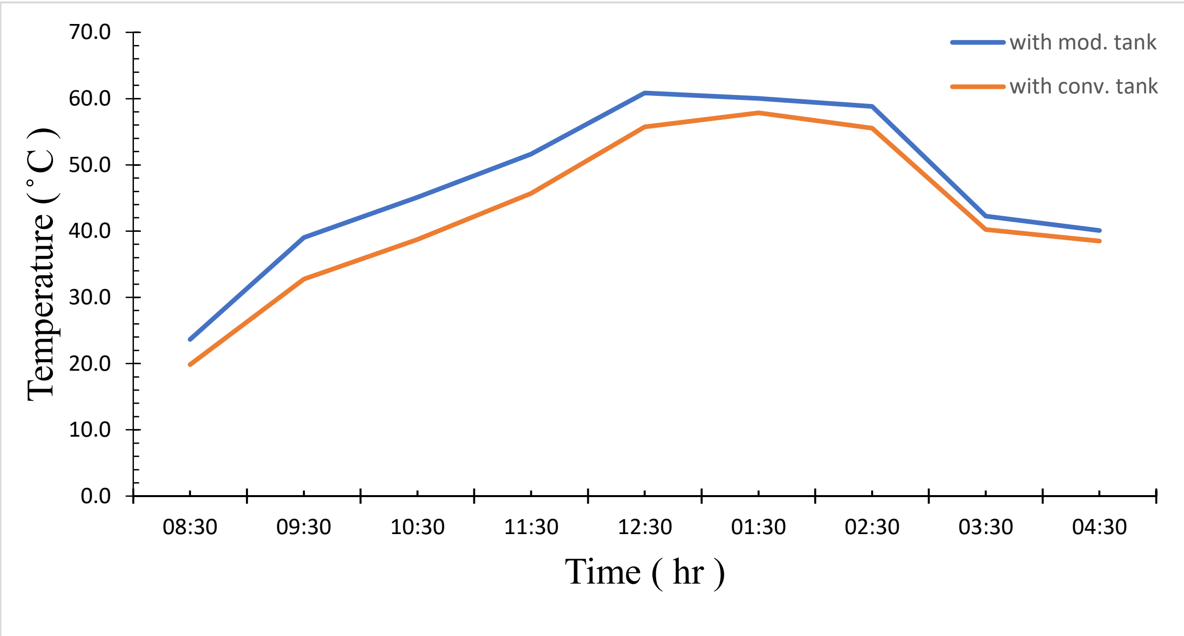


Figure 4.5*:* variation of vapor temperature with time of the experiment

Due to the solar radiation's pre-described behavior and the effect of the improved design water tank, the vapor and glass cover temperatures are both affected and record a temperature more than the conventional still. At 12:30 PM, the maximum vapor temperature difference in the improved still was 5.1 ℃ while the glass cover records a temperature difference of 10.1 ℃, as shown in fig. 4.5, and 4.6.

Fig. 4.7 explains the effects of the improved tank on solar still behaviors, as well as its final productivity. The pre-heating of the input water causes a considerable increment in the improved solar still productivity, and the maximum difference in the two stills productivity was at 12:30 PM. The overall productivity of the enhanced solar still was enhanced by 44.83% compared to the conventional solar still.

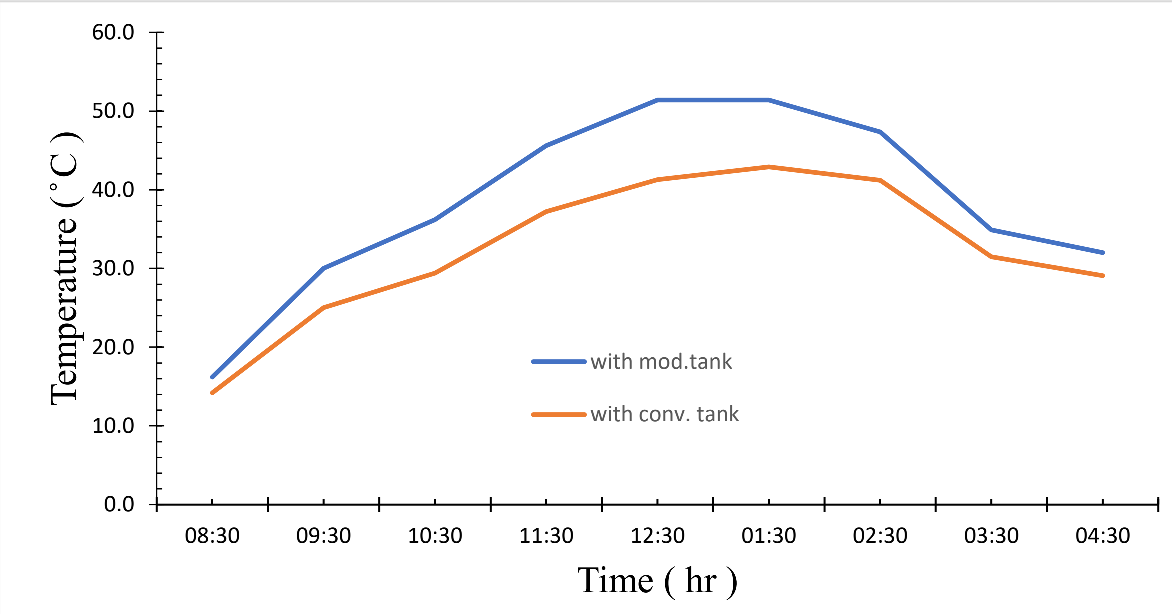


Figure 4.6 variation of glass cover temperature with the time of the experiment

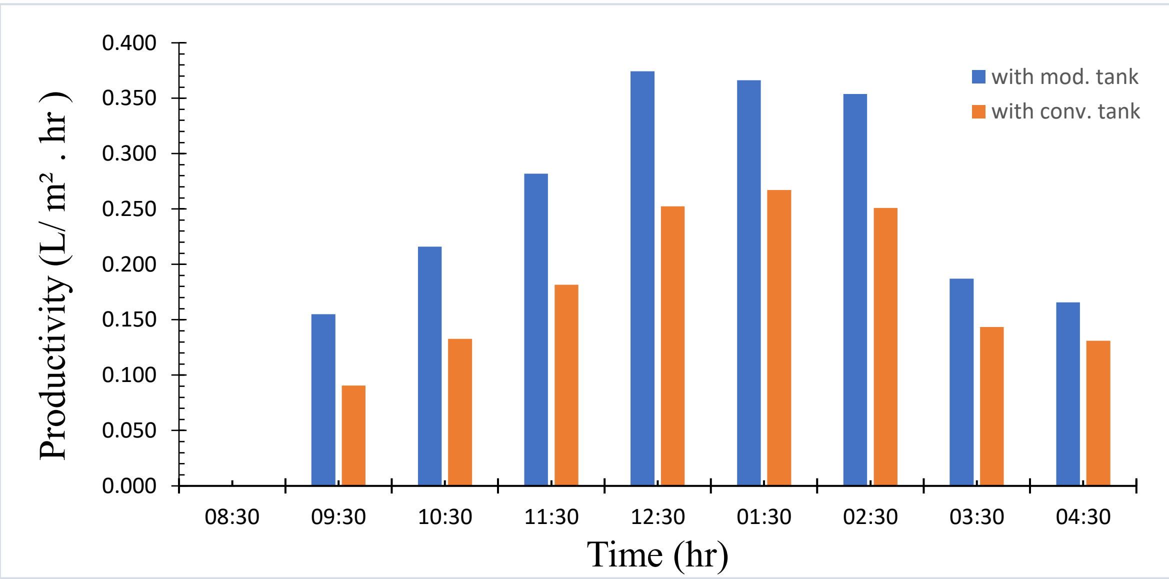


Figure 4.7 productivity variation with time for conventional and modified solar stills

4.2.1.2 Evacuated Copper Pipes

The experiment has been conducted on three identical single slope solar stills. One is equipped with a 15 mm diameter pipe, and the other one was equipped with a 7 mm diameter pipe, while the third one worked as a conventional for comparing the results. All the copper pipes are also evacuated using an evacuating machine (as shown in Appendix B) then filled with water to 100% and 50% in another experiment.

4.2.1.2.1 Copper Tube With 100% Filling

The first experiment was carried out on 4th May 2020 by filling the pipes, after the evacuation, with 100% of its volume with potable water. Water is injected inside the pipes under vacuum without any leakage. Dramatically, the still performance and productivity are strongly depending on the solar radiation, ambient temperature, and wind speed. The average wind speed and maximum ambient temperature were recorded as 6.2 km/hr and 41℃, respectively. Solar radiation starts with a minimum value at the beginning of the experiment. It continuously increases with time until reaching its maximum value of 1140 W/m^2 at 11:30 PM and then decreases to the minimum value at the end of the experiment time, as shown in fig. (4.8 to 4.10).

Due to solar radiation increment as previously mentioned, basin water, vapor and glass cover temperatures start to rise along with the incidence radiation until reaching the maximum value of each one and each solar still at 1:30 PM. Then, it decreases with time the decrease of radiation.

Immersing the copper pipes inside the basin water leads to an increase in the basin water, vapor and glass cover temperatures more than conventional solar still. The immersing of the copper pipes does not directly raise the temperature, and it takes effect after two to three hours due to the absorption of a quantity of heat of the basin water by the water inside the pipes. As noticed in fig. 4.11, basin water temperature inside the conventional solar still had the highest value until 10:30 AM. After that the readings of the basin water of the solar still equipped with the 7 mm copper pipe take the lead for less than one hour before the highest temperature value becomes in the water of the still equipped with 15 mm until the end of the experiment.

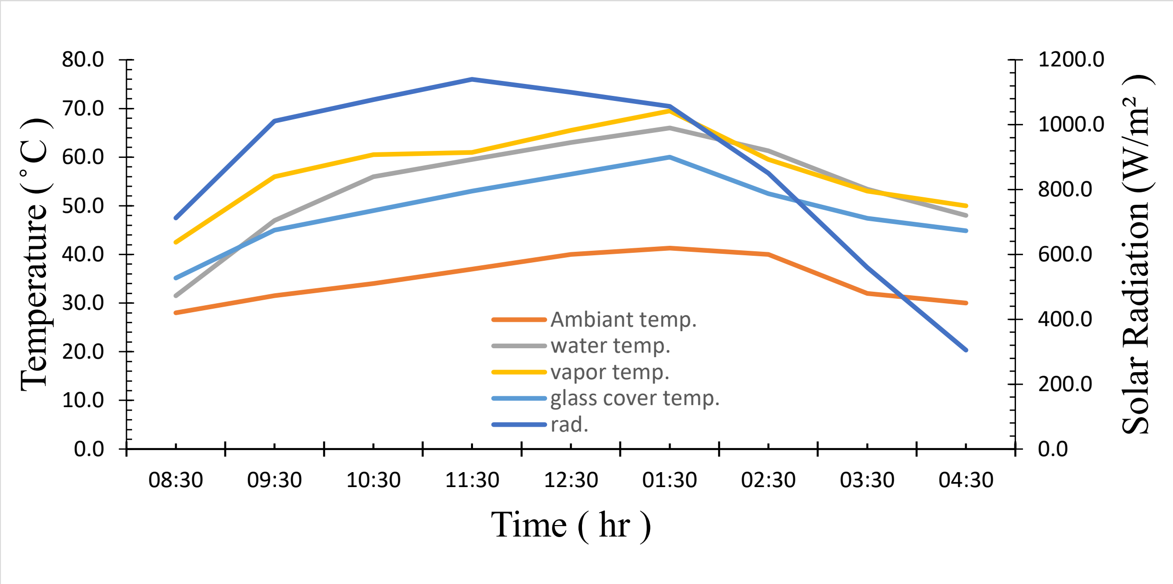


Figure 4.8: variation of temperature and solar radiation with time for conventional solar still

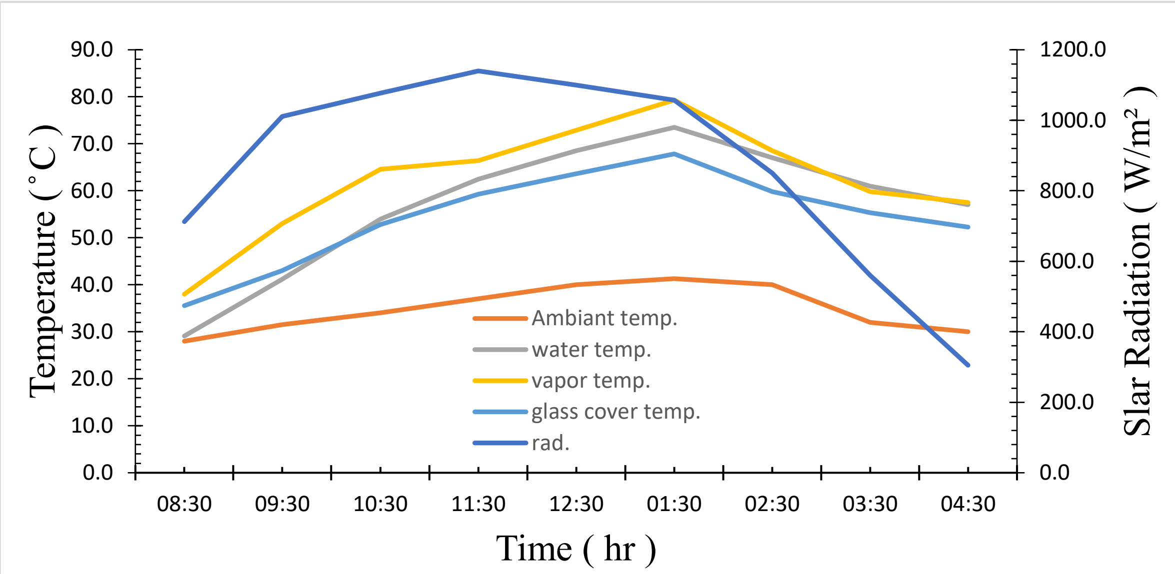


Figure 4.9*:* variation of temperature and solar radiation with time for solar still with 15 mm diameter copper pipe

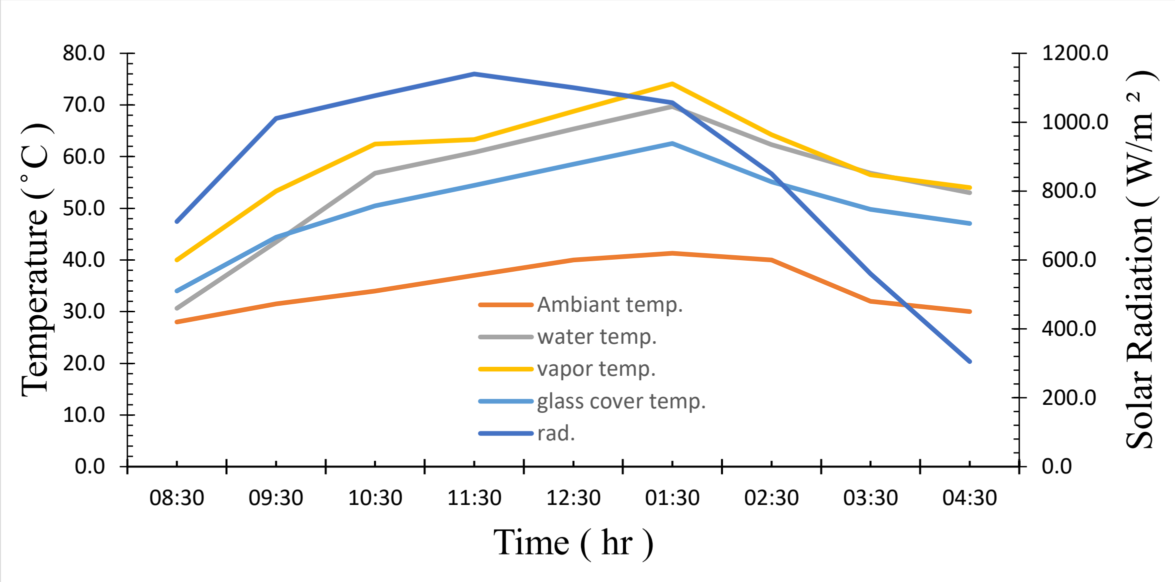


Figure 4.10: variation of temperature and solar radiation with time for solar still with 7 mm diameter copper pipe

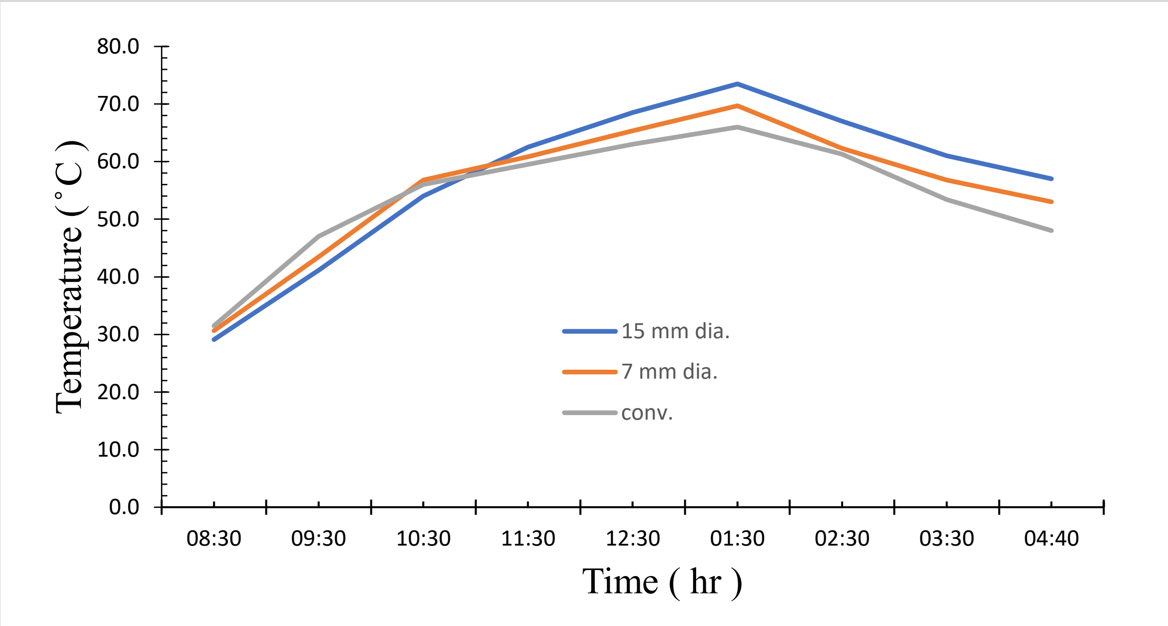


Figure 4.11: variation of basin water temperature with the time of the experiments

As in basin water temperature, vapor and glass cover temperature behave the same. The temperature in conventional still has a value more than that in the other two stills at the beginning of the experiment until 10:00 AM, after that the readings of the still equipped with 15 mm copper pipe increased above them, while the conventional still vapor and glass cover temperatures retreated and the readings keep the same behavior until the end of the experiment as shown in fig. 4.12 and 4.13).

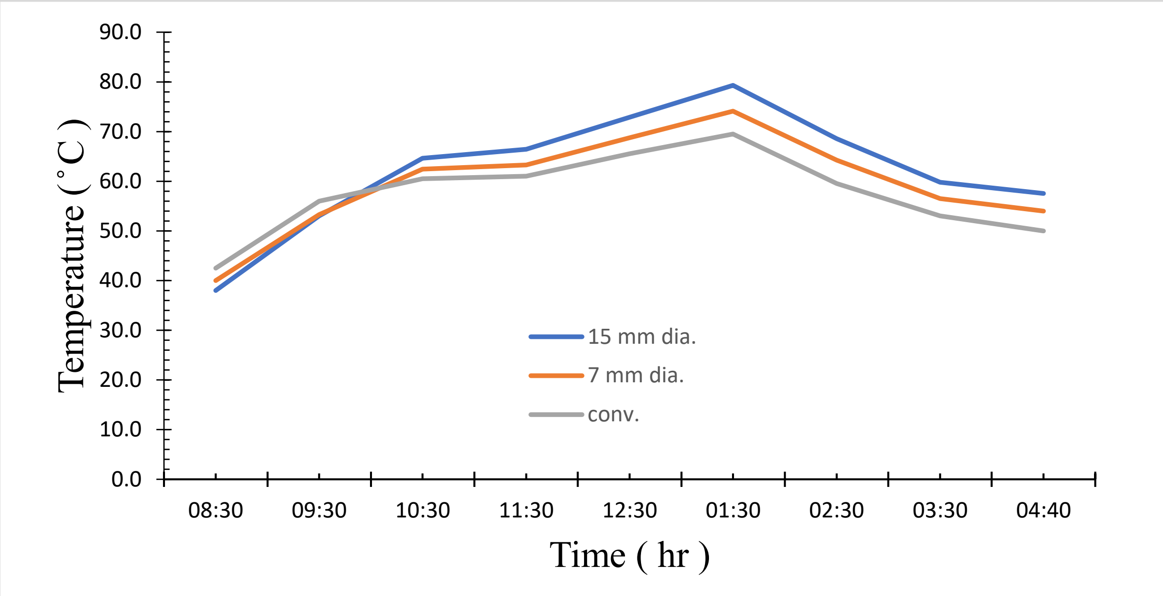


Figure 4.12: variation of vapor temperature with the time of the experiment

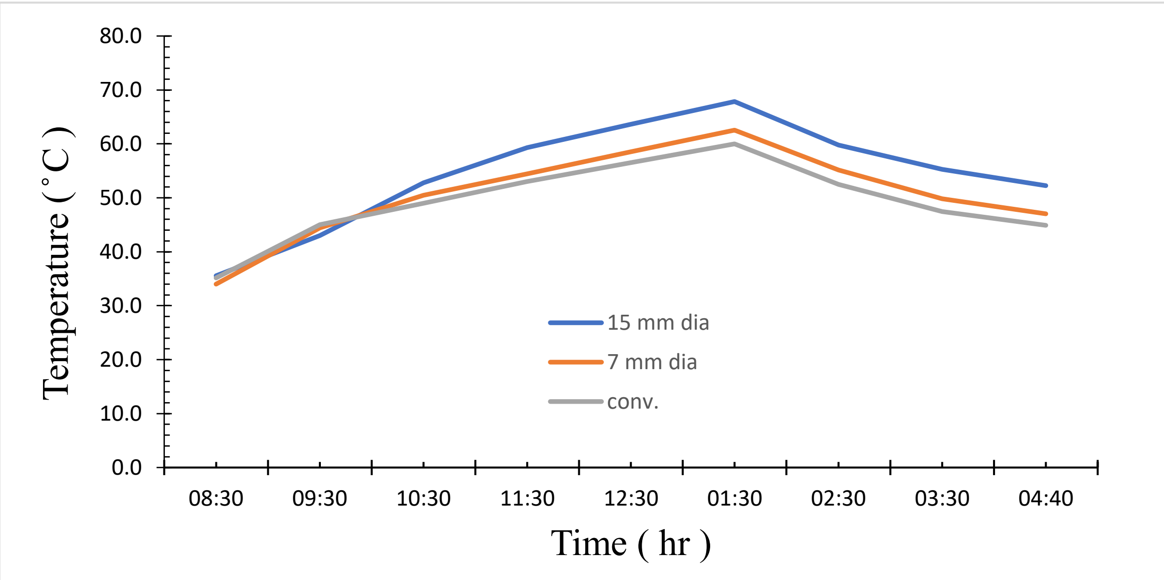


Figure 4.13 variation of glass cover temperature with the time of the experiment

The best pure water production was recorded in the still improved with 15 mm pipe, as shown in fig. 4.14, but it is not like that at the beginning of the experiment. In the first hours, the conventional solar still production rates were better than in the improved stills until 10:30 when the three stills' production rates came nearly close together due to the amount of heat absorbed by the water inside the pipes. With time progress, the solar still equipped production rates with 15 mm pipe recorded the highest value, and the best enhancement in the production is at 01:30 PM with 75.34% more than that of the convention still. While the overall productivity of the pre-mentioned still is enhanced by 46.77 %.

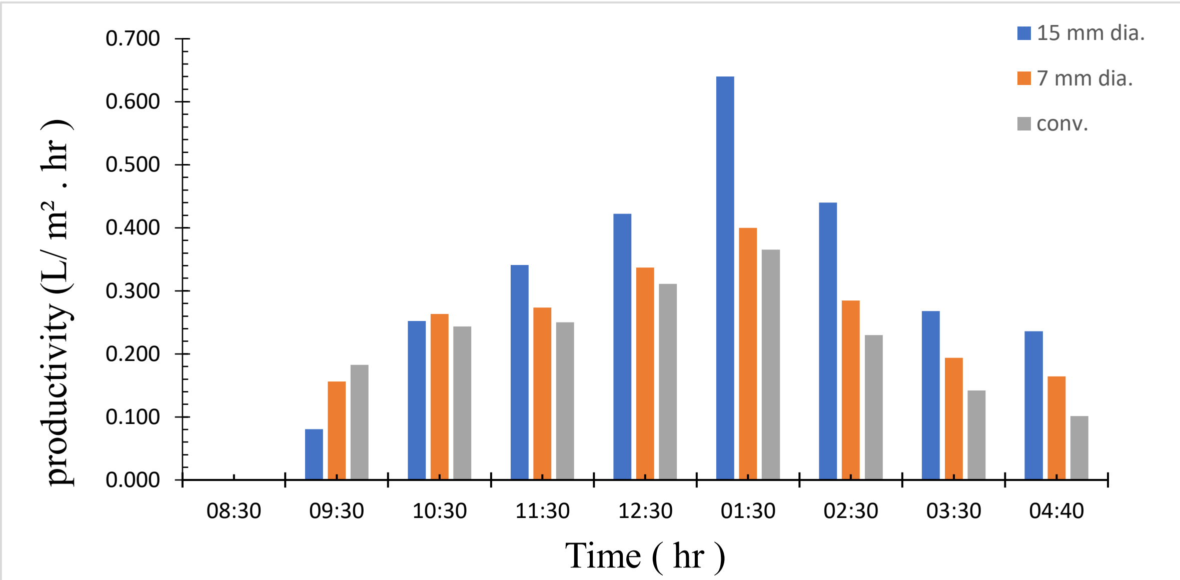


Figure 4.14 productivity variation with time for the three types of stills

4.2.1.2.2 Copper Tube With 50% Filling

For investigating the effect of partially filled copper pipes, an experiment is conducted on the 7th of May 2020 at the same location. As stated previously, the solar radiation rises at the beginning of the experiment until reaching its maximum value of 1207 W/m² at 12:30 PM and then decrease with experiment time progress, as shown in fig. 4.15 to 4.17, while the maximum ambient temperature and average wind speed are 38℃ and 6.3 km/hr, respectively.

The incidence radiation directly affected the raw water and vapor temperatures inside the three stills; with the increase of solar radiation, raw water and vapor temperatures increase. The highest readings for both basin water and vapor are recorded in the still with 15 mm pipes along the experiment time. In contrast, the maximum reading was recorded at 02:30 PM for each one, as shown in fig. 4.18 and 4.19.

It is clear from the above figures that adding evacuated copper pipes with a 50% filling ratio increased water basin temperature by 17.41% and 6.7% for the stills equipped with 15mm and 7 mm, respectively, compared to conventional still. Also, that temperature increment directly affects vapor and glass cover temperatures, as shown in fig. 4.19 and 4.20.

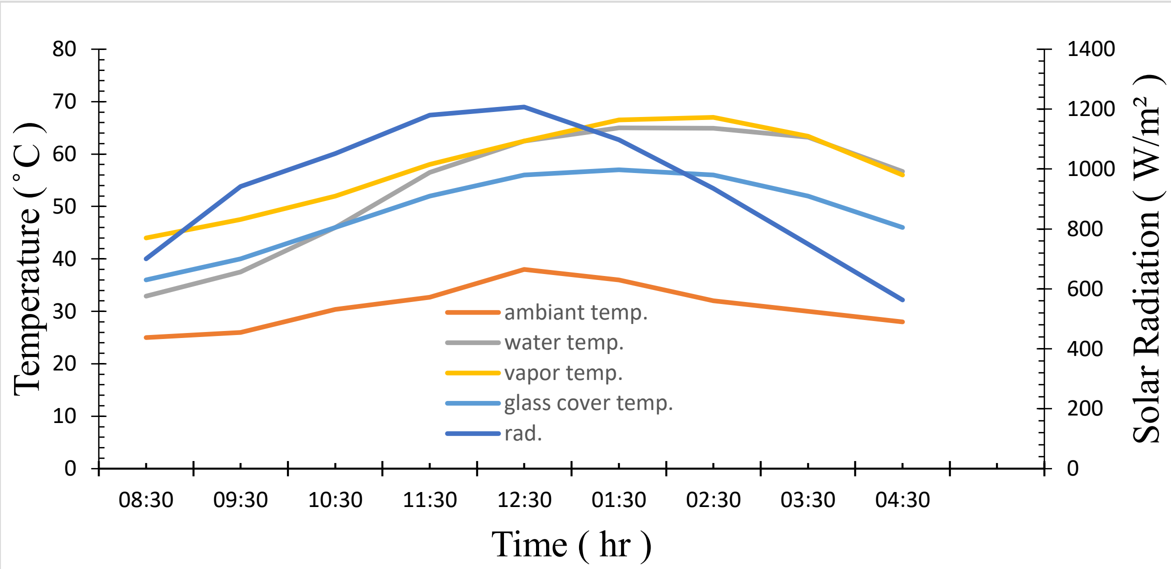


Figure 4.15: variation of temperature and solar radiation with measurement time for conventional solar still

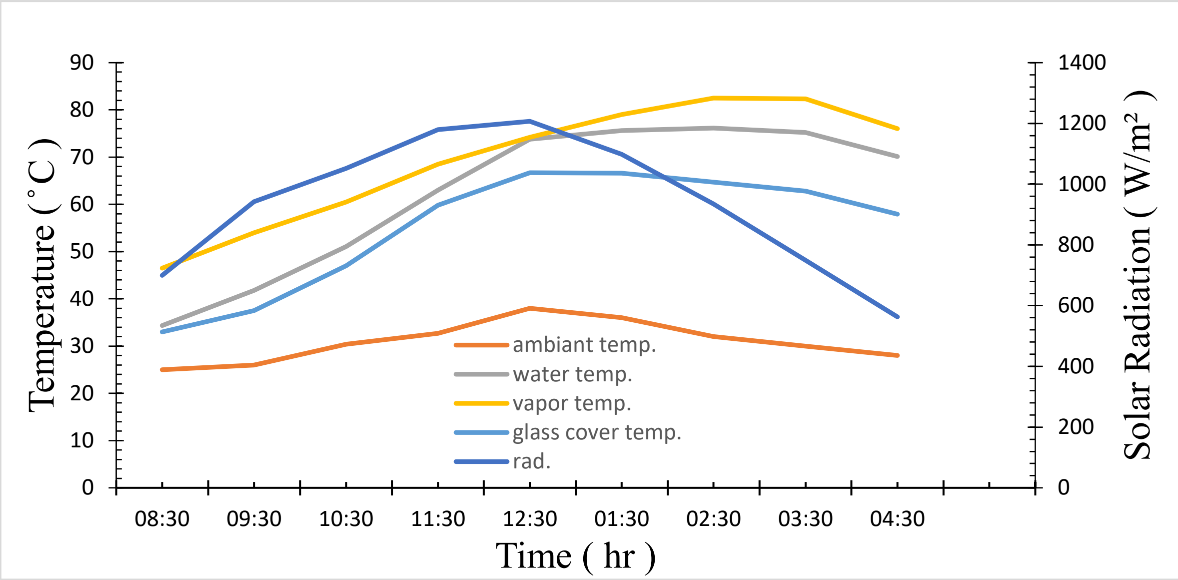


Figure 4.16: variation of temperature and solar radiation with measurement time for solar still with 15 mm diameter copper pipe

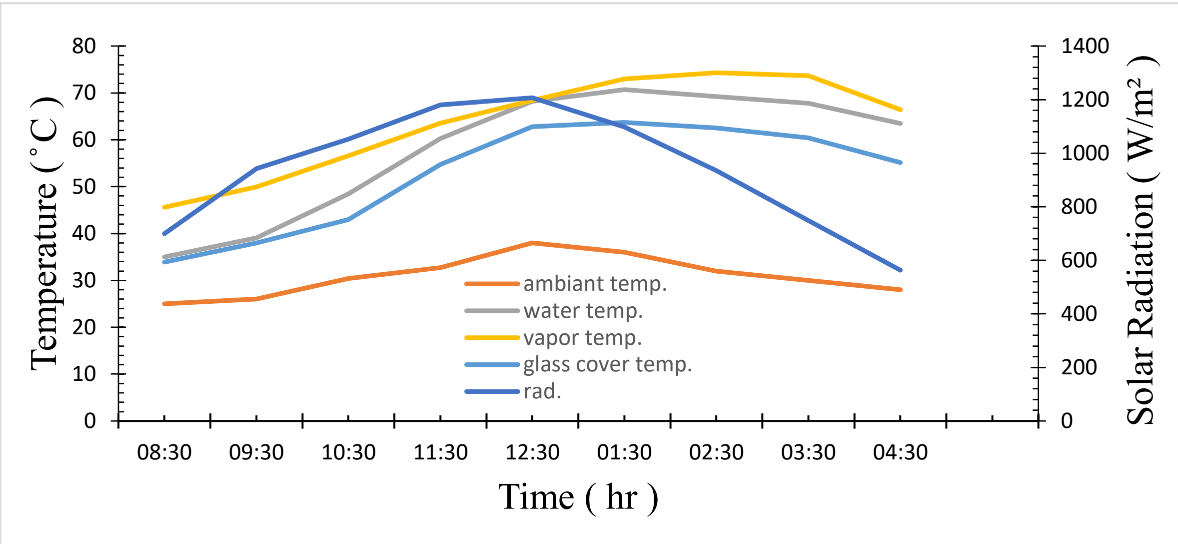


Figure 4.17: variation of temperature and solar radiation with measurement time for solar still with 7 mm diameter copper pipe

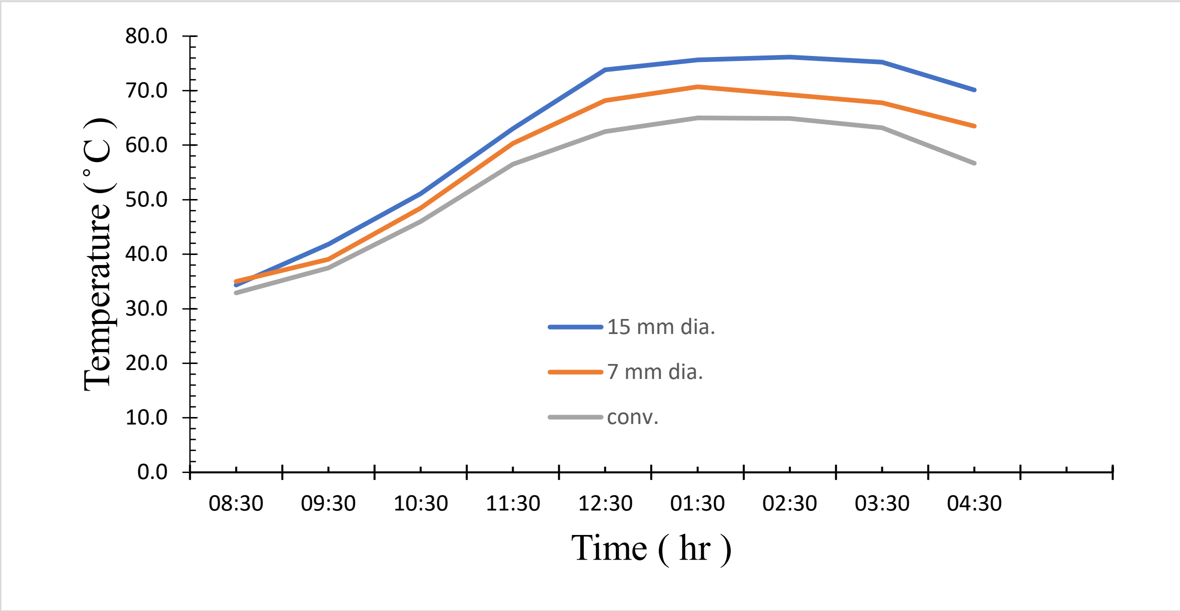


Figure 4.18: variation of basin water temperature with the time of the experiment

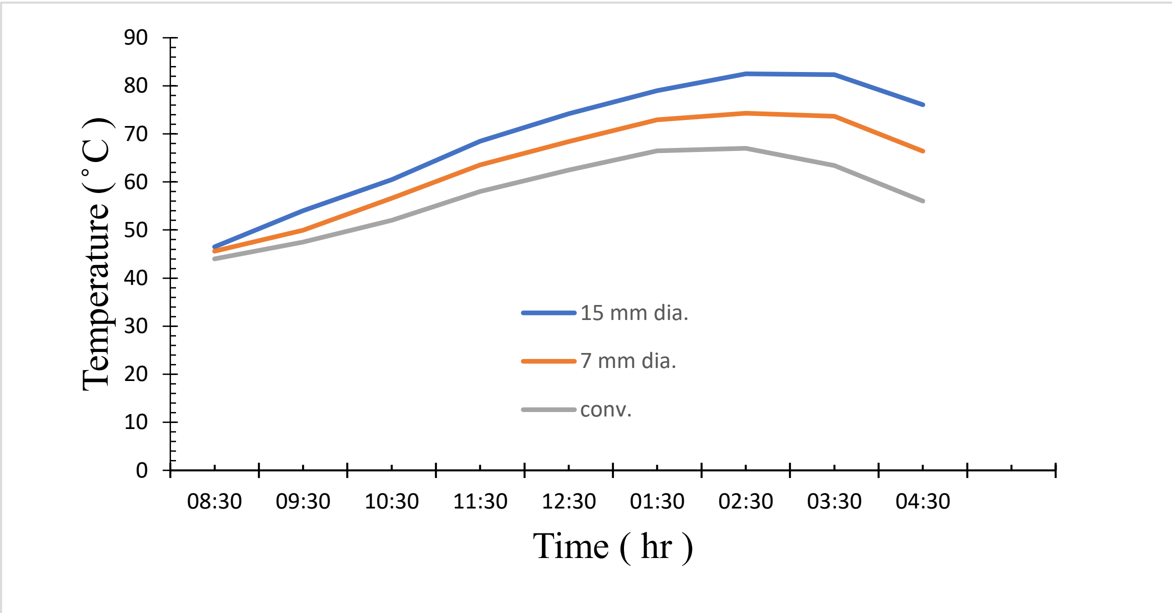


Figure 4.19: variation of basin water temperature with the time of the experiment

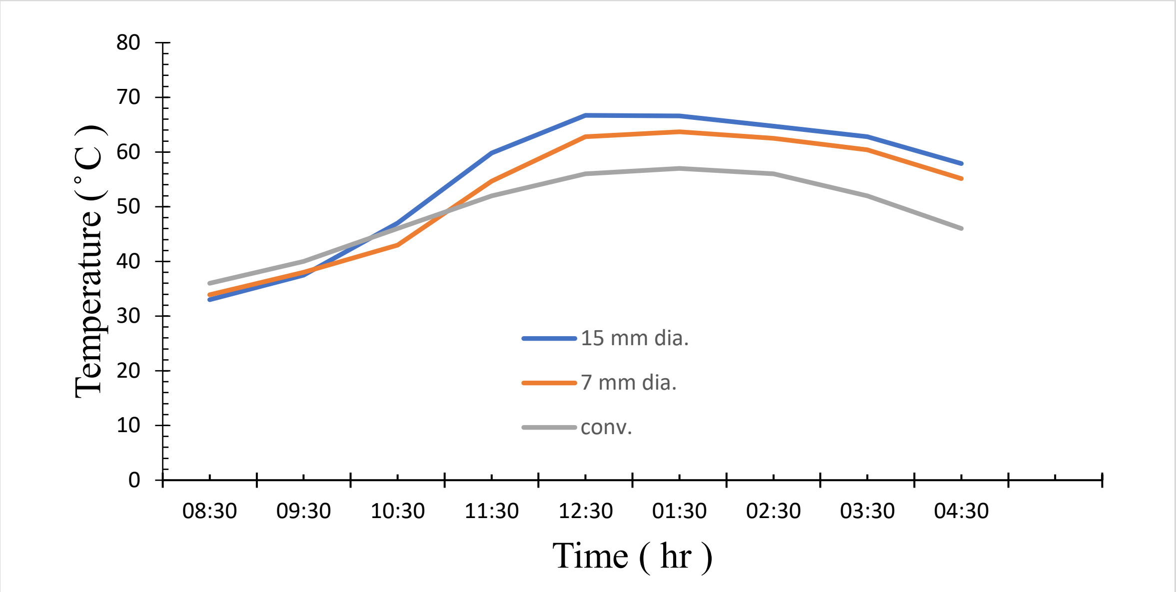


Figure 4.20: variation of basin water temperature with the time of the experiment

These experiments conducted that the use of 50% filling ratio has more effectiveness on the thermal performance because the low boiling point of the water under evacuation. As for the pipe size, it seems that using 15 mm pipe has more effectiveness on the thermal performance and productivity due to the increasing the thermal contact area as well as the amount of heat stored. And the maximum efficiency as expected, was recorded utilizing 15 mm pipe filled with 50% water. as shown in table 4.1

Table 4.1: enhancements of stills equipped with evacuated copper pipes with a different filling ratio

Solar still with copper pipe	50% filling ratio	100 % filling ratio
15 mm dia.	90.09 %	46.77 %
7 mm dia.	27.83 %	19.93%

The productivity of all the solar stills increased depending on the increase of solar radiation and had the maximum value for all of them at 2:30 PM, while the highest production rates among them all was in the solar still equipped with 15 mm copper pipe from the beginning of the experiment until its end as shown in fig. 4.21.

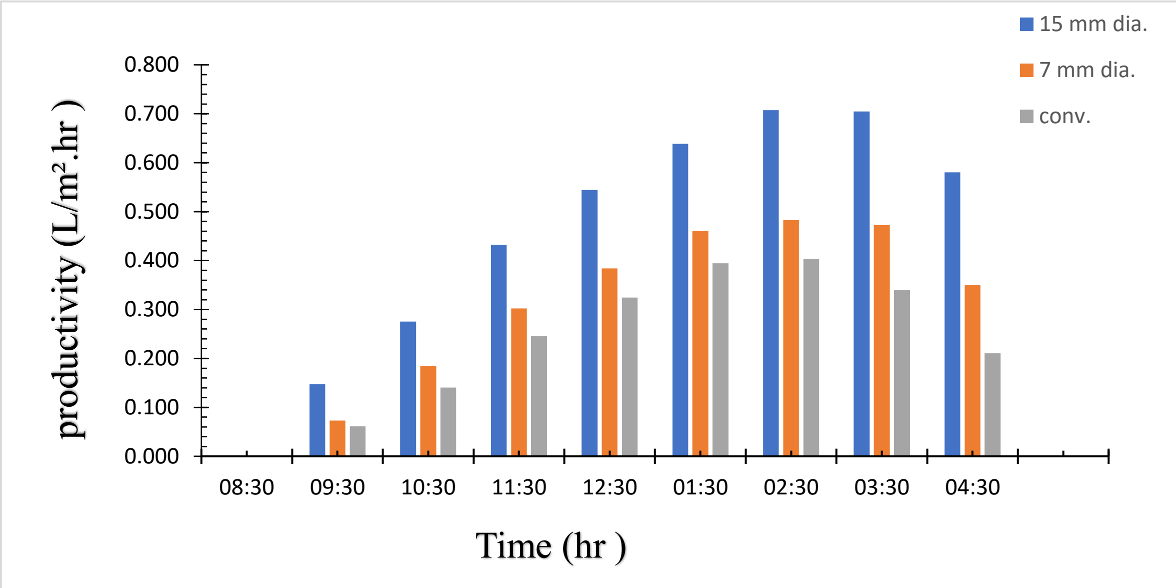


Figure 4.21 productivity variation with time for the three types of stills

4.2.1.3 Galvanized Wick

When the basin plate absorbed the incident solar radiation on it, the energy will be transferred entirely from the plate to the water, if considered the solar still insulated from all sides and bottom. Enhancing the energy transfer between the basin plate and water inside will enhance the solar still productivity. The overall heat transfer could be increased in several ways, and increasing the contact area is one of them, and it performed in these experiments by using two sized galvanized iron wicks.

4.2.1.3.1 Single Wick

The experiment was conducted with the same solar stills on the 5th of March 2020. As in the previous experiments, the solar still productivity was affected by climate conditions such as wind speed and ambient temperature, recorded 31℃

and 9.4 km/hr, respectively, as maximum and average values. As usual, the solar radiation started with its minimum value at the beginning of the experiment and increased gradually to its maximum value at 11:30 AM with more than 1270 W/m² and decreased gradually with experiment time progress, as shown in fig. 4.22 to 4.24.

Two grid size of wicks were used in this experiment. 25*25 mm apart in the first still, 50*50 apart for the second, while third left to be work as conventional. The wicks are black painted and immersed inside the basin water for each still.

Increasing the thermal contact area between the absorbing object and the water basin directly influences the raw water temperature and the evaporation rates. As shown in fig. 4.25 and 4.26, the basin water and vapor temperatures in the three stills record close readings each other from the beginning of the experiment until 10:30 AM, after this, the temperatures in the still equipped with 25*25 mm wick started to take the lead for the rest of the experiment time with a maximum value of 72.25℃ and 80.1℃ respectively.

The increase of water and vapor temperature inside each solar still with the increase of solar radiation causes an increase in the glass cover temperature until it reaches its highest value of 68.5℃ at 03:30 as shown in fig. 4.27.

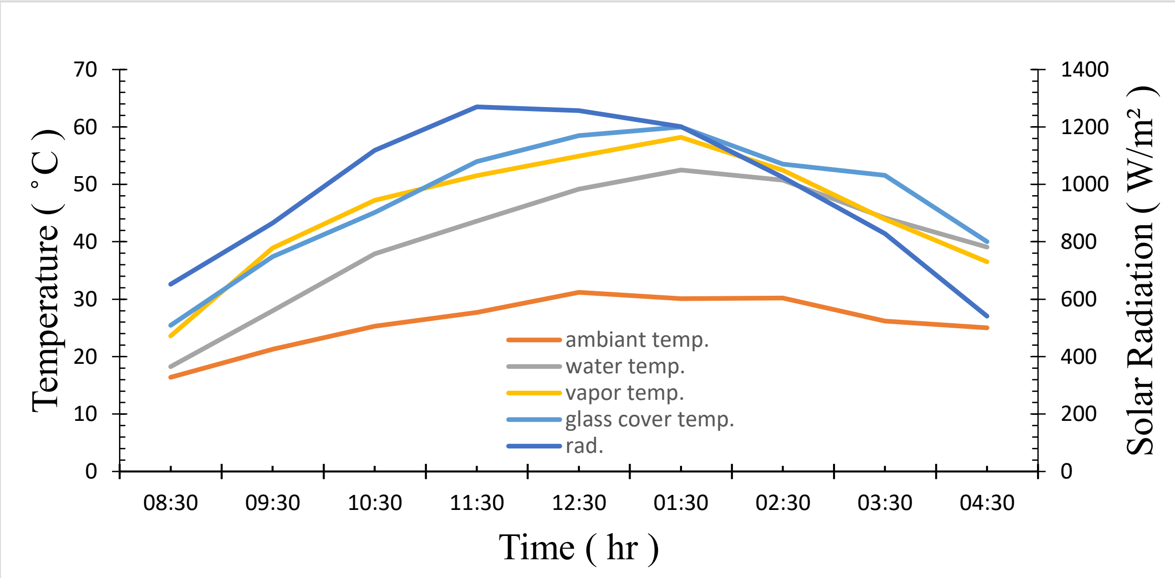


Figure 4.22: variation of temperature and solar radiation with measurement time for conventional solar still

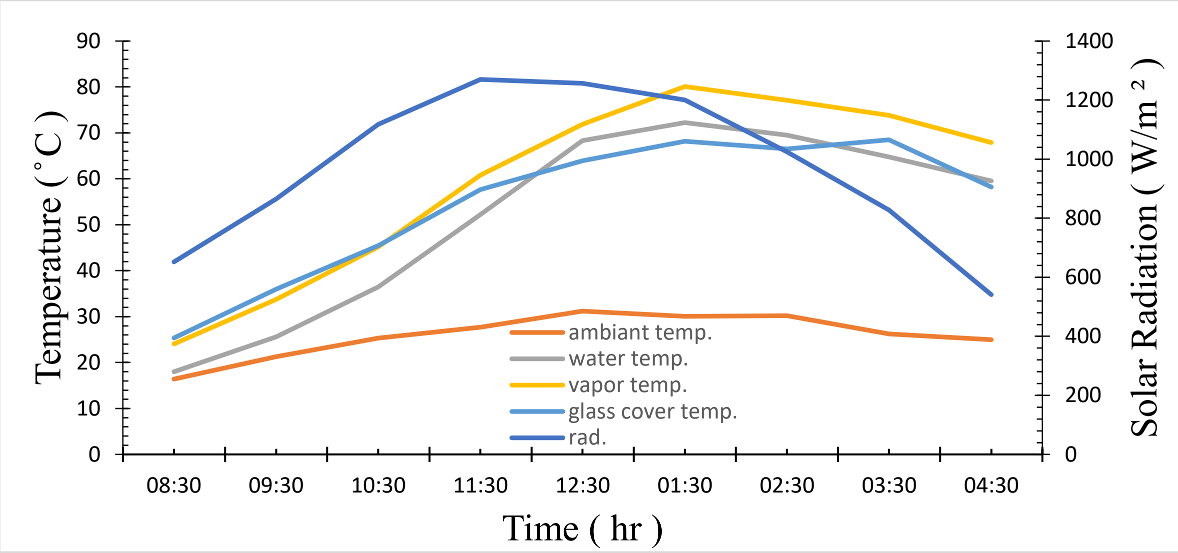


Figure 4.23: variation of temperature and solar radiation with measurement time for solar still with 25 *25 grid size wick still

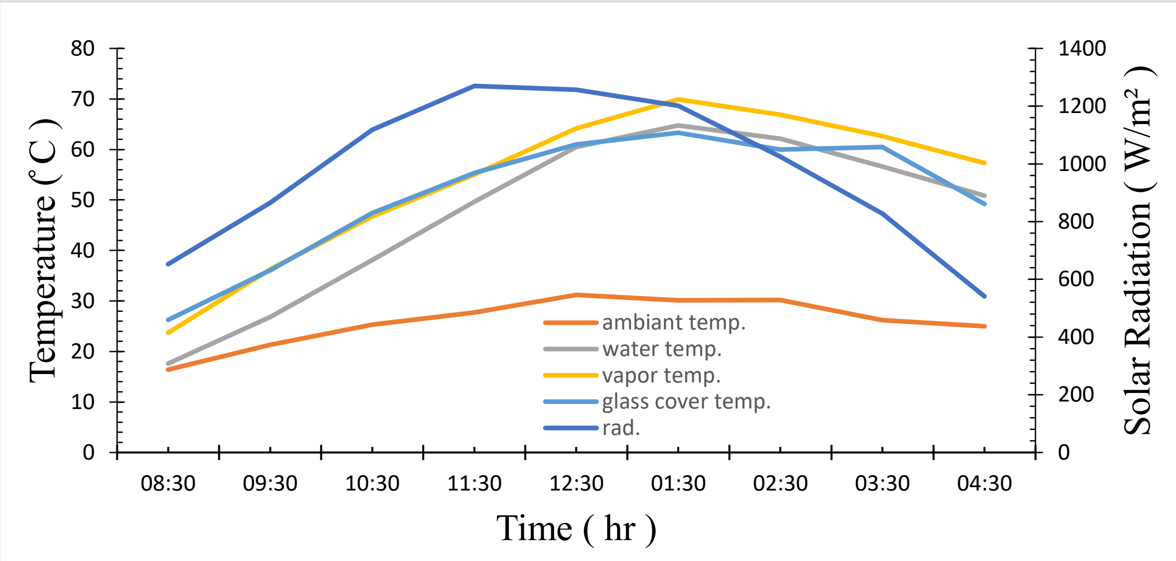


Figure 4.24: variation of temperature and solar radiation with measurement time for still with 50 * 50 grid size wick

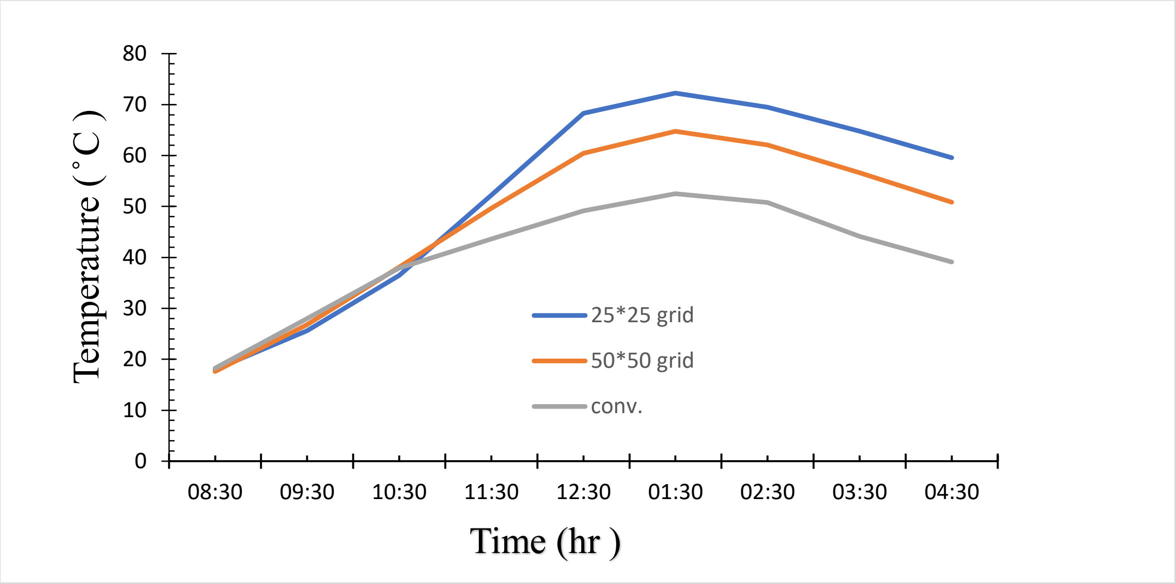


Figure 4.25 variation of basin water temperature with the time of the experiment

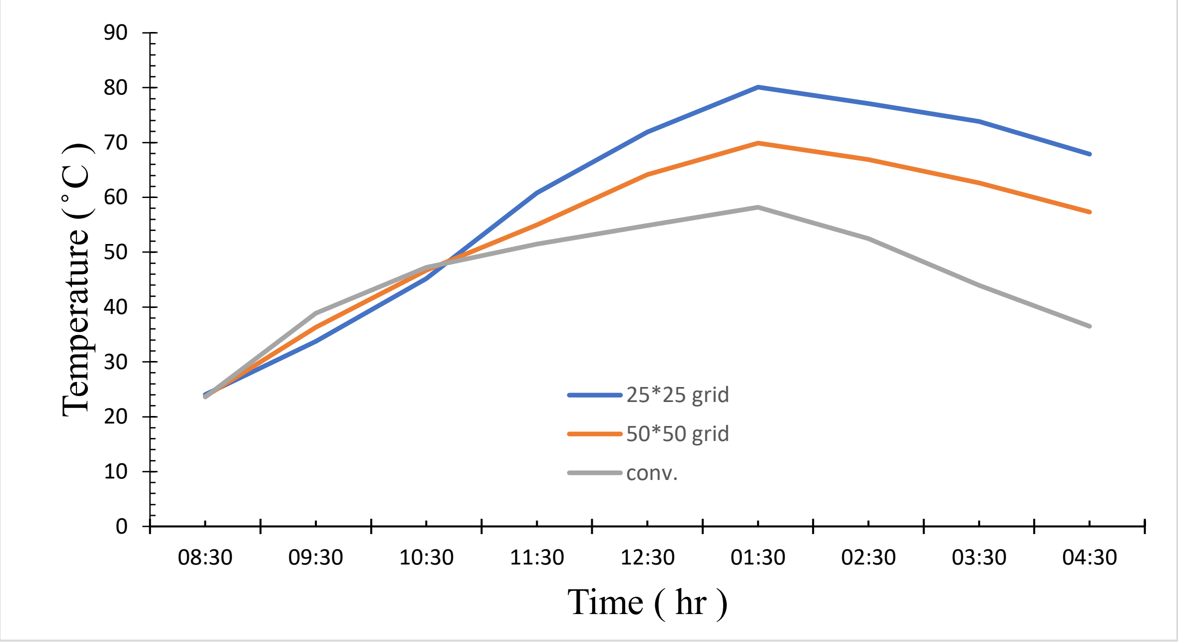


Figure 4.26 variation of vapor temperature with the time of the experiment

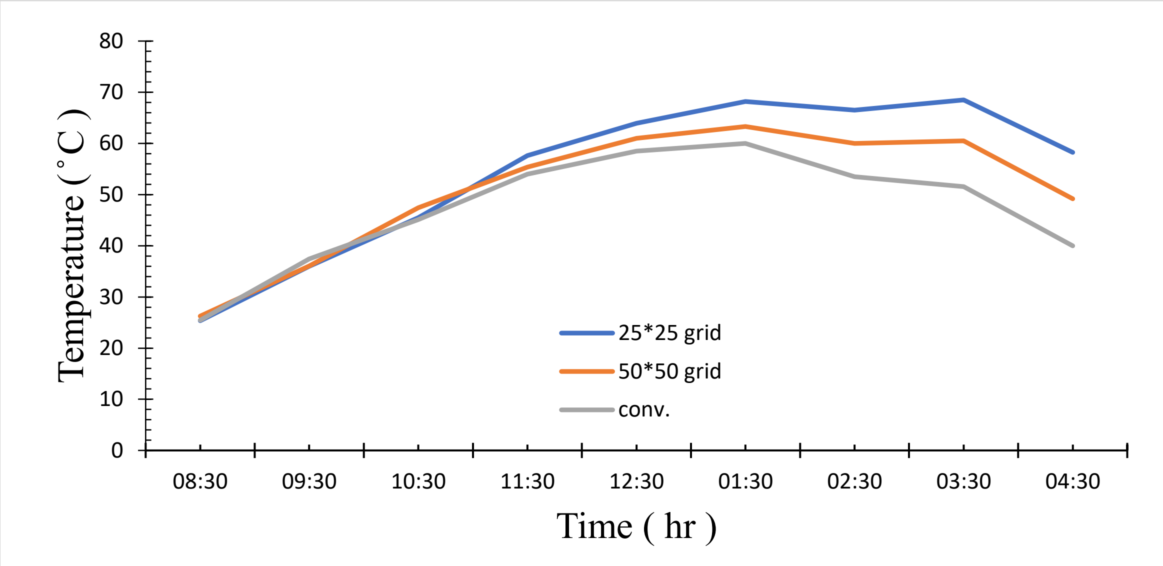


Figure 4.27 variation of glass cover temperature with the time of the experiment

With the increasing incidence of solar radiation, the production rates increase until reach up the maximum value recorded in the still with 25*25 mm wick at 01:30 PM with an instant enhancement of 111% and an overall enhancement of 86.65%, as shown in fig. 4.28.

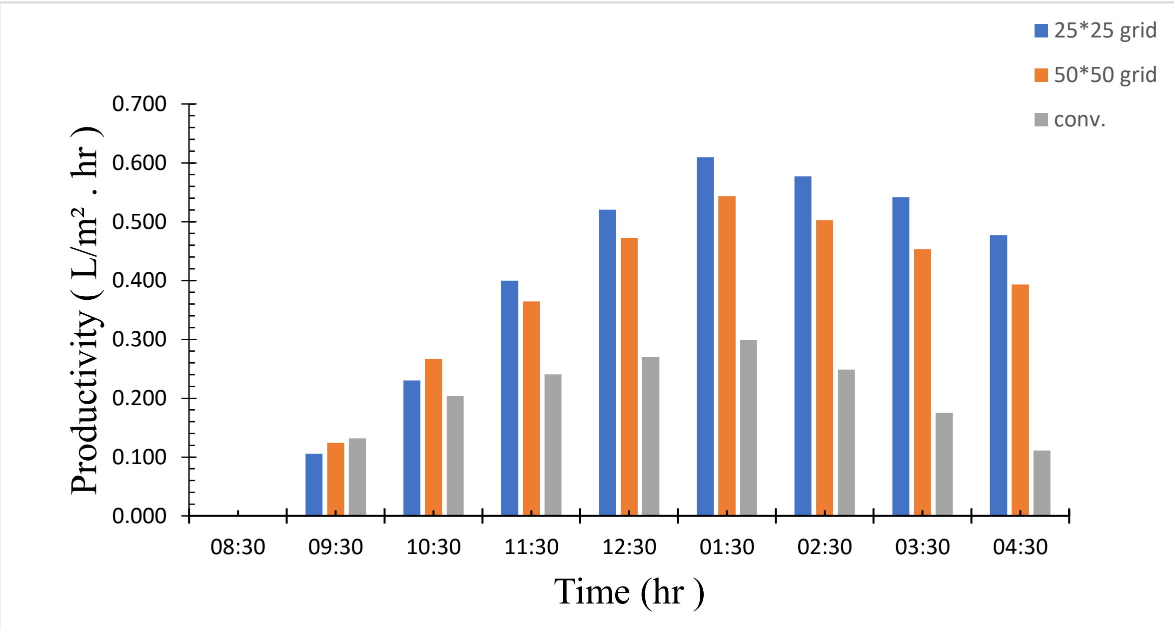


Figure 4.28 productivity variation with the time the experiment

4.2.1.3.2 Double with Single Wicks

Adding galvanized wick in the solar still basin has an obvious effect on the thermal performance and productivity. In this respect, studying the effect of utilizing both types of the wick and compare it with both the still equipped with single wick and the conventional are carried out. An experiment was conducted on the 10th of August 2020 for solar still provided with two wicks (25*25 and 50*50 mm) and operated along with others. The average wind speed and maximum ambient temperature recorded were 9.5 km/h and 45℃, respectively. The solar radiation varies along the experiment time, and the maximum value recorded was 1201 W/m^2 at 12:30 PM, as shown in fig. 4.29 to 4.31.

The increasing of absorbed solar radiation led to temperature increment of basin water and vapor for each still until reaching its maximum value at 01:30 PM and then decreased with decreasing radiation.

As it was evident in fig. 4.32, the basin water temperature was not affected directly by radiation due to the time needed to raise the temperature of the basin plat and the added wicks together, but after the first hour, the water temperature starts to increases due to the additional thermal contact area of the surface of the wick.

The maximum basin water temperature was recorded in the basin equipped with double wicks was 89.5℃ and 81℃ and 77℃ in the still equipped with single wick and the conventional, respectively.

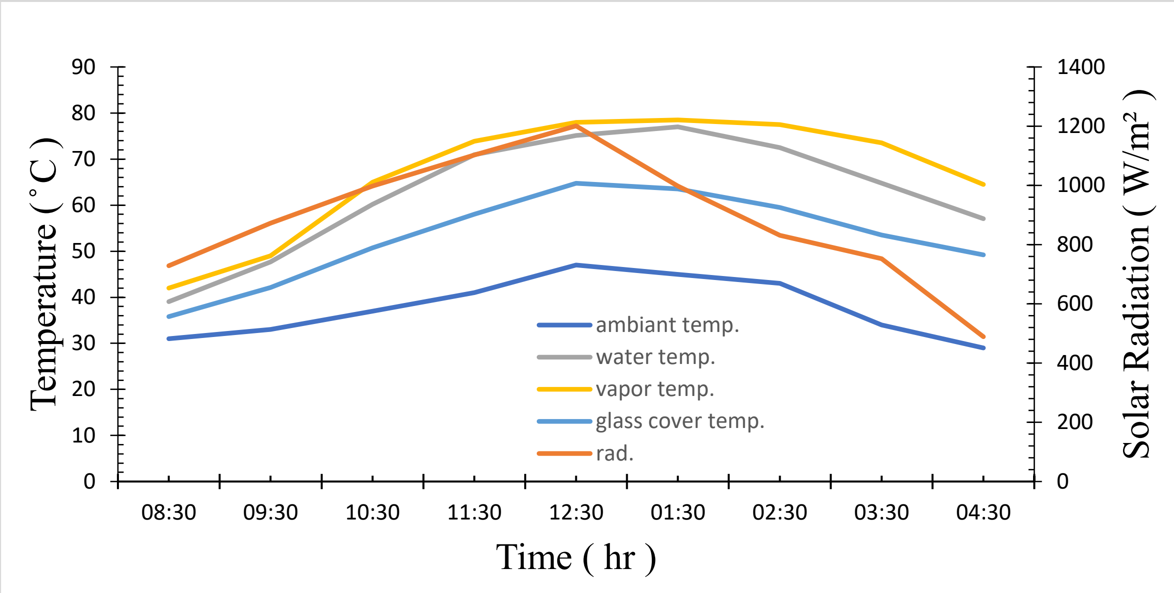


Figure 4.29: variation of temperature and solar radiation with measurement time for conventional solar still

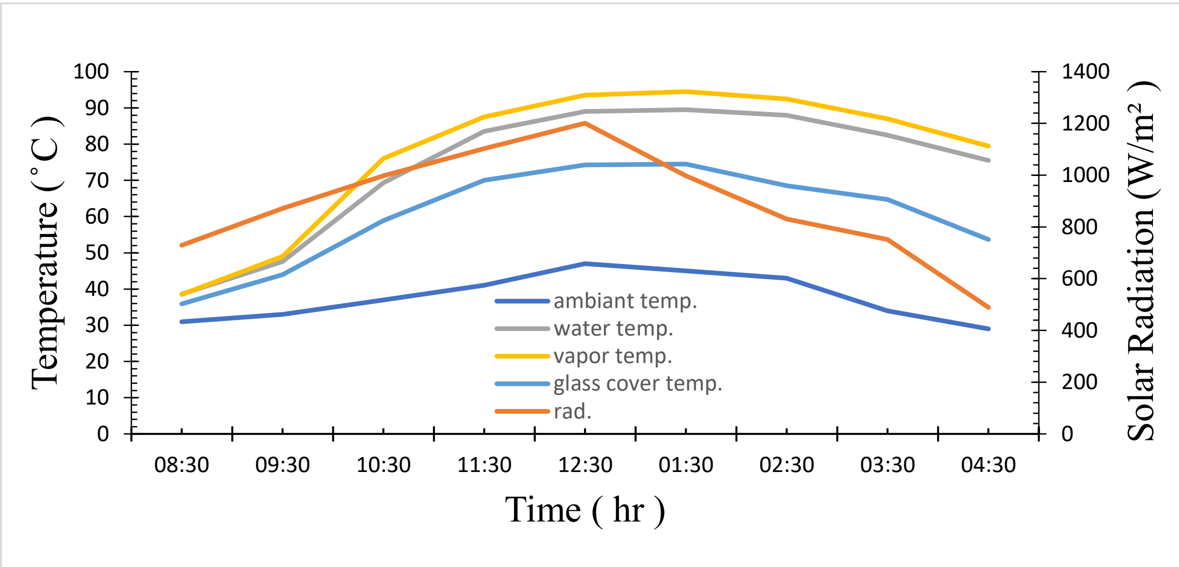


Figure 4.30: variation of temperature and solar radiation with measurement time for solar still with double wicks (25 * 25 and 50 *50 grids size)

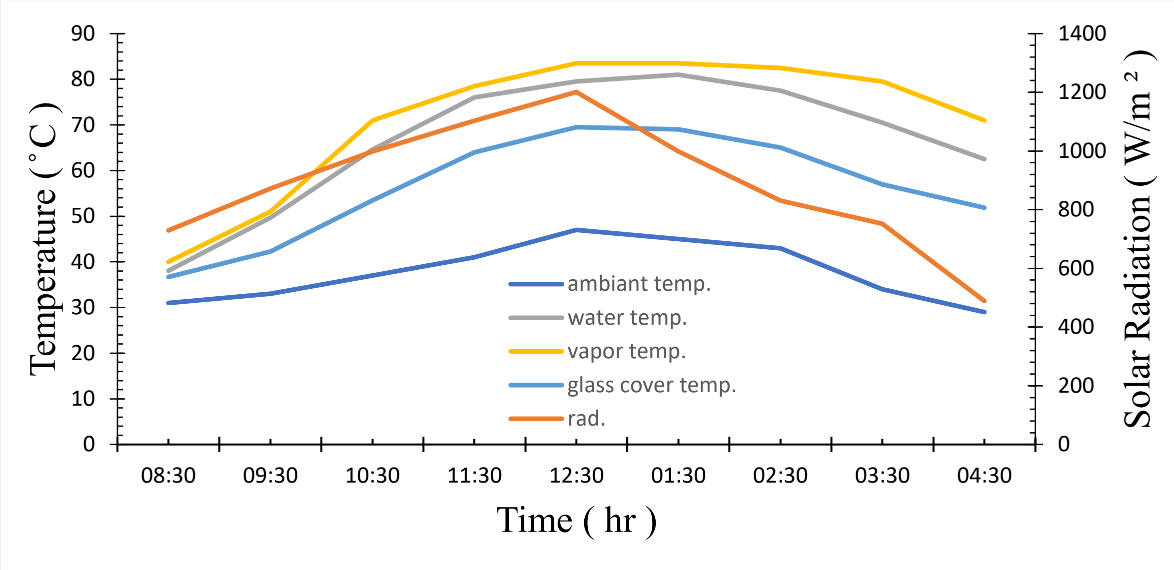


Figure 4.31: variation of temperature and solar radiation with measurement time for solar still with single wick (25 *25 grid size)

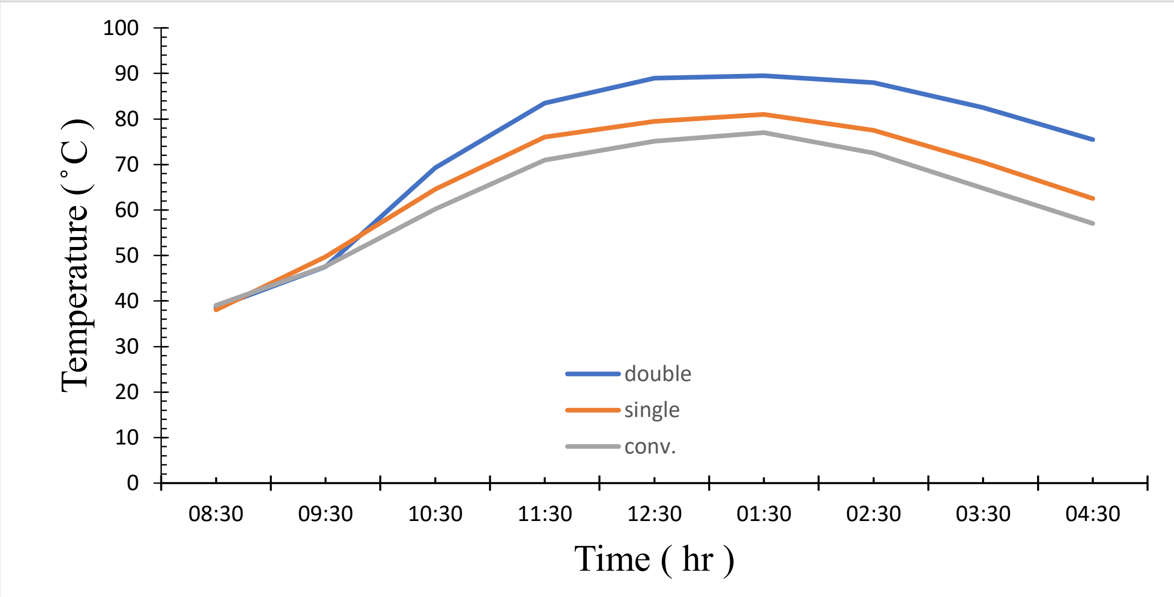


Figure 4.32 variation of basin water temperature with the time of the experiment

Increasing the saturated moisture air inside solar still is due to the increase in the basin water temperature. However, the increase in the saturated water vapor will cause improvement in the still productivity because of the increase in temperature difference between the vapor and the glass cover. The maximum vapor temperature is recorded inside the solar still equipped with double wicks with 94.5℃, which is more than the still with single wick and the conventional by 13.17% and 20.2% respectively as shown in fig. 4.33 and 4.34.

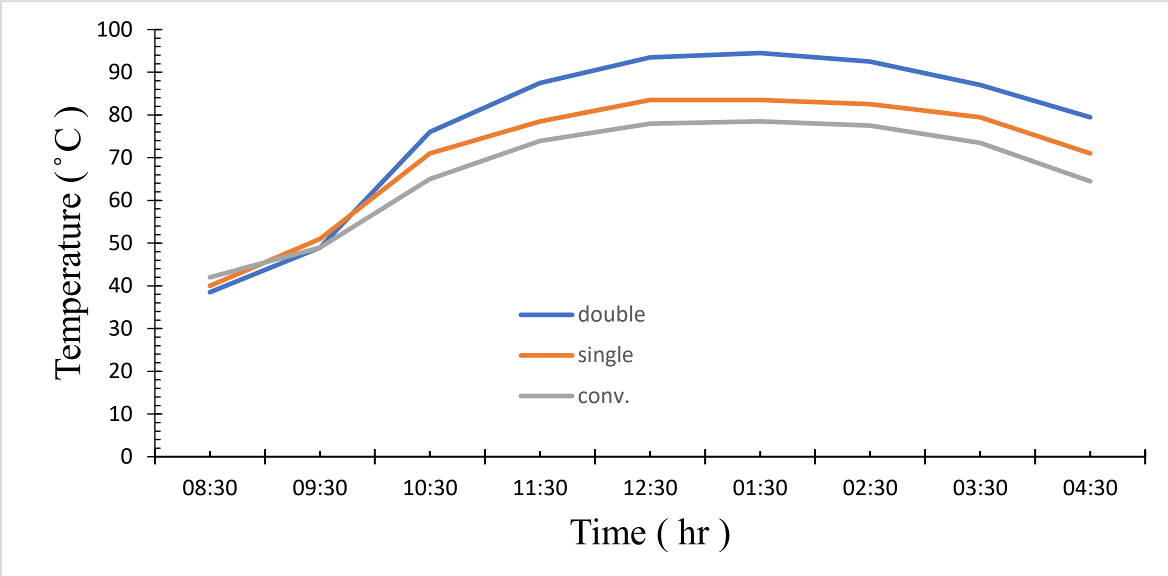


Figure 4.33 variation of vapor temperature with the time of the experiment

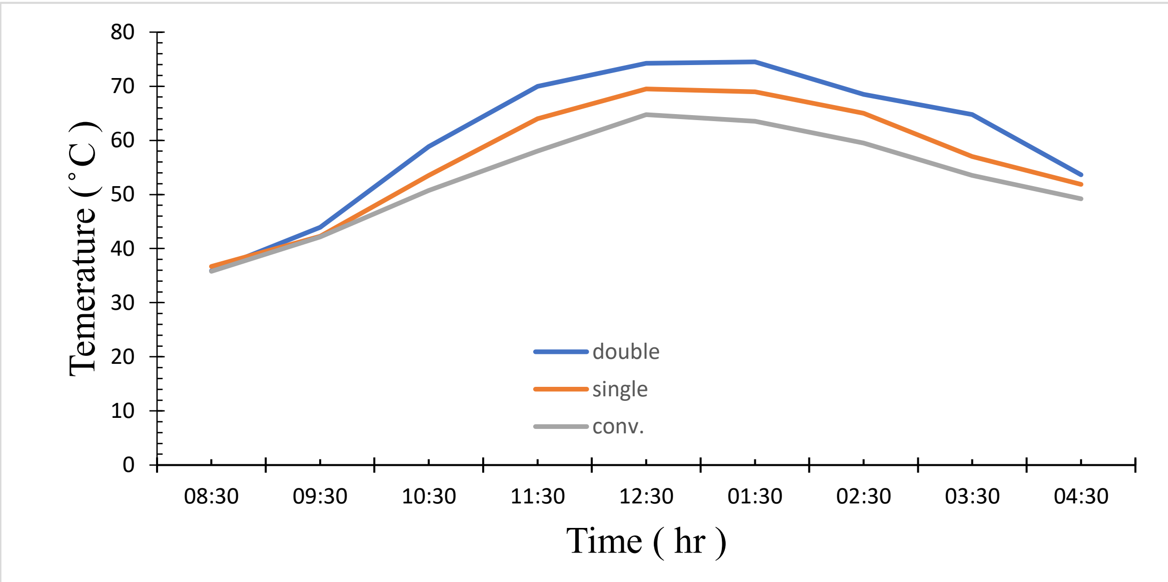


Figure 4.34 variation glass cover temperature with the time of the experiment

The pure water productivity was strongly affected by the rise of water and vapor temperature. As expected, the most effective solar still was equipped with double wick with pure water productivity of 6.823 L/day.m². The enhancement was 151% compared with the conventional and 33.75% more than the still with a single 25*25mm wick. As in all the previse experiments, solar stills productivity increase with the increase of solar radiation and hit a maximum value of 1.087 L/m².hr at 01:30 PM as in fig. 4.35.

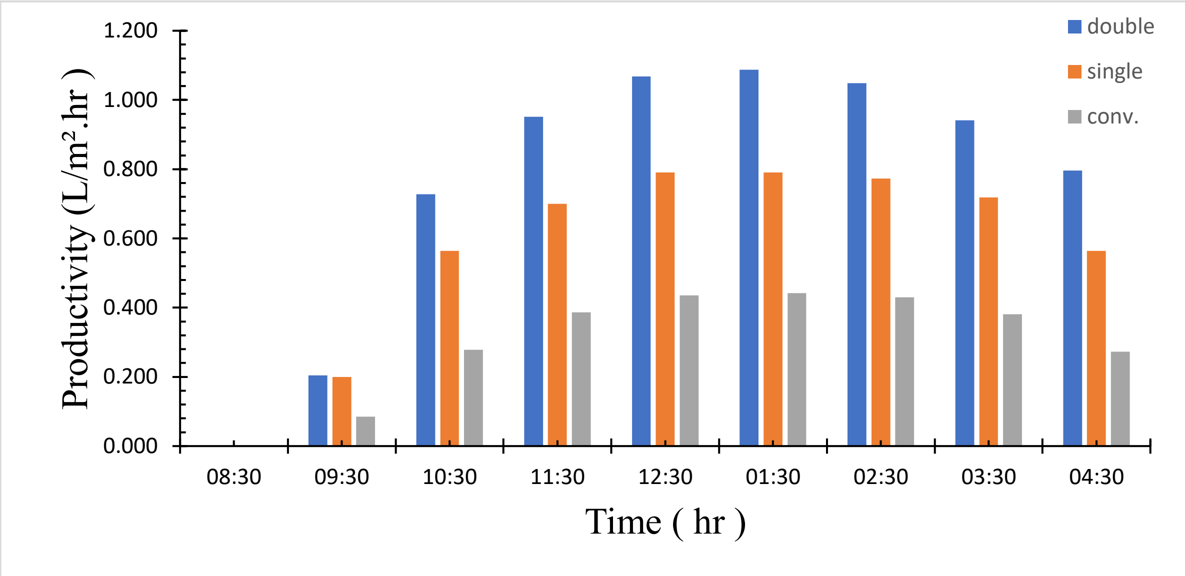


Figure 4.35 variation of productivity with the time of the experiment

4.2.2 Condensation Enhancement

Condensation is one of the main parameters that control the solar still productivity, and it strongly depends upon the temperature difference between the vapor and the condensing surface, glass cover. In the previous experiments, it is focused on raising the vapor temperature and increasing the evaporation rates. These experiments are concerned with reducing the condensing surface temperature to increase the temperature difference between it and vapor temperature and finally enhance the condensation rates.

4.2.2.1 Water Channel

Two types of water channels are presented in this experiment (N) shape and (U) shape. The water channels are made of transparent glass and installed on the glass cover's upper surface, around the rims, with tap water flowing inside it with different flow rates to reduce the glass cover temperature. The experiment included three single slopes solar still two different configurations working simultaneously with conventional solar still to compare the results.

The experiments primary objectives are to investigate the effectiveness of the U and N shape channels and which design affects pure water productivity more than others, simultaneously studying the effect of increasing the water flow rate inside that water channels. Therefore, three experiments with three different water flow rates are conducted using three single slope solar stills with the same dimensions and working under the same environmental conditions.

4.2.2.1.1 Water Channel With 1 L/min. Flow Rate

The experiment was conducted on the 30^{th} of May 2020. The three stills are operated simultaneously at the same environmental conditions. The solar radiation varies with the experiment time and starts to increase continuously until it reaches up to a maximum value of 1110 W/m^2 at 12:30 PM and reduces after that until the end of the experiment, as shown in fig. 4.36 - 4.38. During this experiment, the maximum ambient temperature and average wind speed were 42℃ and 13.6 km/hr, respectively. The gradual increase in the value of incident solar radiation directly affect both basin water and vapor temperatures, and it starts to increase gradually until reaching the highest value between 12:30 PM and 01:30 PM with an average temperature of 62.5℃ and 70℃ for the three solar stills as shown in (fig. 4.39 and 3.40).

The water inside the channel extracts a certain amount of the energy distributed on the front glass, reducing its temperature. The glass in the three solar stills temperature increased with the rise of solar radiation. The highest value was recorded in the conventional solar still at 12:30 PM, while the solar stills improved with N shape, and U shape cooling channels record temperatures with 10.97% and 7.93% less than the conventional solar still as shown in (fig. 4.41).

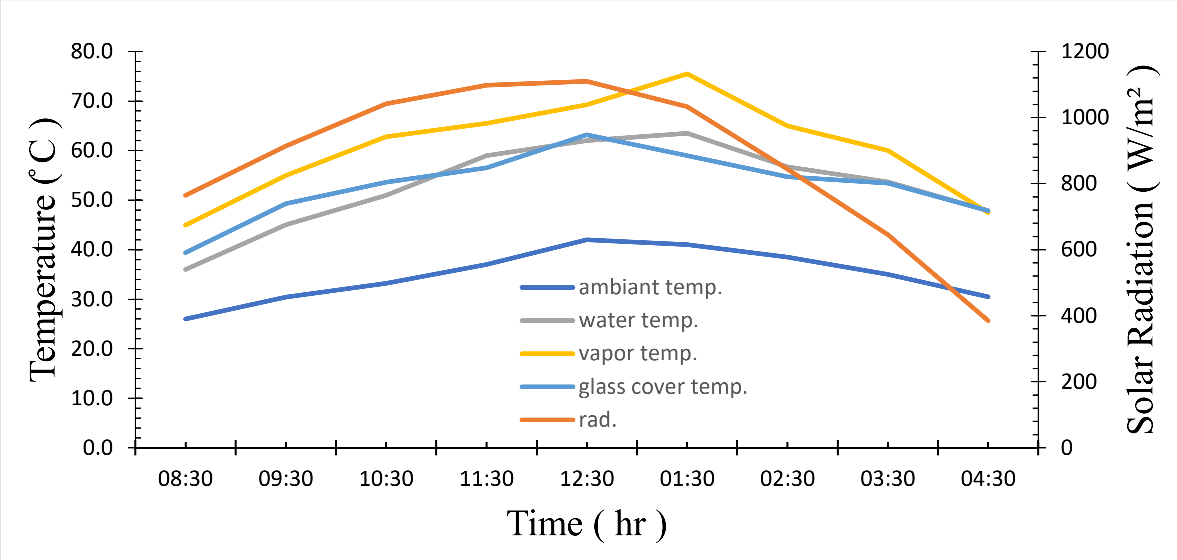


Figure 4.36: variation of temperature and solar radiation with measurement time for conventional solar still

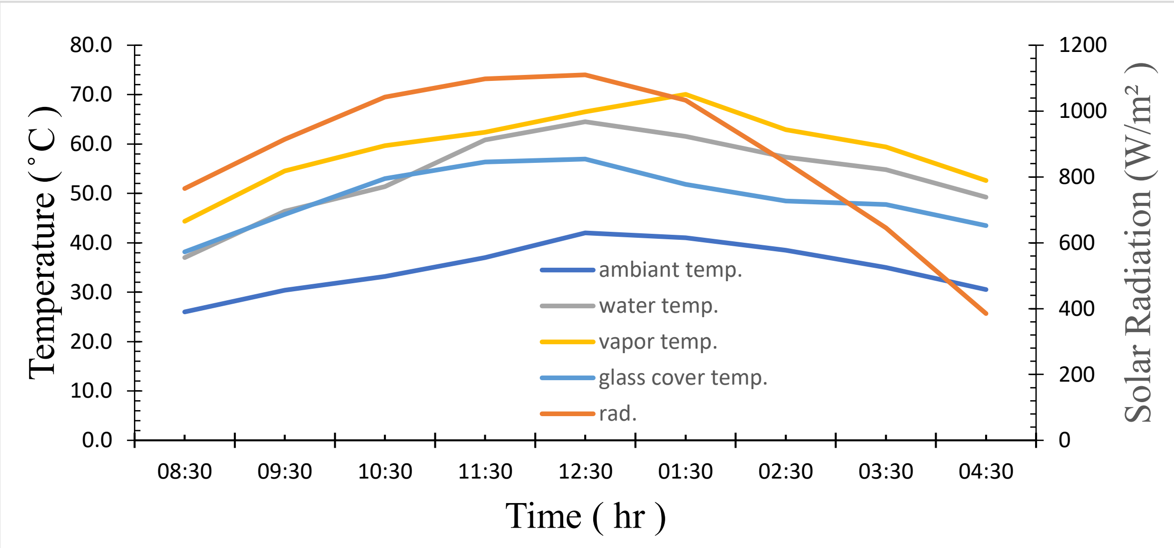


Figure 4.37: variation of temperature and solar radiation with measurement time for solar still with N shape water channel at 1 L/min.

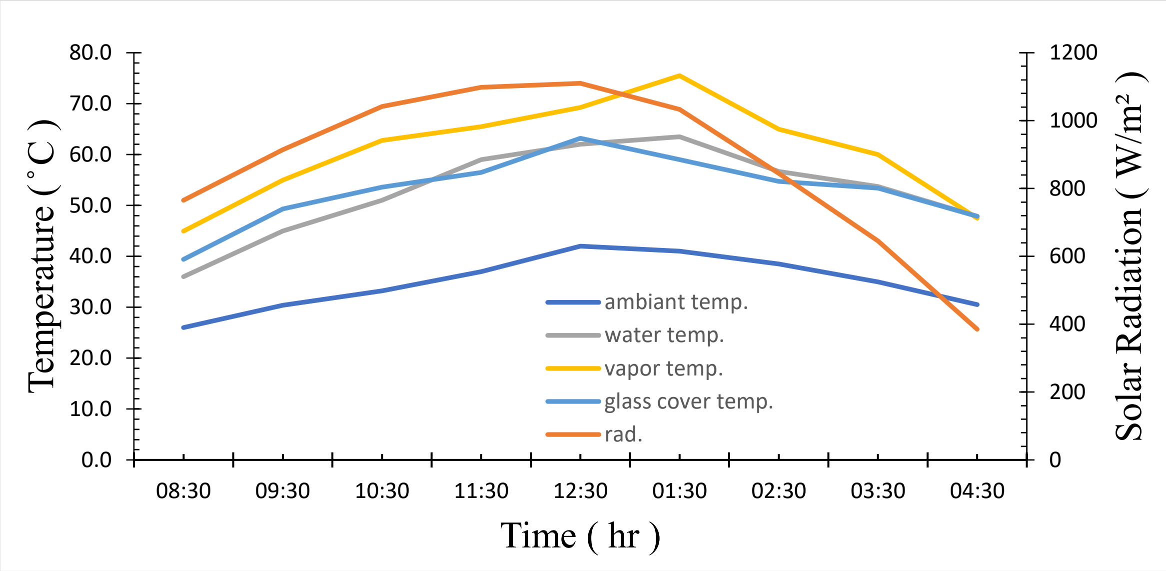


Figure 4.38: variation of temperature and solar radiation with measurement time for solar still with U shape water channel at 1 L/min.

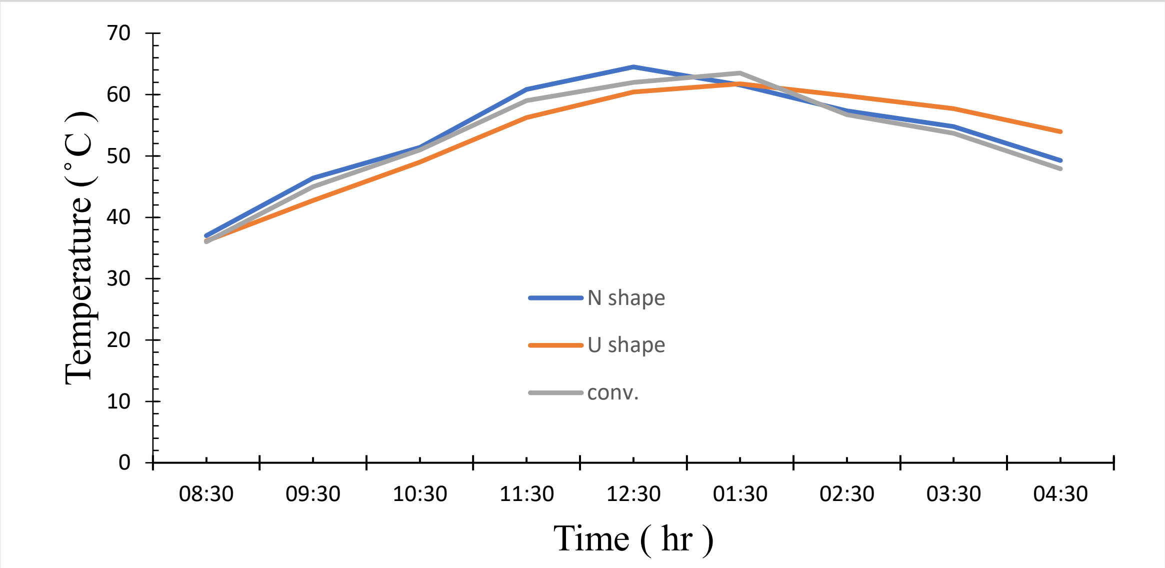


Figure 4.39: variation of basin water temperature with the time of the experiment

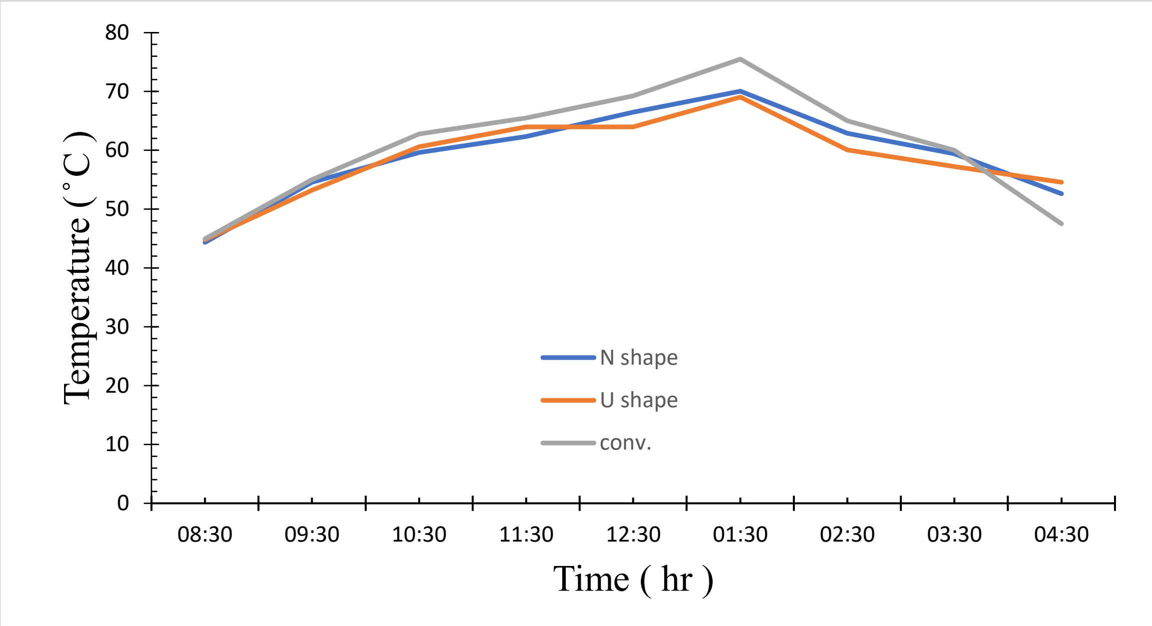


Figure 4.40: variation of vapor temperature with the time of the experiment

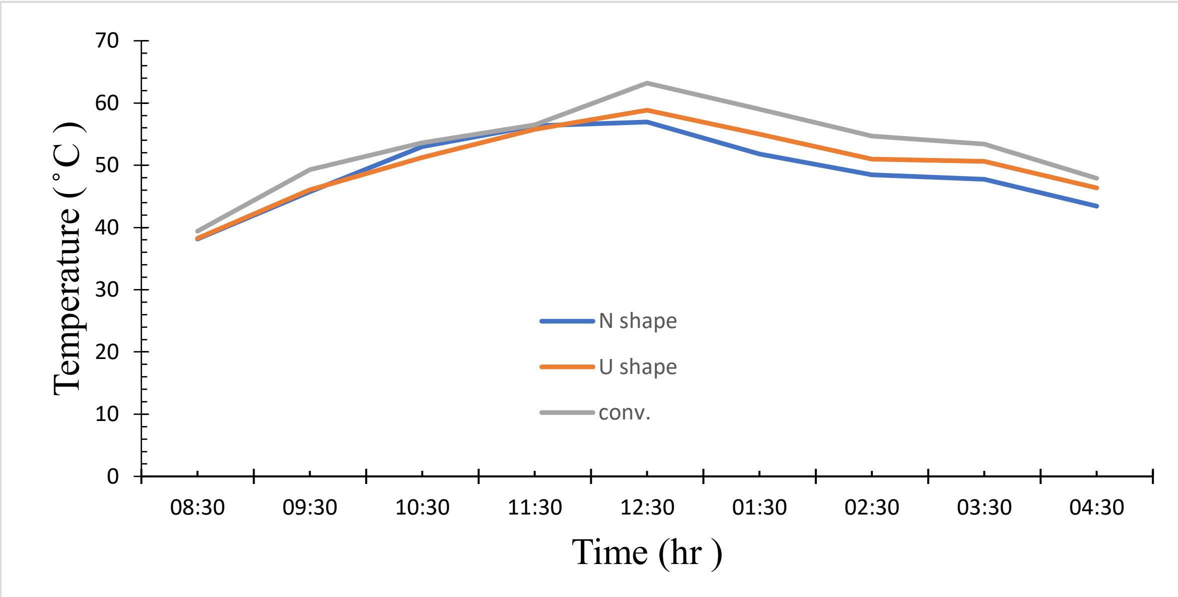


Figure 4.41: variation of glass cover temperature with the time of the experiment

As noticed in the above figures. the difference between the vapor and the glass temperatures increases when using water channels. That difference in temperature leads to enhance condensation rates, and eventually, the solar still productivity. As shown in (fig. 4.42), the productivity using N shape cooling channel has more production rates than the still improved by U shape channel until 01:30 PM where the U shape still production rates start to overcome the other solar stills until the end of the experiment

The accumulative freshwater production was enhanced by 33.33% and 20% using N and U shape cooling channels respectively. And the maximum production rate is recorded at 12:30 PM with the solar still improved with N shape channel with 0.536 L/m².hr.

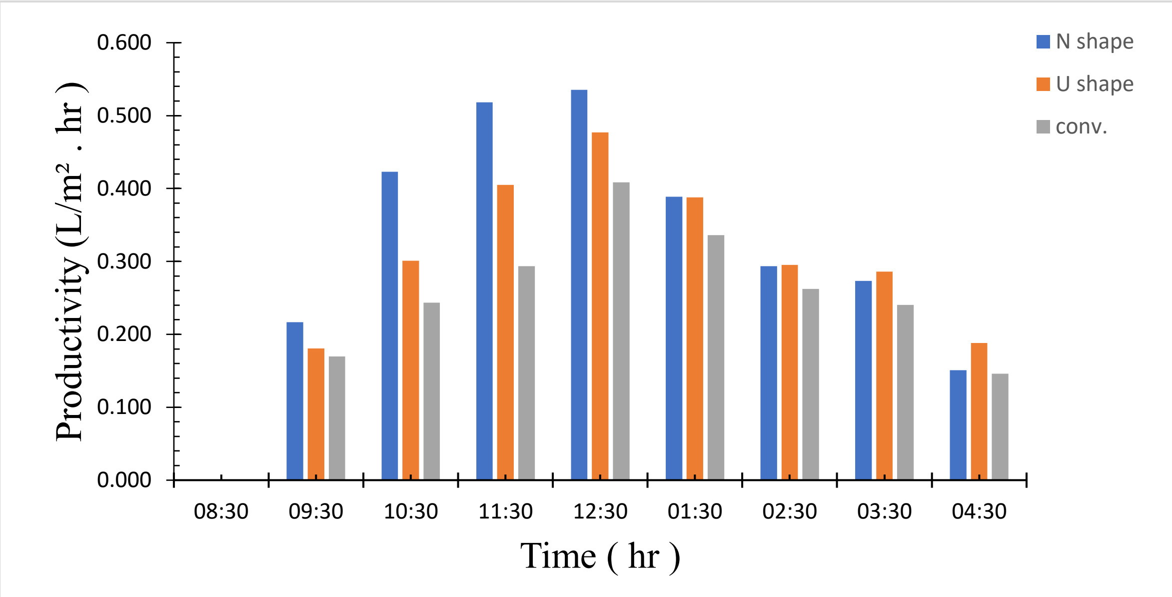


Figure 4.42: variation productivity with the time of the experiment

4.2.2.1.2 Water Channel With 1.5 L/min Flow Rate

For investigating the effect of increasing the cooling water flow rate inside the cooling channels, an experiment was conducted on the 31st of May 2020 in the same previous location. Solar radiation and the ambient temperature variation along the day were recorded, and it shows an increase until it reaches 1106 W/m² and 41℃ at 12:30 PM while the average wind speed was 10.3 km/hr. Then the solar radiation starts to reduce until the experiment ends, as shown in fig. 4.43 to 4.45. Like the previous experiment, the water and vapor temperatures' values were affected by the variation radiation. They all had the same thermal behavior and reached the maximum value at 12:30 PM.

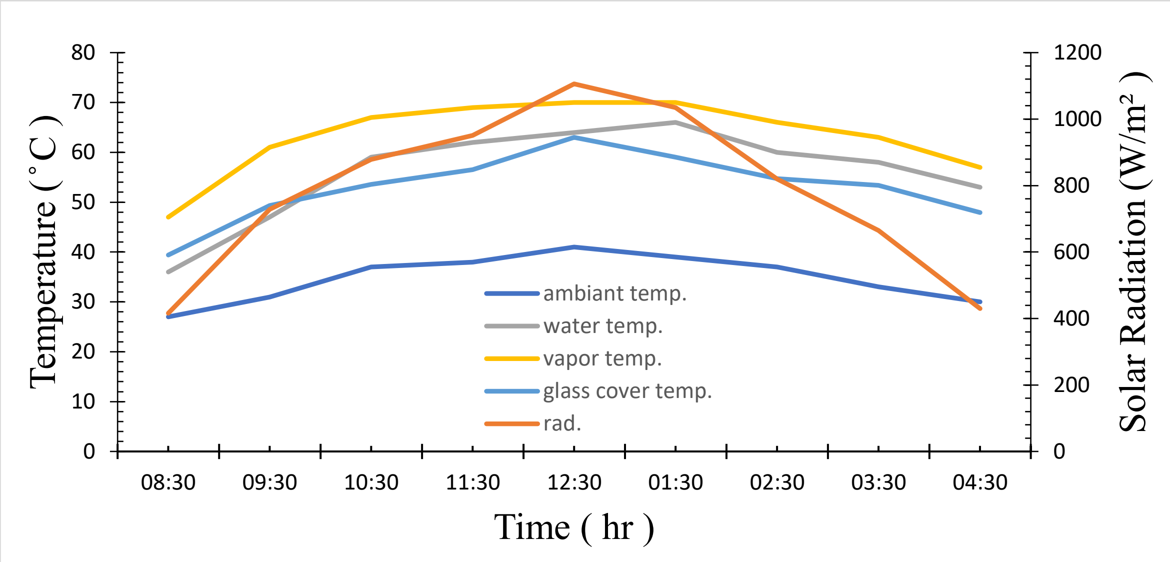


Figure 4.43: variation of temperature and solar radiation with measurement time for conventional solar still

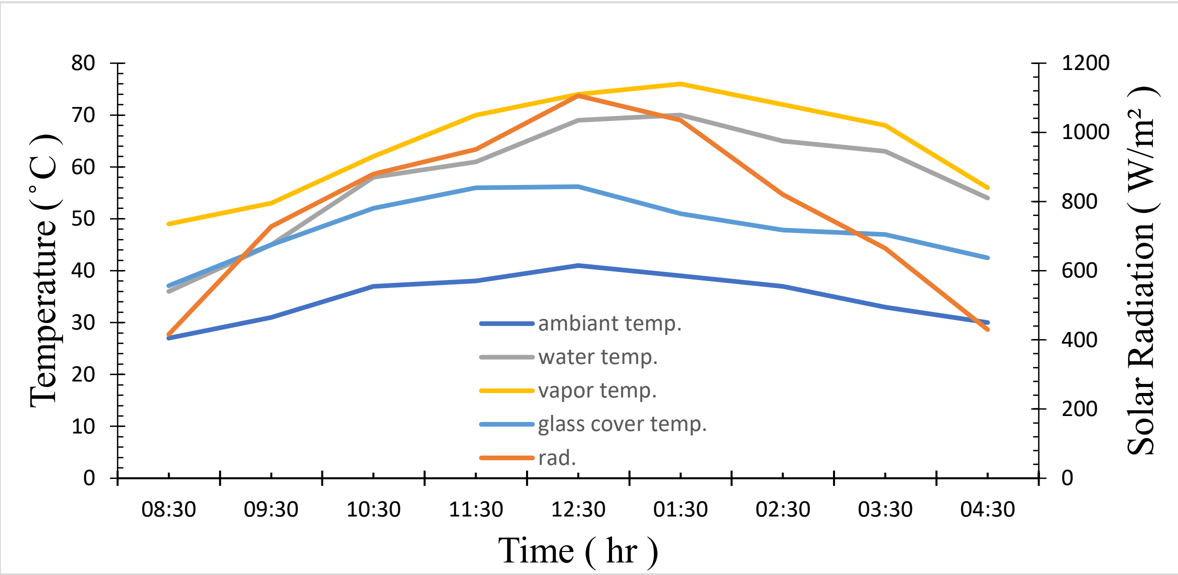


Figure 4.44: variation of temperature and solar radiation with measurement time for solar still with N shape water channel at 1.5 L/min.

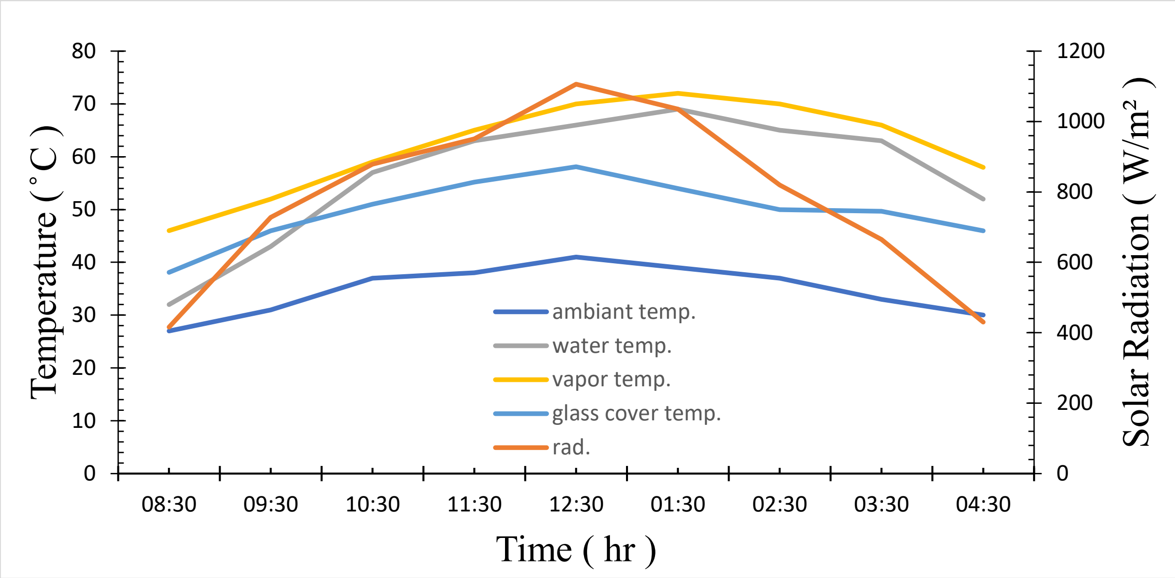


Figure 4.45: variation of temperature and solar radiation with measurement time for solar still with U shape water channel at 1.5 L/min.

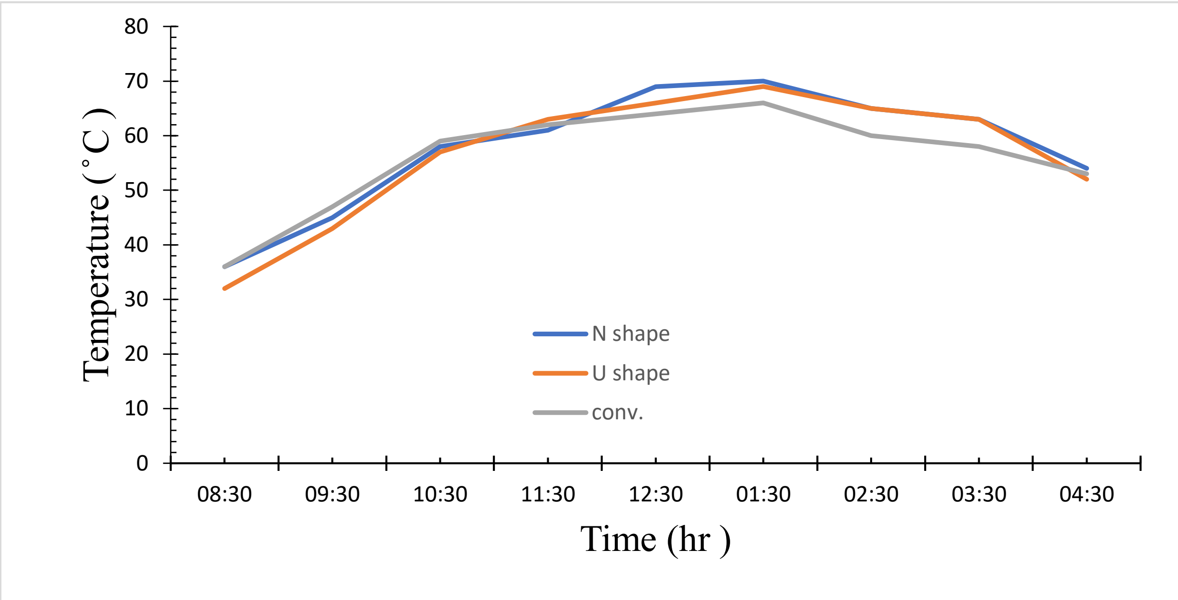


Figure 4.46: variation of basin water temperature with the time of the experiment

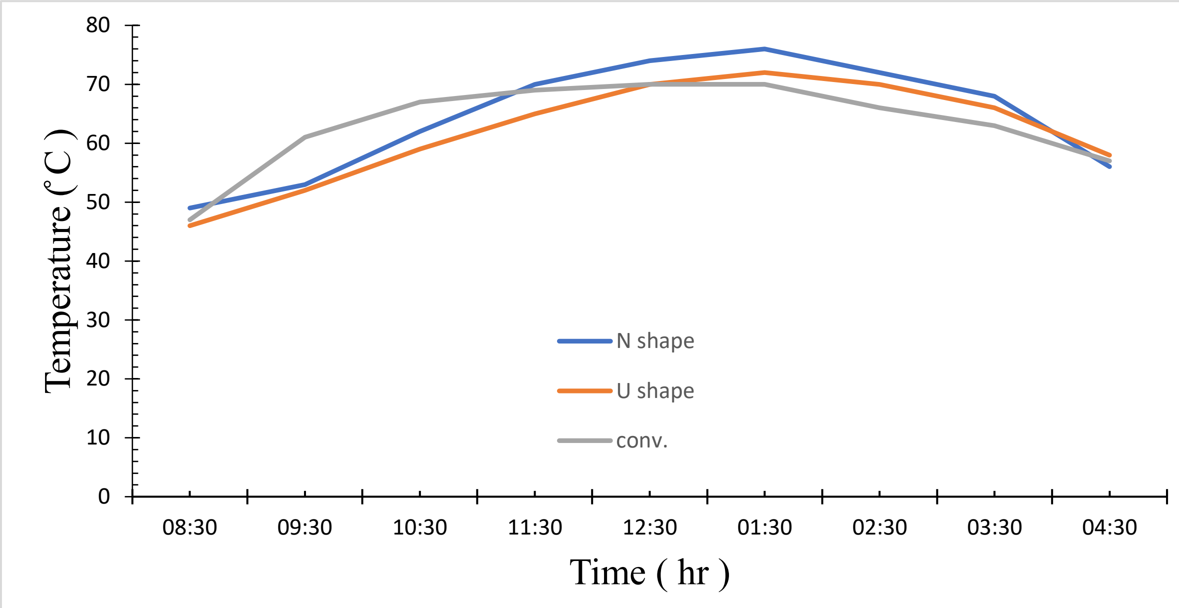


Figure 4.47: variation of vapor temperature with the time of the experiment

The glass cover temperature was affected by the cooling channels and had the same thermal behavior as the last experiment with a temperature less than the conventional with 12.09% and 8.4% for the N and U shape channels, respectively, as shown in (fig. 4.48).

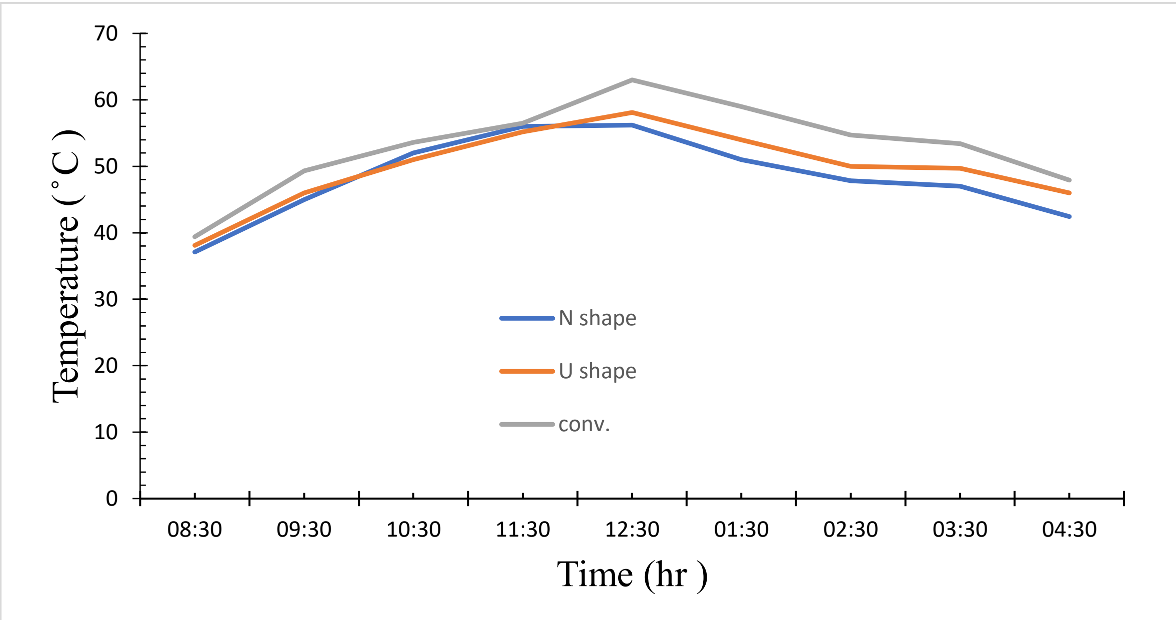


Figure 4.48: variation of glass cover temperature with the time of the experiment

Increasing the cooling flow rate directly affected the solar still productivity, and using 1.5 L/min instead of 1L/min increases the enhancement rate from 33.33% up to 46.18% compared to the conventional solar still. As in the previous experiment, the solar still improved with N shape cooling channel has more productivity from the beginning of the experiment until 01:30 PM when the U shape solar still productivity starts to overcome the other solar stills, and the behavior of the results continues until the end of the experiment. The maximum freshwater production was recorded in the N shape solar still with 0.576 L/min. as shown in fig. 4.42.

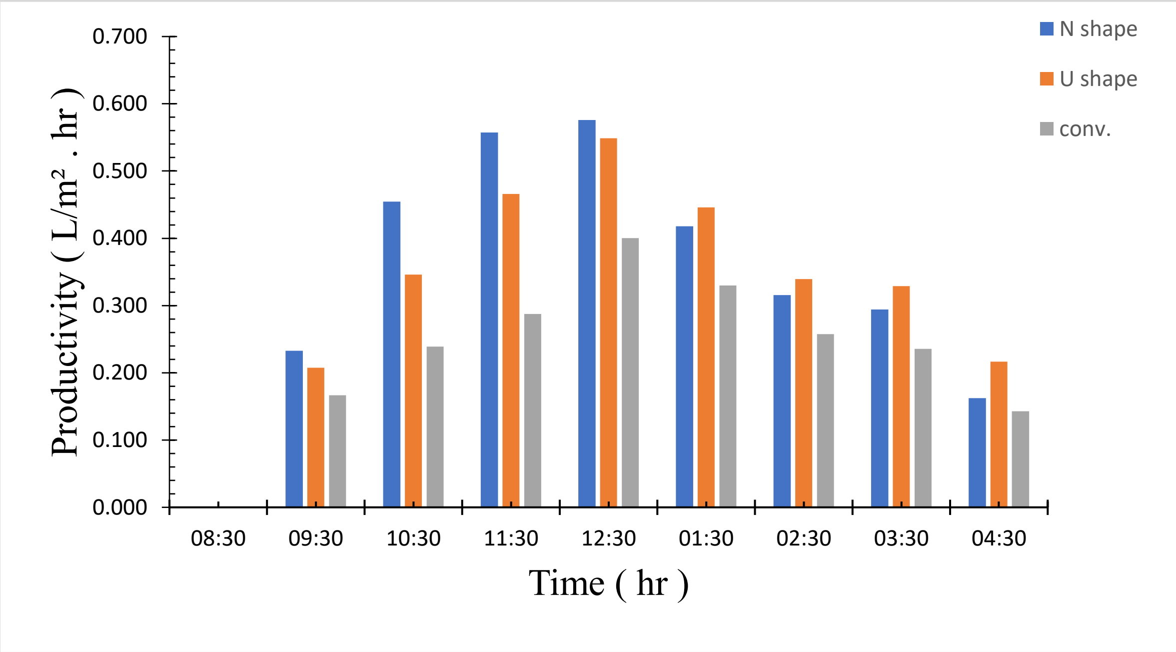


Figure 4.49: variation of productivity with the time of the experiment

4.2.2.1.3 Water Channel With 2 L/Min Flow Rate

For continue inspecting the relation of the solar still performance with the increase of the cooling water flow rate, an experiment is conducted on the 3rd of June 2020 using 2 L/min. cooling water flow rate. Solar radiation varies as always from its minimum value until peak when recorded 1119 W/m² between 11:30 AM to 12:30 PM. then start reducing until the end of the experiment. As shown in fig.

(4.50 to 4.52). While the maximum ambient temperature and average wind speed was 50℃ and 12.2 km/hr.

The increase in solar radiation directly influences the water and vapor temperatures. The increase continues until reaching its maximum values at 12:30 PM and reduces after that due to solar radiation reduction.

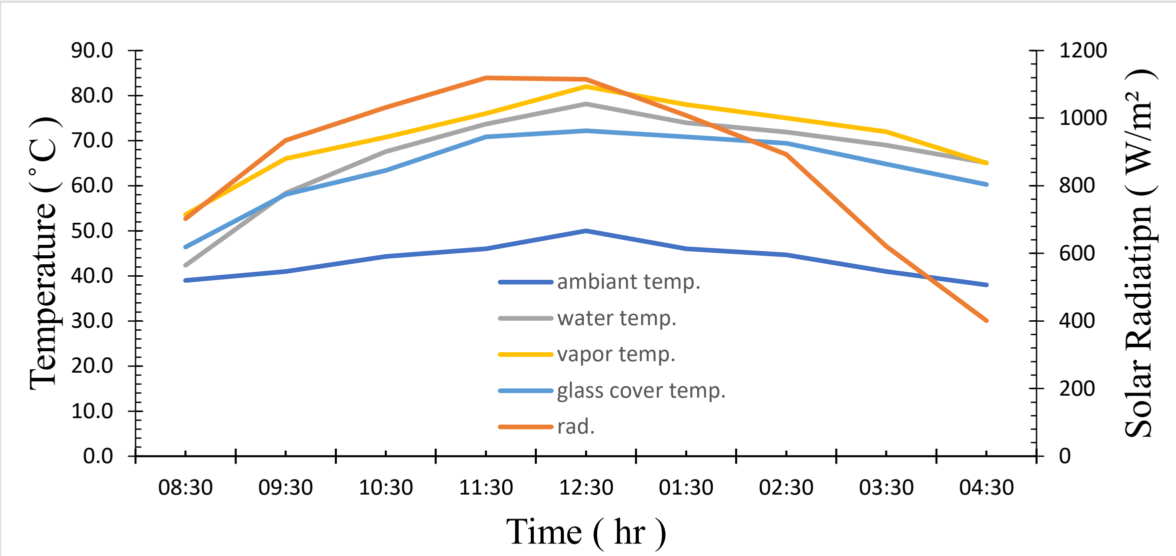


Figure 4.50: variation of temperature and solar radiation with measurement time for conventional solar still

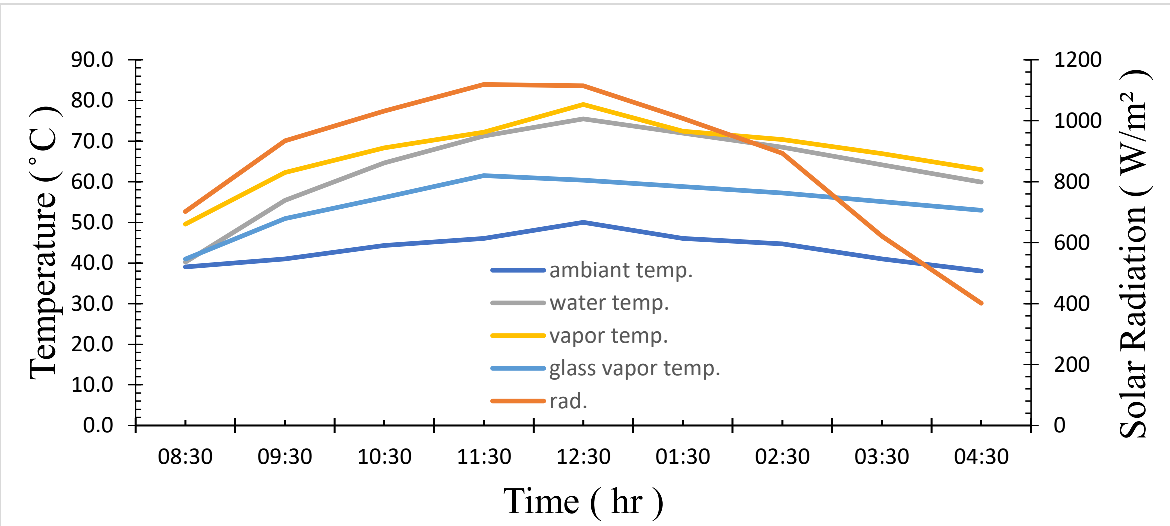


Figure 4.51: variation of temperature and solar radiation with measurement time for solar still with N shape water channel

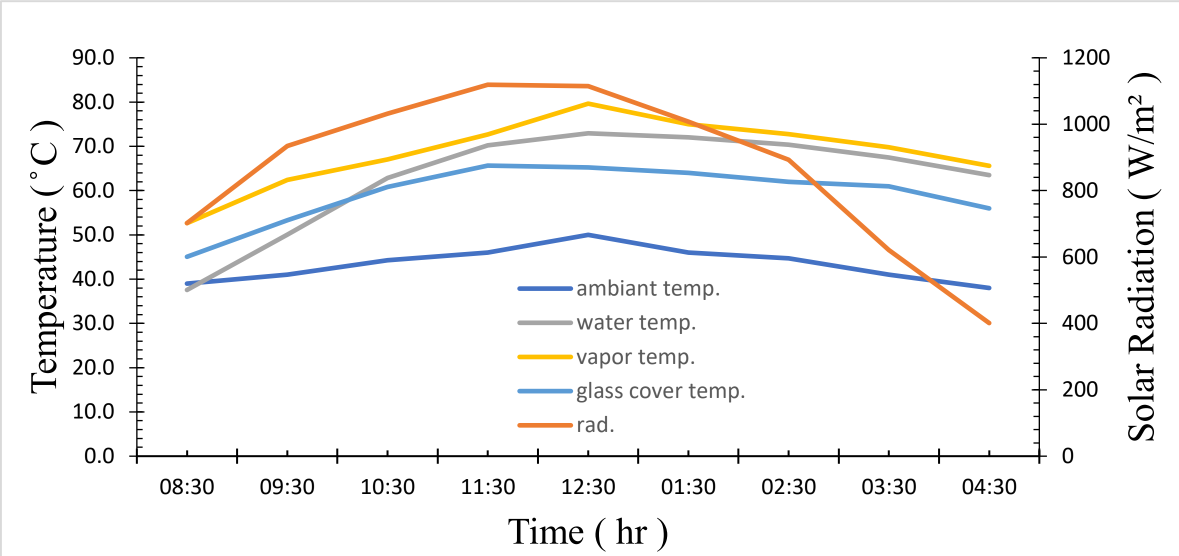


Figure 4.52: variation of temperature and solar radiation with measurement time for solar still with U shape water channel

Fig. 4.53 and 4.54 describe the water and vapor thermal behaviors inside solar still and shows the direct relation between its temperatures and the intensity of the incidence solar radiation and the cooling channels.

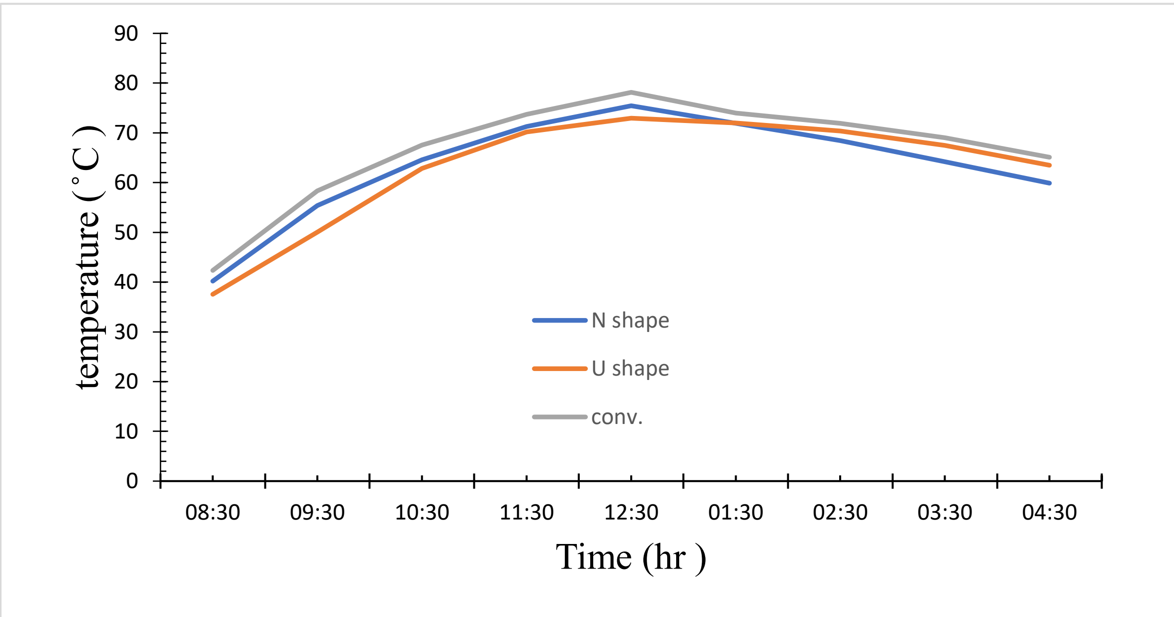


Figure 4.53: variation of basin water temperature with time of experiment

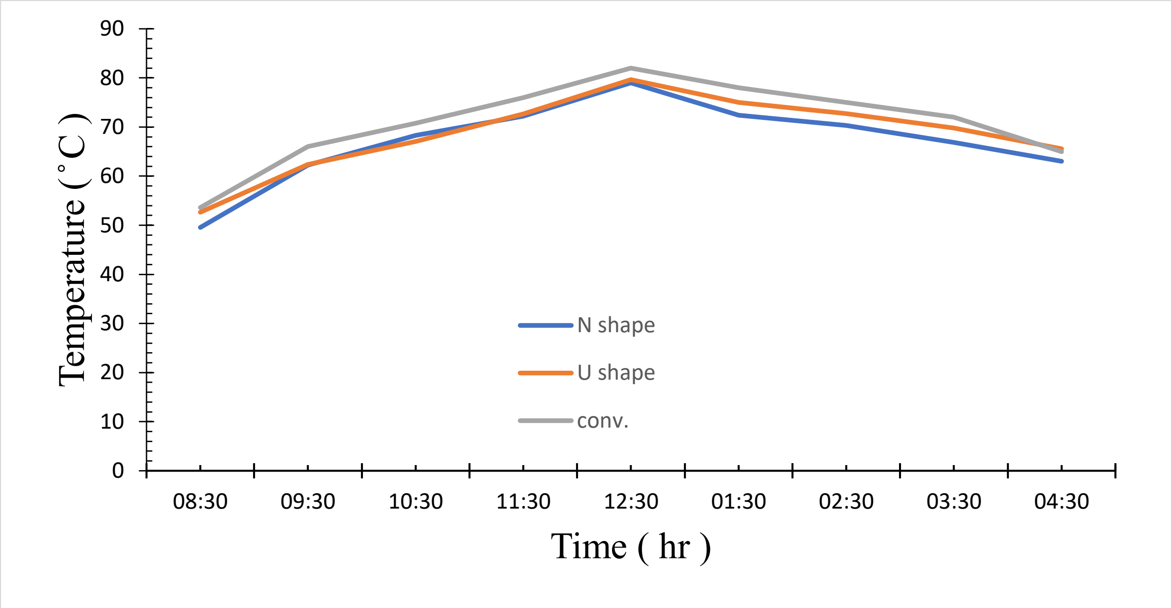


Figure 4.54: variation of vapor temperature with the time of the experiment

Due to the effect of front cover cooling, the glass cover temperature of both improved solar stills records glass temperature less than the conventional glass. At the peak time of 12:30 PM, the glass cooled with N shape channel records a temperature less than the conventional by 19.6% while the still improved with U shape channel records 8.12% less than conventional. (As shown in fig. 4.55).

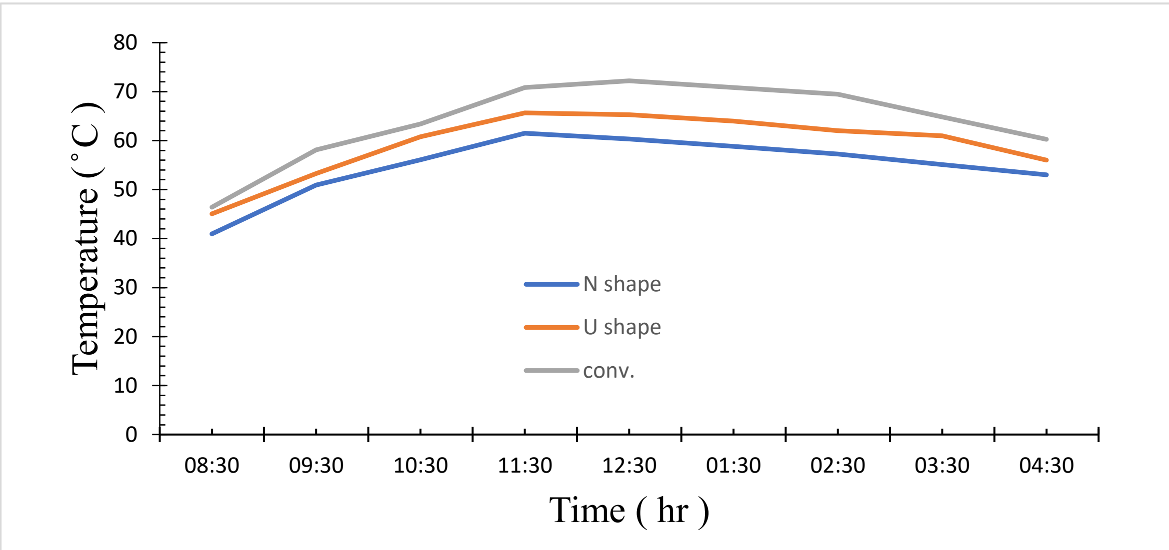


Figure 4.55: variation of glass cover temperature with the time of the experiment

The solar still productivity was directly affected by flow rate increment. The productivity of the solar still improved with N shape has more values for the entire experiment. And its records enhancement of 65.7% while the solar still uses U shape channel record enhancement of 52.73% at the production peak hour. (as shown in fig. 4.56)

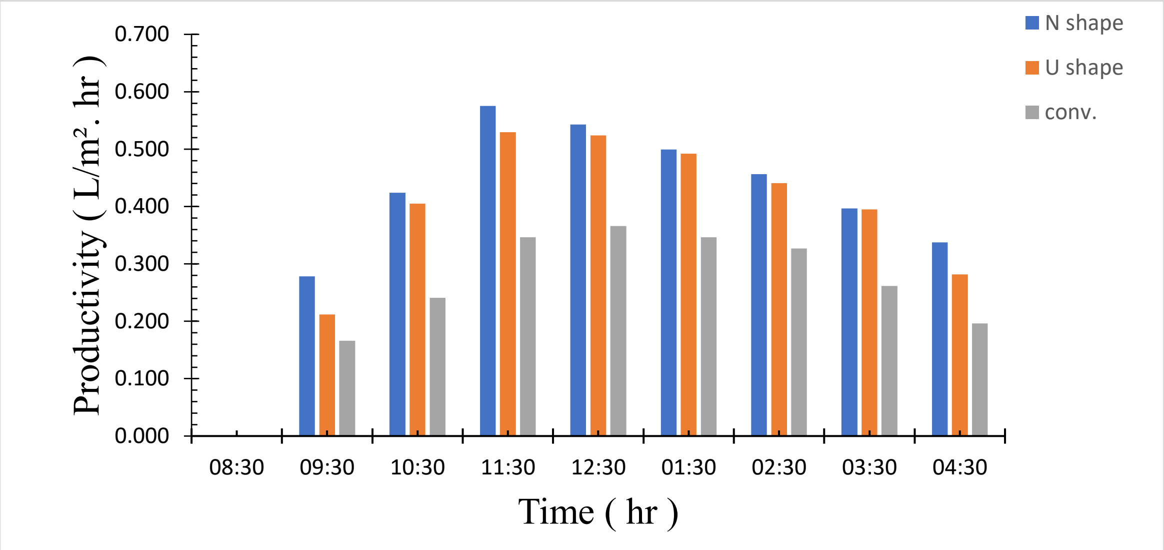


Figure 4.56: variation of productivity with the time of the experiment

Chapter Five

Conclusions and recommendations

Chapter five

Conclusions and recommendations

5.1 Conclusions

As previously explained the solar still productivity is strongly depending on the evaporation and condensation rates, and changing any parameter that effect either one of them would directly affect the freshwater productivity, beast on the above briefly described results and dissections we can conducted some conclusions and as below.

1- Preheating the input water using solar collecting tank with area of 0.176 m^2 tilted with the same angle of the front glass cover helps gain more energy and enhancing the evaporation rates as well as the pure water productivity with 44.83%.

2- Increasing the thermal contact area between the basin water and the absorbing object using different types of galvanized wicks helps improve the solar still thermal performance and directly affected the freshwater productivity by 86.65% ,72.53%, and151% when using 25*25, 50*50 mm grid sizes and both of them together respectively.

3- Improving the thermal performance using evacuated black painted copper pipes with 7, 15 mm diameters, increases the evaporation rated and helps improve the pure water productivity by 90.09% and 27.82% when using 15 and 7 mm pipes filled with 50% water. And it was 46.77% and 19.93 using the same pipes filled with 100% of its volume with water.

4- Reducing the front glass cover temperature increasing the temperature difference between the saturated vapor and the front glass which enhancing the condensation rates. The freshwater productivity improved by 56 % when using N shape water cooling channel with a water flow rate of 2 L/min. while it was 45.71 % using U shape water channel with the same water flow rate.

5.2 Recommendations

Several parameters could be subjected for future studies for enhancing the single slope solar still as below.

1- Using different types of PCM inside the evacuated pipes.

2- Using solar concentration focused on the evacuated pipes to enhance its thermal performance.

3- Adding metal balls with the galvanized wicks for increasing the heat storage and the thermal contact area simultaneously.

4- Increasing the surface area of the solar collecting tanks for improving the preheating process.

References

[1] UNESCO, “Water, a Shared Responsibility". UNESCO, The United NationsWorld Water Development Report-2, WWDR-2, UN WATER/WWAP/2006/2.52,” 2006.

[2] M. A. S. Malik, G. N. Tiwari, A. Kumar, and M. S. Sodha, “Solar distillation.,” 1982.

[3] N. Mohal, Z. H. Khan, and N. Rahman, “Impact of Sea level Rise on Coastal Rivers of Bangladesh,” *Proc. 10th Int. River Symp. Environ. Flows Conf.*, 2007.

[4] http://www.greenrhinoenergy.com/solar/radiation/empiricalevidence.php, “direct normal solar irradiation.” .

[5] “Iraqi solar irradiation.” https://www.researchgate.net/figure/Shows-the-rates-of-solar-radiation-distribution-in-Iraq-Al-kayiem-20196_fig2_339029483.

[6] T. Elango, A. Kannan, and K. Kalidasa Murugavel, “Performance study on single basin single slope solar still with different water nanofluids,” *Desalination*, vol. 360, pp. 45–51, 2015, doi: 10.1016/j.desal.2015.01.004.

[7] W. L. Cheng, Y. K. Huo, and Y. Le Nian, “Performance of solar still using shape-stabilized PCM: Experimental and theoretical investigation,” *Desalination*, vol. 455, no. October 2018, pp. 89–99, 2019, doi: 10.1016/j.desal.2019.01.007.

[8] A. E. Kabeel, “Performance of solar still with a concave wick evaporation surface,” *Energy*, vol. 34, no. 10, pp. 1504–1509, 2009, doi: 10.1016/j.energy.2009.06.050.

[9] A. E. Kabeel, A. Khalil, Z. M. Omara, and M. M. Younes, “Theoretical and experimental parametric study of modified stepped solar still,” *Desalination*, vol. 289, pp. 12–20, 2012, doi: 10.1016/j.desal.2011.12.023.

[10] K. H. Nayi and K. V. Modi, “Pyramid solar still: A comprehensive review,” *Renewable and Sustainable Energy Reviews*. 2018, doi: 10.1016/j.rser.2017.07.004.

[11] V. Velmurugan, M. Gopalakrishnan, R. Raghu, and K. Srithar, “Single basin solar still with fin for enhancing productivity,” *Energy Convers. Manag.*, vol. 49, no. 10, pp. 2602–2608, 2008, doi: 10.1016/j.enconman.2008.05.010.

[12] A. A. El-Sebaii and E. El-Bialy, “Advanced designs of solar desalination systems: A review,” *Renewable and Sustainable Energy Reviews*. 2015, doi: 10.1016/j.rser.2015.04.161.

[13] A. A. El-Sebaii, A. A. Al-Ghamdi, F. S. Al-Hazmi, and A. S. Faidah, “Thermal performance of a single basin solar still with PCM as a storage medium,” *Appl. Energy*, vol. 86, no. 7–8, pp. 1187–1195, 2009, doi: 10.1016/j.apenergy.2008.10.014.

[14] A. Bilal, B. Jamil, N. U. Haque, and A. Ansari, “Groundwater for Sustainable Development Investigating the e ff ect of pumice stones

sensible heat storage on the performance of a solar still," *Groundw. Sustain. Dev.*, vol. 9, no. May, p. 100228, 2019, doi: 10.1016/j.gsd.2019.100228.

[15] M. Bhargva and A. Yadav, "Experimental investigation of single slope solar still using different wick materials: A comparative study," *J. Phys. Conf. Ser.*, vol. 1276, no. 1, 2019, doi: 10.1088/1742-6596/1276/1/012042.

[16] S. J. P. Gnanaraj, S. Ramachandran, and D. S. Christopher, "Enhancing the productivity of double-slope single-basin solar still with internal and external modifications," *Int. J. Ambient Energy*, vol. 39, no. 8, pp. 777–782, 2018, doi: 10.1080/01430750.2017.1340338.

[17] T. Arunkumar *et al.*, "Productivity enhancement of solar still by using porous absorber with bubble-wrap insulation," *J. Clean. Prod.*, vol. 195, pp. 1149–1161, 2018, doi: 10.1016/j.jclepro.2018.05.199.

[18] S. Rashidi, N. Rahbar, M. S. Valipour, and J. A. Esfahani, "Enhancement of solar still by reticular porous media: Experimental investigation with exergy and economic analysis," *Appl. Therm. Eng.*, vol. 130, pp. 1341–1348, 2018, doi: 10.1016/j.applthermaleng.2017.11.089.

[19] Z. Haddad, A. Chaker, and A. Rahmani, "Improving the basin type solar still performances using a vertical rotating wick," *Desalination*, vol. 418, no. November 2016, pp. 71–78, 2017, doi: 10.1016/j.desal.2017.05.030.

[20] M. H. Sellami, T. Belkis, M. L. Aliouar, S. D. Meddour, H. Bouguettaia, and K. Loudiyi, "Improvement of solar still performance by covering absorber with blackened layers of sponge," *Groundw. Sustain. Dev.*, vol. 5, pp. 111–117, 2017, doi: 10.1016/j.gsd.2017.05.004.

[21] T. Vellingri and A. Hikmet, "Experimental Study on Enhancing the Productivity of Solar Still Using Locally Available Material as a Storage Medium," vol. 98, no. June, pp. 191–196, 2017, doi: 10.1007/s40032-016-0280-7.

[22] V. Ramanathan, B. Kanimozhi, and V. K. Bhojwani, "Experimental study on productivity of modified single-basin solar still with a flat plate absorber," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 197, no. 1, 2017, doi: 10.1088/1757-899X/197/1/012032.

[23] M. El-Naggar, A. A. El-Sebaii, M. R. I. Ramadan, and S. Aboul-Enein, "Experimental and theoretical performance of finned-single effect solar still," *Desalin. Water Treat.*, vol. 57, no. 37, pp. 17151–17166, 2016, doi: 10.1080/19443994.2015.1085451.

[24] K. K. Matrawy, A. S. Alosaimy, and A. F. Mahrous, "Modeling and experimental study of a corrugated wick type solar still: Comparative study with a simple basin type," *Energy Convers. Manag.*, vol. 105, pp. 1261–1268, 2015, doi: 10.1016/j.enconman.2015.09.006.

[25] G. Rajasekhar and M. Eswaramoorthy, "Performance evaluation on solar still integrated with nano-composite phase change materials," *Appl. Sol. Energy (English Transl. Geliotekhnika)*, vol. 51, no. 1, pp. 15–21, 2015, doi: 10.3103/S0003701X15010119.

[26] M. A. Eltawil and Z. M. Omara, “Enhancing the solar still performance using solar photovoltaic, flat plate collector and hot air,” *Desalination*, vol. 349, pp. 1–9, 2014, doi: 10.1016/j.desal.2014.06.021.
[27] Z. M. Omara and M. A. Eltawil, “Hybrid of solar dish concentrator, new boiler and simple solar collector for brackish water desalination,” *Desalination*, 2013, doi: 10.1016/j.desal.2013.07.019.
[28] M. Sakthivel, S. Shanmugasundaram, and T. Alwarsamy, “An experimental study on a regenerative solar still with energy storage medium - Jute cloth,” *Desalination*, vol. 264, no. 1–2, pp. 24–31, 2010, doi: 10.1016/j.desal.2010.06.074.
[29] S. Abdallah, O. Badran, and M. M. Abu-Khader, “Performance evaluation of a modified design of a single slope solar still,” *Desalination*, vol. 219, no. 1–3, pp. 222–230, 2008, doi: 10.1016/j.desal.2007.05.015.
[30] P. Dumka, Y. Kushwah, A. Sharma, and D. R. Mishra, “Comparative analysis and experimental evaluation of single slope solar still augmented with permanent magnets and conventional solar still,” *Desalination*, vol. 459, no. February, pp. 34–45, 2019, doi: 10.1016/j.desal.2019.02.012.
[31] A. Agrawal and R. S. Rana, “Theoretical and experimental performance evaluation of single-slope single-basin solar still with multiple V-shaped floating wicks,” *Heliyon*, vol. 5, no. 4, p. e01525, 2019, doi: 10.1016/j.heliyon.2019.e01525.
[32] H. Panchal, D. K. Patel, and P. Patel, “Theoretical and experimental performance analysis of sandstones and marble pieces as thermal energy storage materials inside solar stills,” *Int. J. Ambient Energy*, vol. 39, no. 3, pp. 221–229, 2018, doi: 10.1080/01430750.2017.1298059.
[33] A. Agrawal, R. S. Rana, and P. K. Srivastava, “Heat transfer coefficients and productivity of a single slope single basin solar still in Indian climatic condition: Experimental and theoretical comparison,” *Resour. Technol.*, vol. 3, no. 4, pp. 466–482, 2017, doi: 10.1016/j.reffit.2017.05.003.
[34] D. B. Singh, J. K. Yadav, V. K. Dwivedi, S. Kumar, G. N. Tiwari, and I. M. Al-Helal, “Experimental studies of active solar still integrated with two hybrid PVT collectors,” *Sol. Energy*, vol. 130, pp. 207–223, 2016, doi: 10.1016/j.solener.2016.02.024.
[35] D. G. Harris Samuel, P. K. Nagarajan, R. Sathyamurthy, S. A. El-Agouz, and E. Kannan, “Improving the yield of fresh water in conventional solar still using low cost energy storage material,” *Energy Convers. Manag.*, vol. 112, pp. 125–134, 2016, doi: 10.1016/j.enconman.2015.12.074.
[36] M. R. Karimi Estahbanati, A. Ahsan, M. Feilizadeh, K. Jafarpur, S. S. Ashrafmansouri, and M. Feilizadeh, “Theoretical and experimental investigation on internal reflectors in a single-slope solar still,” *Appl. Energy*, vol. 165, pp. 537–547, 2016, doi: 10.1016/j.apenergy.2015.12.047.
[37] P. K. Srivastava and S. K. Agrawal, “Experimental and theoretical analysis of single sloped basin type solar still consisting of multiple low thermal

inertia floating porous absorbers," *Desalination*, vol. 311, pp. 198–205, 2013, doi: 10.1016/j.desal.2012.11.035.

[38] M. Bhargva and A. Yadav, "Effect of shading and evaporative cooling of glass cover on the performance of evacuated tube-augmented solar still," *Environ. Dev. Sustain.*, vol. 22, no. 5, pp. 4125–4143, 2020, doi: 10.1007/s10668-019-00375-8.

[39] K. Vinoth Kumar and R. Kasturi Bai, "Performance study on solar still with enhanced condensation," *Desalination*, vol. 230, no. 1–3, pp. 51–61, 2008, doi: 10.1016/j.desal.2007.11.015.

[40] L. Mu *et al.*, "Enhancing the performance of a single-basin single-slope solar still by using Fresnel lens: Experimental study," *J. Clean. Prod.*, vol. 239, p. 118094, 2019, doi: 10.1016/j.jclepro.2019.118094.

[41] Hassanain Ghani Hameed, "Enhancement of a Single – Slope Solar Still Productivity For a Different Water Depths," *Eng. Sci. Ref. Sci. J.*, vol. 20–2, no. 2012.

[42] A. K. Kaushal, M. K. Mittal, and D. Gangacharyulu, "An experimental study of floating wick basin type vertical multiple effect diffusion solar still with waste heat recovery," *Desalination*, vol. 414, pp. 35–45, 2017, doi: 10.1016/j.desal.2017.03.033.

[43] S. W. Sharshir *et al.*, "Enhancing the solar still performance using nanofluids and glass cover cooling: Experimental study," *Appl. Therm. Eng.*, 2017, doi: 10.1016/j.applthermaleng.2016.11.085.

[44] M. Faegh and M. B. Shafii, "Experimental investigation of a solar still equipped with an external heat storage system using phase change materials and heat pipes," *Desalination*, vol. 409, pp. 128–135, 2017, doi: 10.1016/j.desal.2017.01.023.

[45] R. A. Kumar, G. Esakkimuthu, and K. K. Murugavel, "Performance enhancement of a single basin single slope solar still using agitation effect and external condenser," *Desalination*, vol. 399, pp. 198–202, 2016, doi: 10.1016/j.desal.2016.09.006.

[46] A. E. Kabeel, Z. M. Omara, and F. A. Essa, "Enhancement of modified solar still integrated with external condenser using nanofluids: An experimental approach," *Energy Convers. Manag.*, vol. 78, pp. 493–498, 2014, doi: 10.1016/j.enconman.2013.11.013.

[47] S. N. Danish, A. El-Leathy, M. Alata, and H. Al-Ansary, "Enhancing solar still performance using vacuum pump and geothermal energy," *Energies*, vol. 12, no. 3, pp. 1–13, 2019, doi: 10.3390/en12030539.

[48] S. Nazari, H. Safarzadeh, and M. Bahiraei, "Performance improvement of a single slope solar still by employing thermoelectric cooling channel and copper oxide nanofluid: An experimental study," *J. Clean. Prod.*, 2018, doi: 10.1016/j.jclepro.2018.10.194.

Appendix -A-
Temperature Sensor Calibration

A.1 Introduction

The calibration is the relation between the measured and the exact values in the same system. In this study, the thermocouples are used for being easy to handle and have acceptable accuracy. The thermocouples are connected to a digital data logger for data recording. For ensuring the maximum accuracy possible, all of these thermocouples' readings calibrated with an alcohol thermometer and found the fitting relation among these readings.

A.2 Thermocouple Calibration

One of the well-known temperature sensing equipment used in many engineering experiments is the thermocouples. For its accuracy and sensing wide range. In this experiment 22 type-K thermocouples are used and calibrated using an alcohol thermometer and data logger. All the thermocouples were connected to the data logger while the props immersed in a pure water bath with the thermometer and the temperature raised from zero degree centigrade until the boiling point with 20℃ step and the fitting between the thermometer and the thermocouple are as shown in fig. (A.1 - A.22).

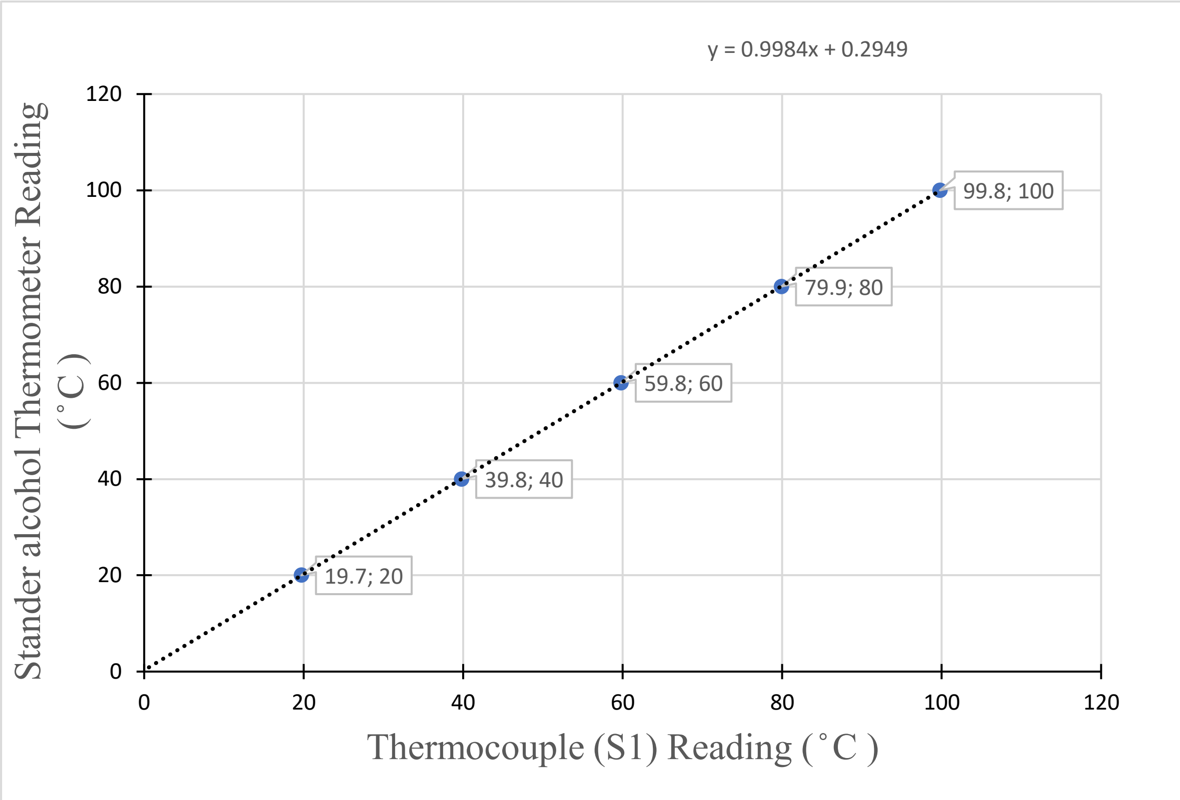


Figure A .1: Thermocouple (S1) calibration, ISS 1, water basin

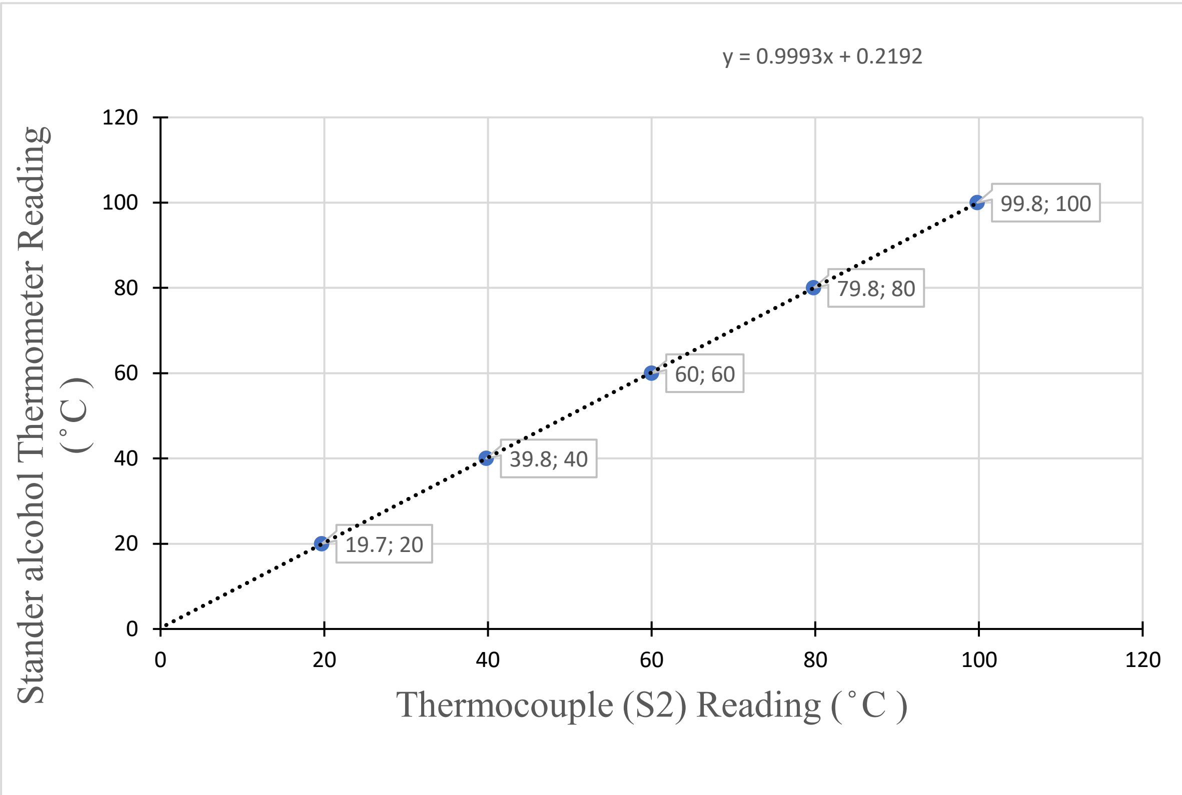


Figure A .2: Thermocouple (S2) calibration, ISS 1, water basin

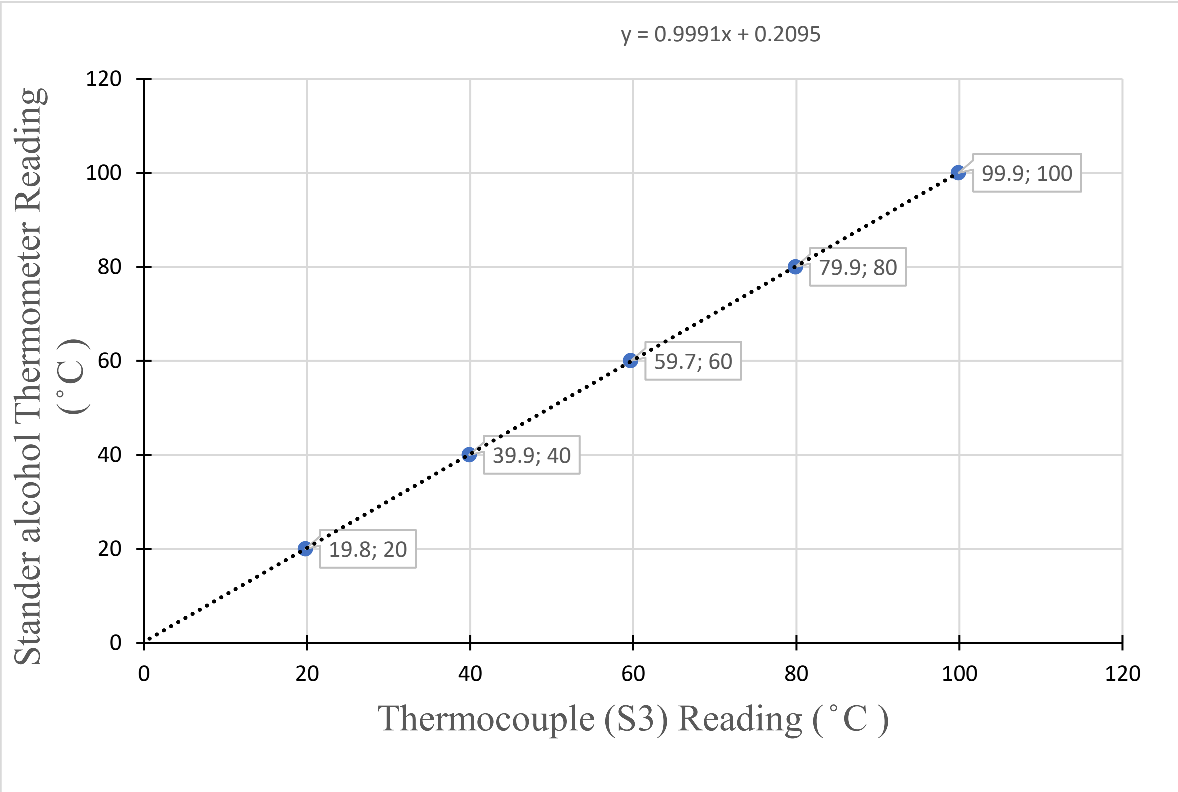


Figure A .3: Thermocouple (S3) calibration, ISS 1, vapor

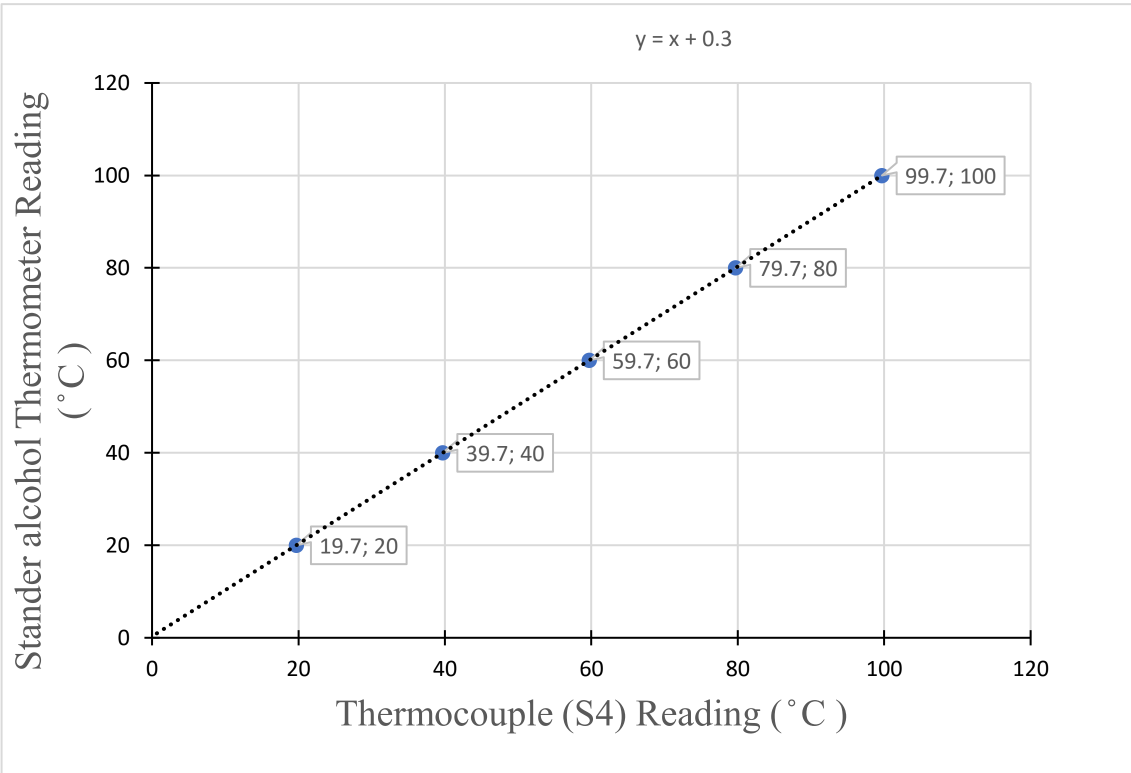


Figure A .4: Thermocouple (S4) calibration, ISS 1, vapor

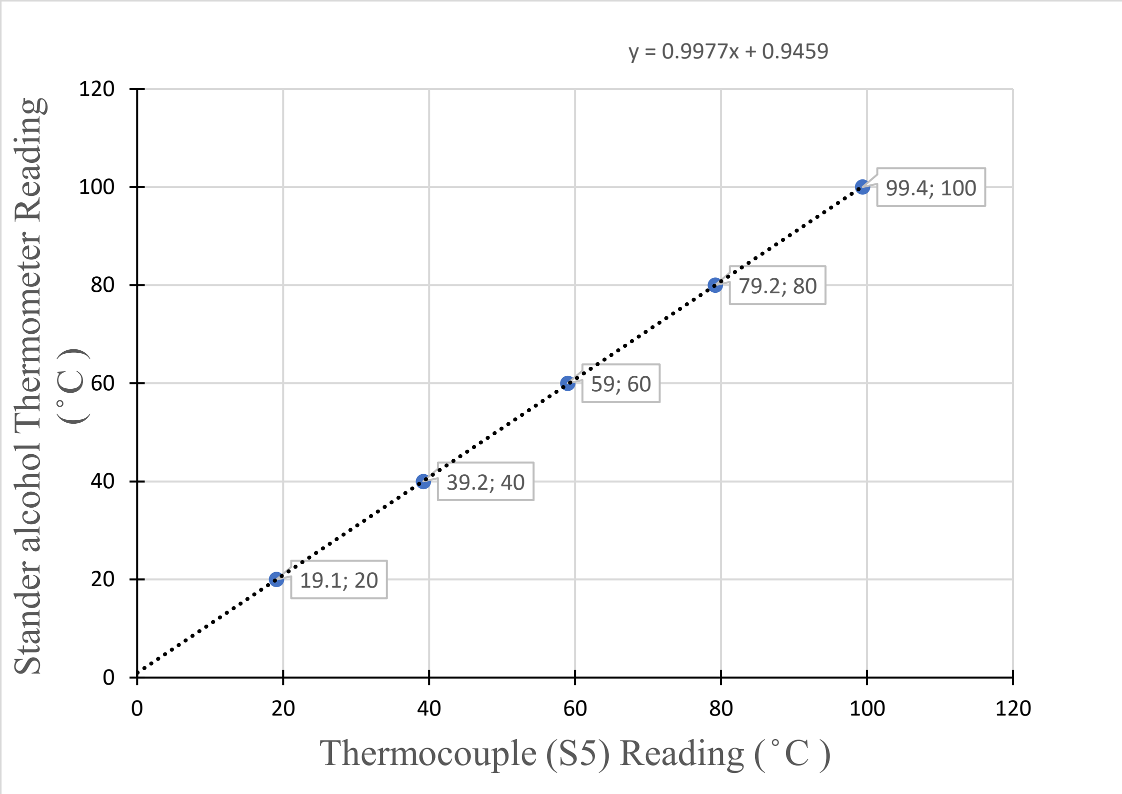


Figure A .5: Thermocouple (S5) calibration, ISS 1, glass cover

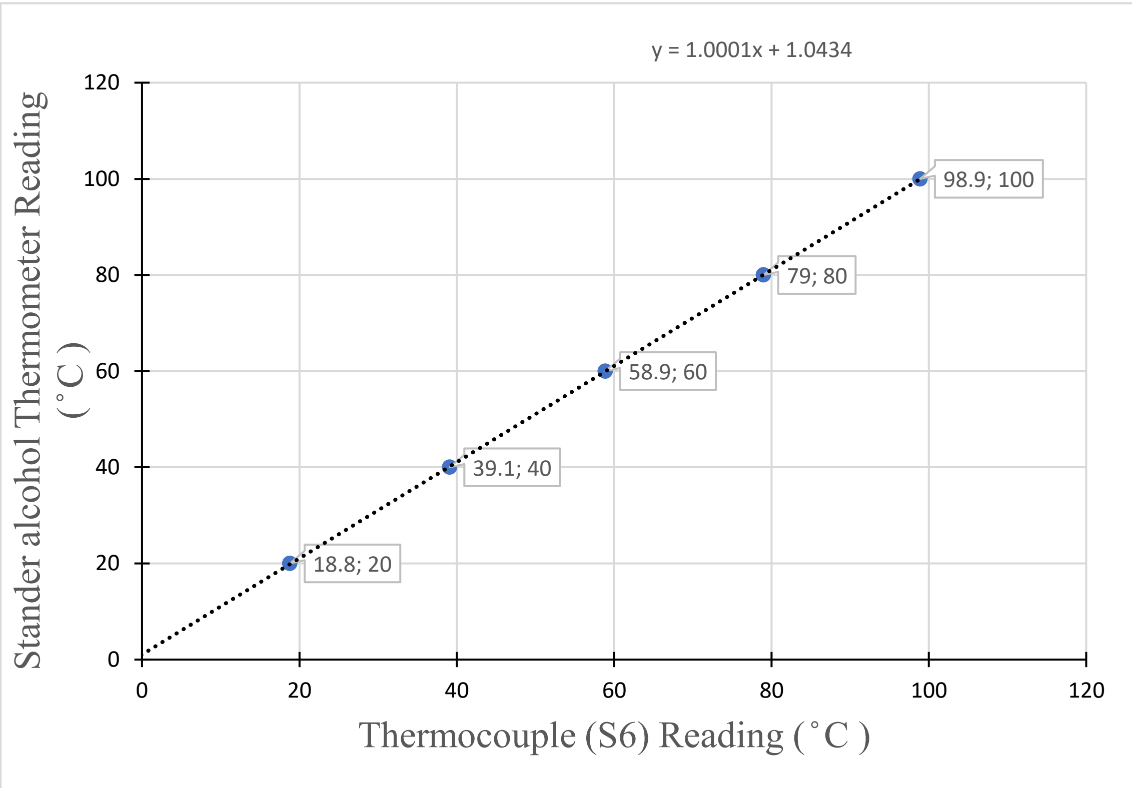


Figure A .6: Thermocouple (S6) calibration, ISS 1, glass cover

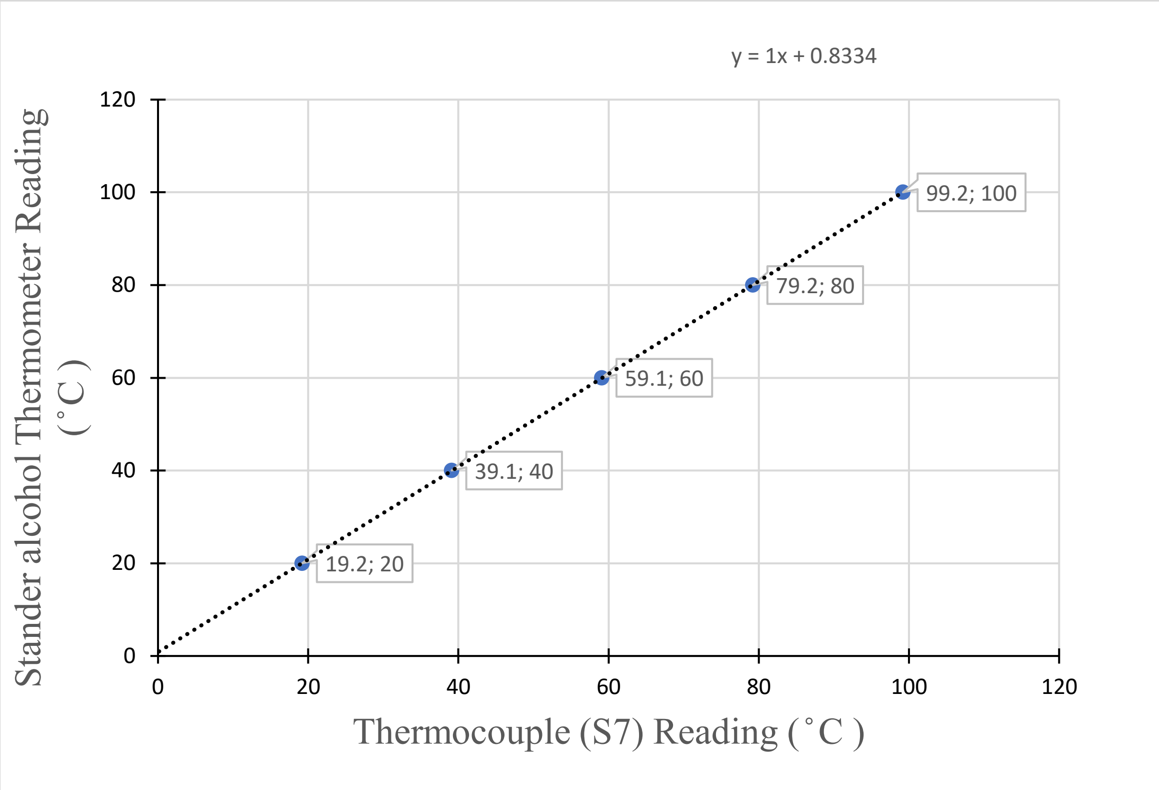


Figure A .7: Thermocouple (S7) calibration, ISS 2, basin water

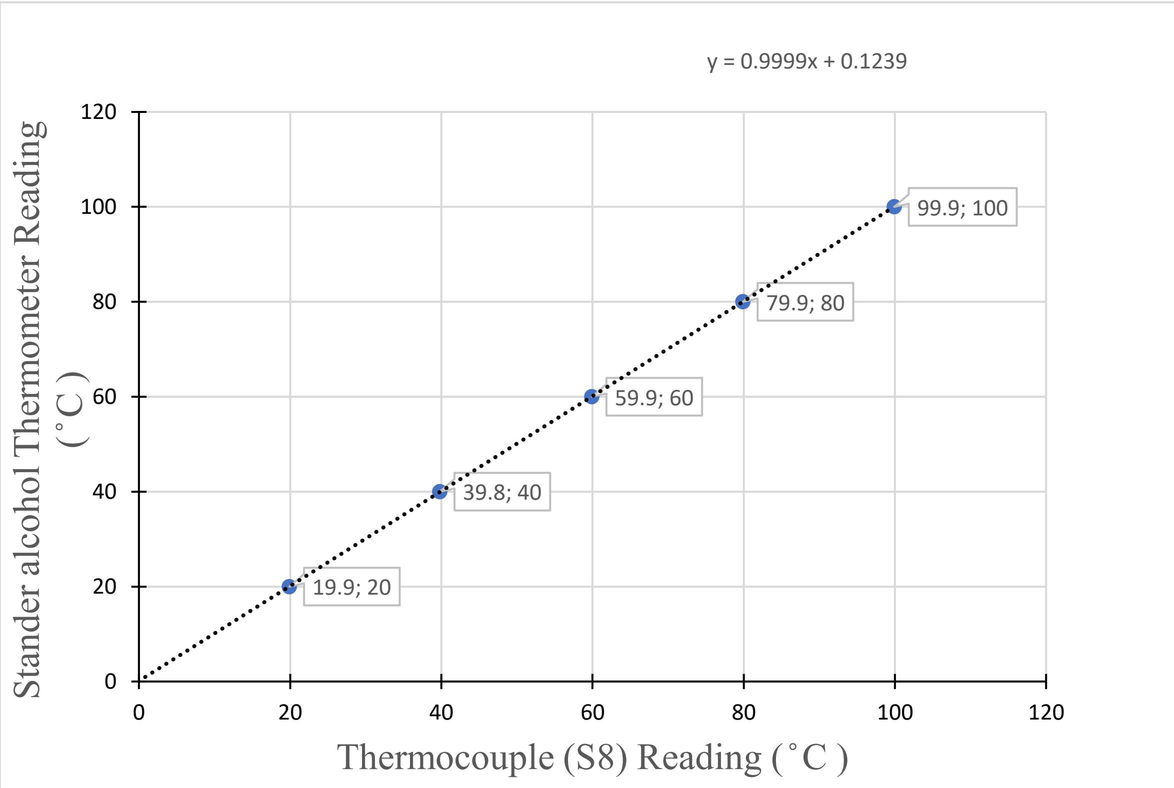


Figure A .8: Thermocouple (S8) calibration, ISS 2, basin water

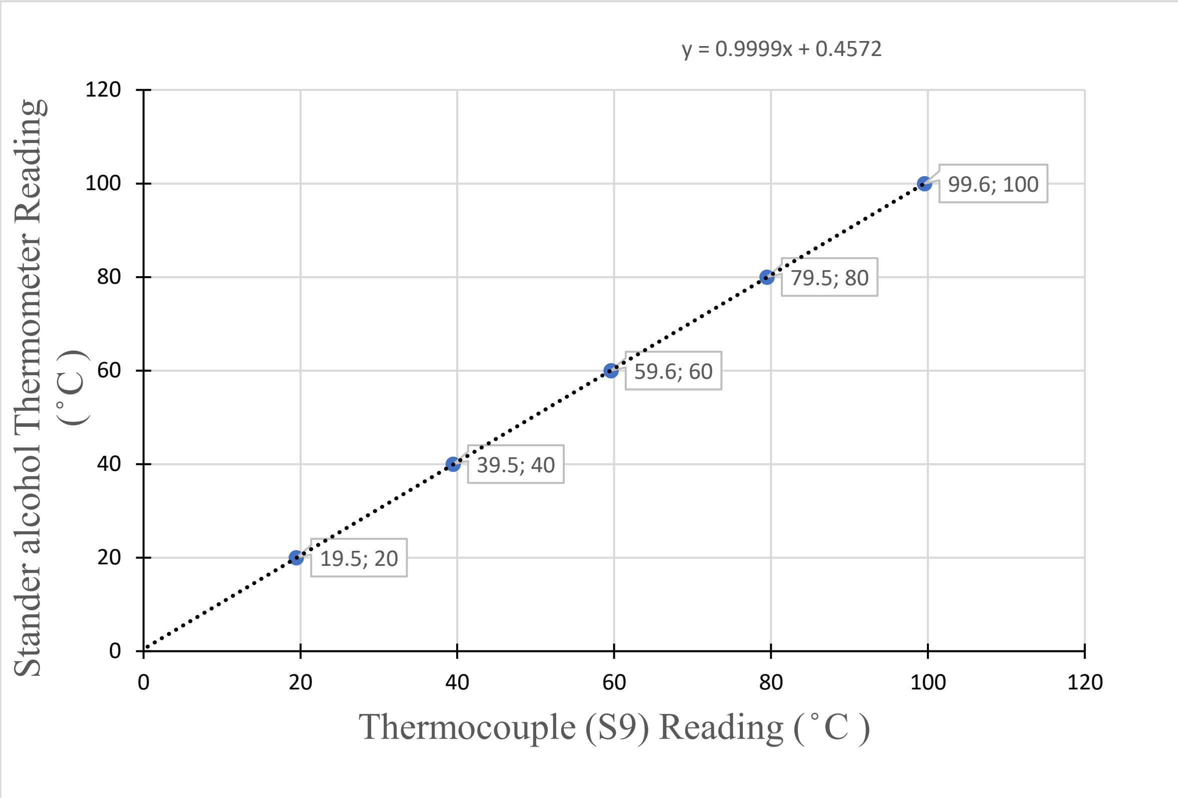


Figure A .9: Thermocouple (S9) calibration, ISS 2, vapor

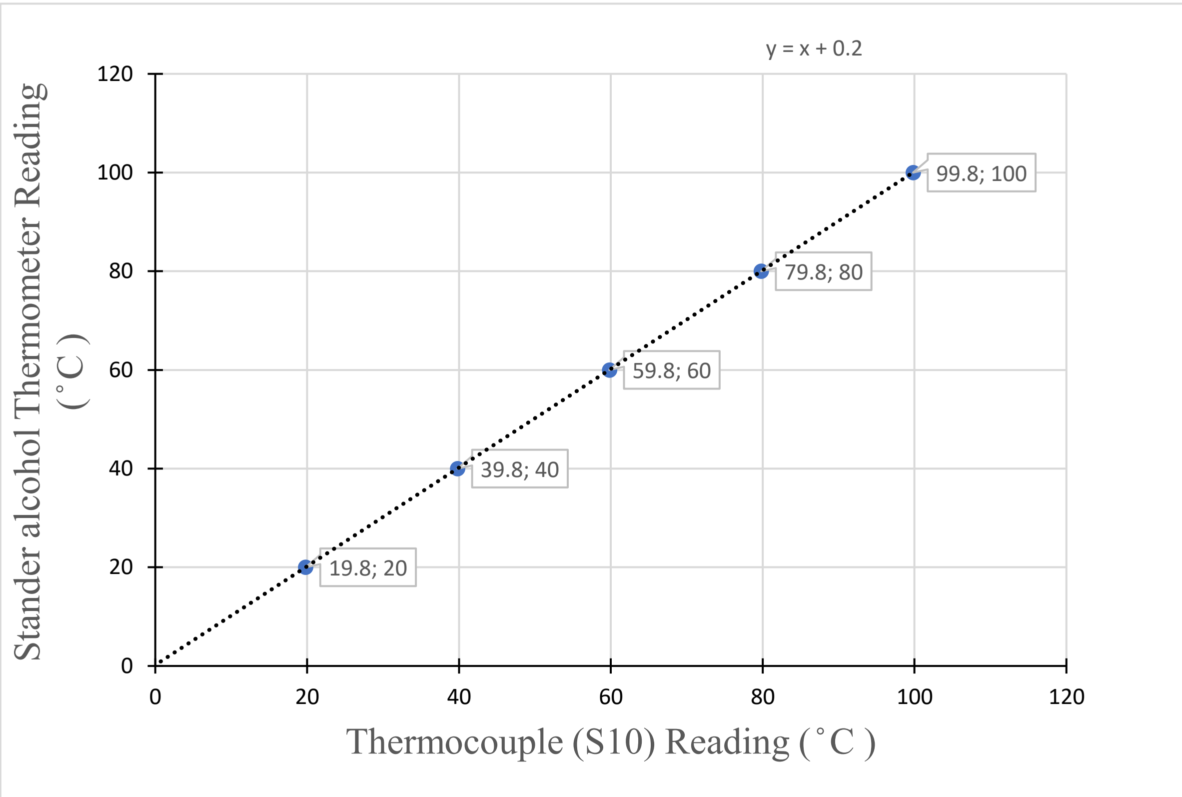


Figure A .10: Thermocouple (S10) calibration, ISS 2, vapor

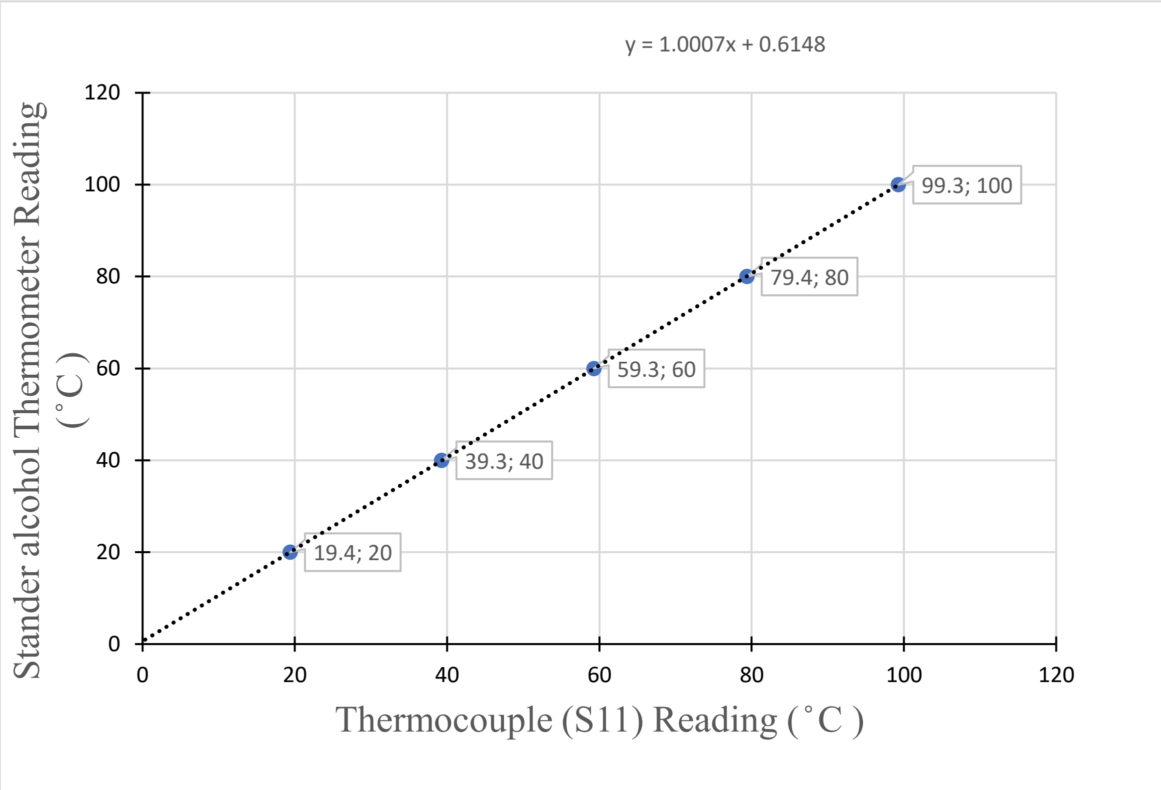


Figure A .11: Thermocouple (S11) calibration, ISS 2, glass cover

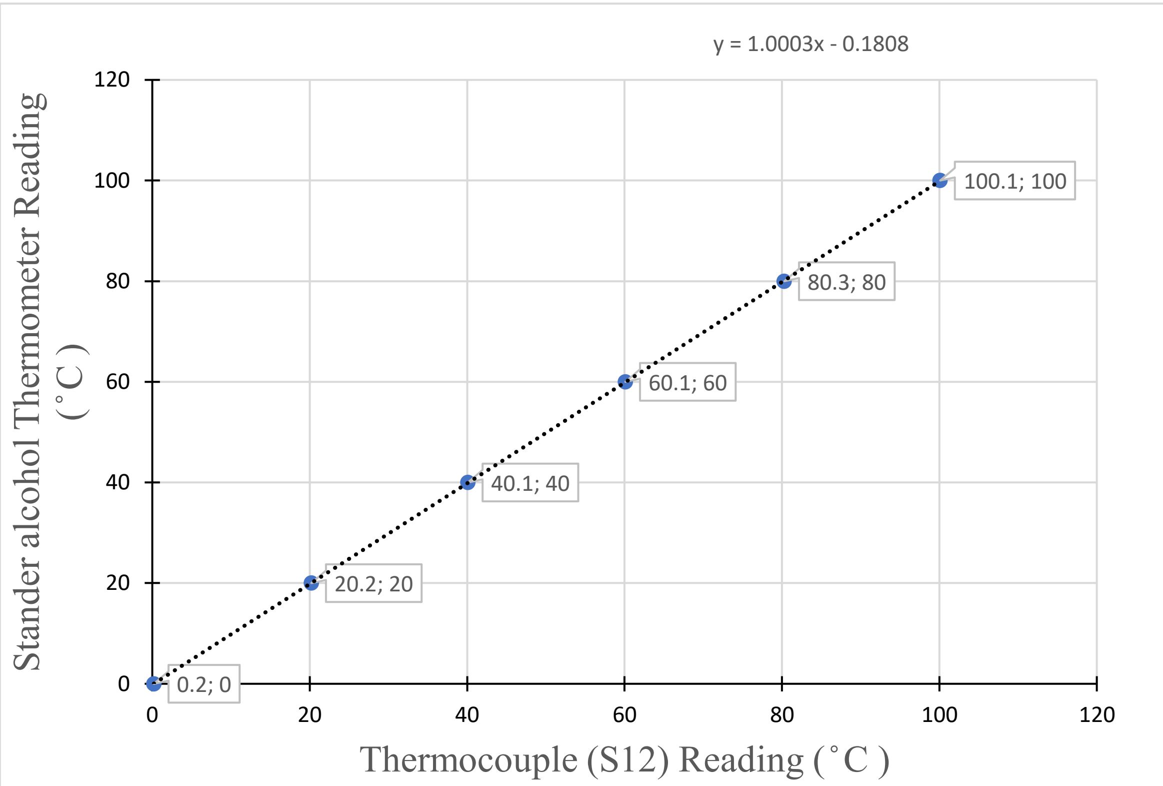


Figure A .12: Thermocouple (S12) calibration, ISS 2, glass cover

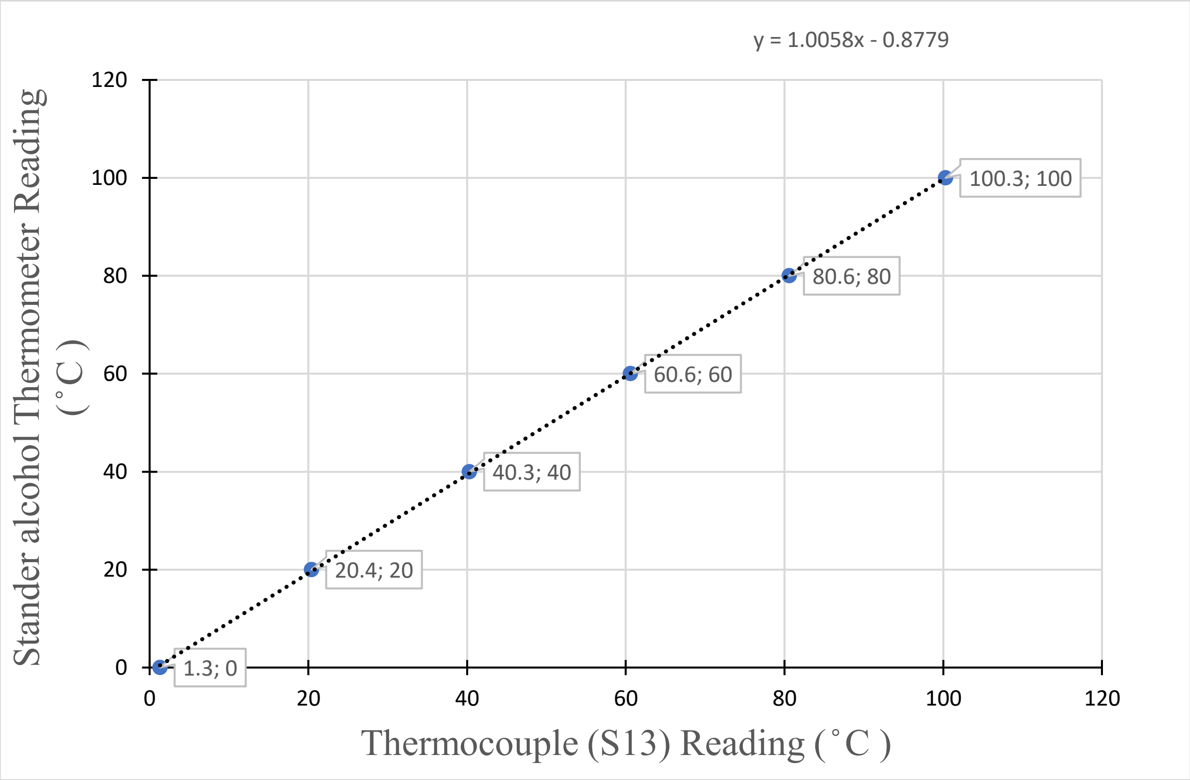


Figure A .13: Thermocouple (S13) calibration, CSS, basin water

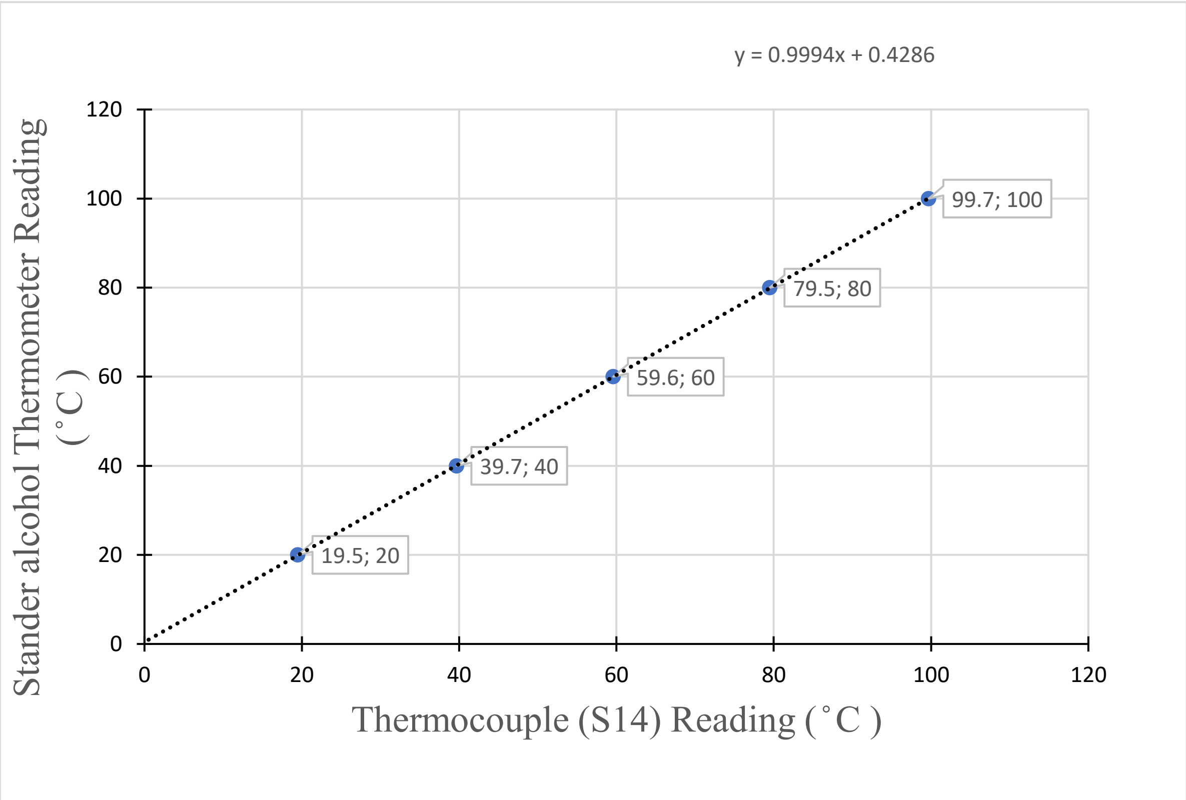


Figure A .14: Thermocouple (S14) calibration, CSS, basin water

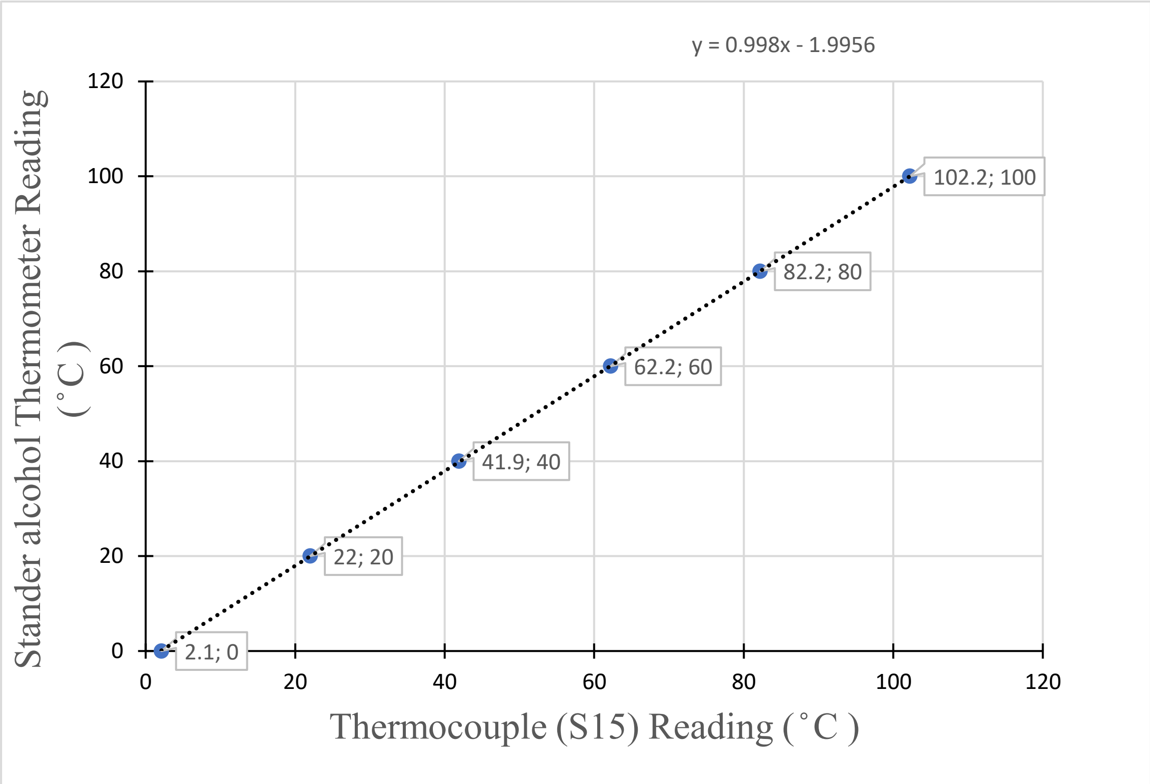


Figure A .15: Thermocouple (S15) calibration, CSS, vapor

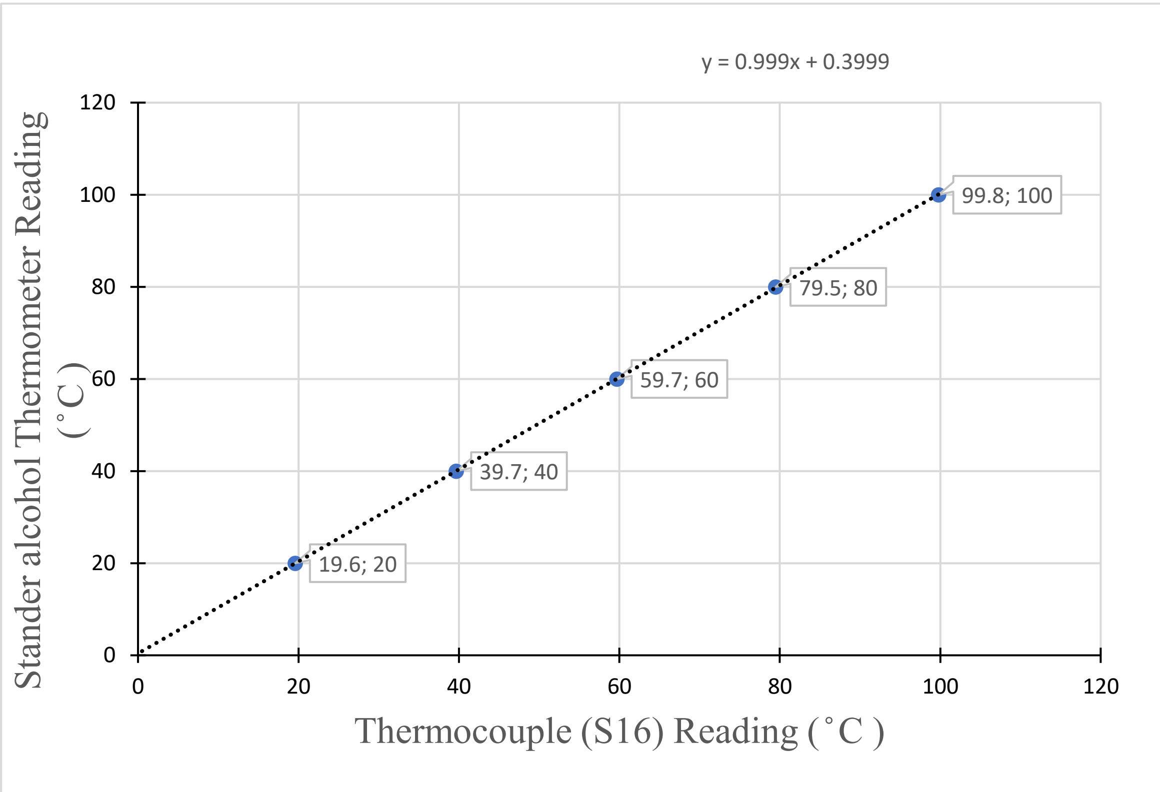


Figure A .16: Thermocouple (S16) calibration, CSS, vapor

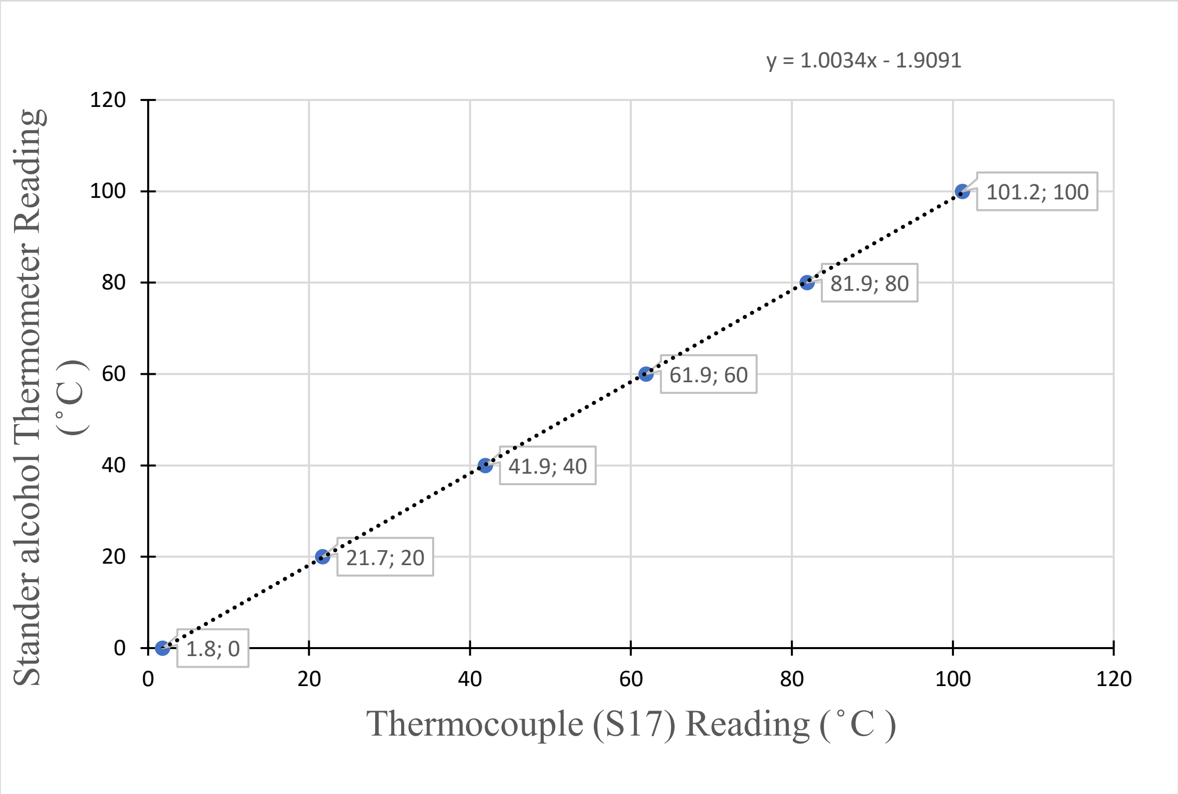


Figure A .17: Thermocouple (S17) calibration, CSS, glass cover

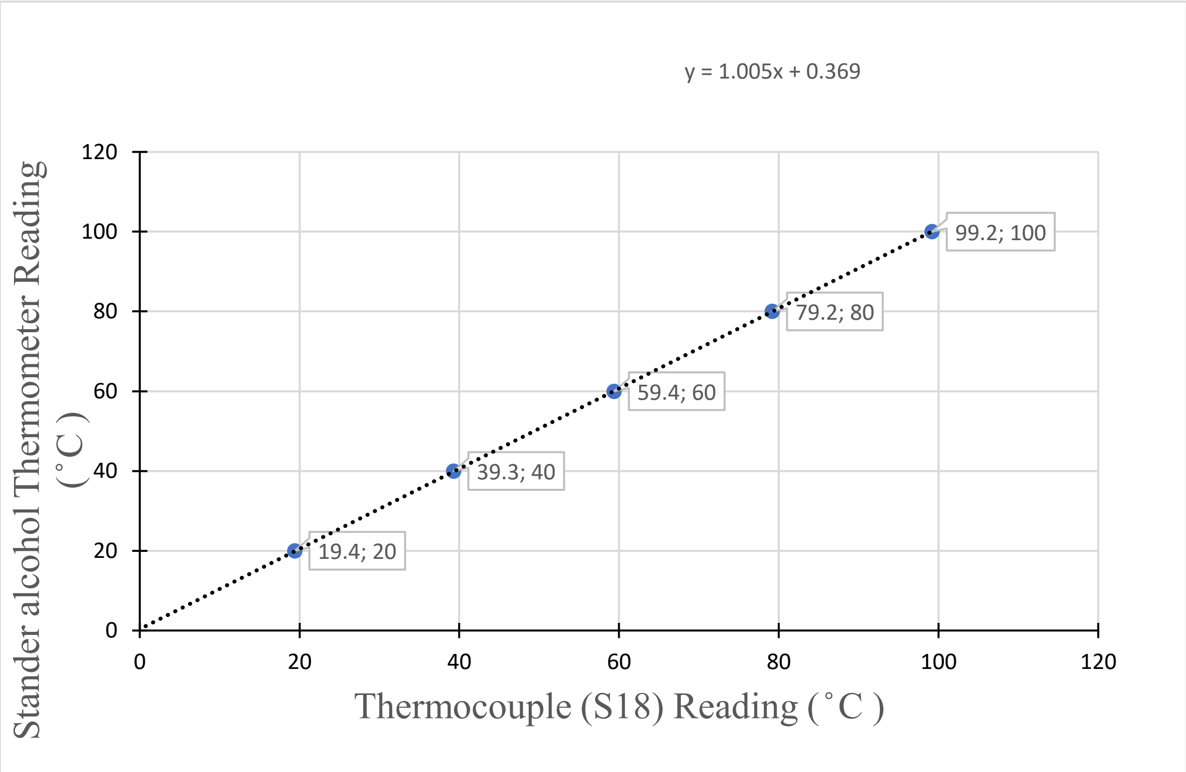


Figure A .18: Thermocouple (S18) calibration, CSS, glass cover

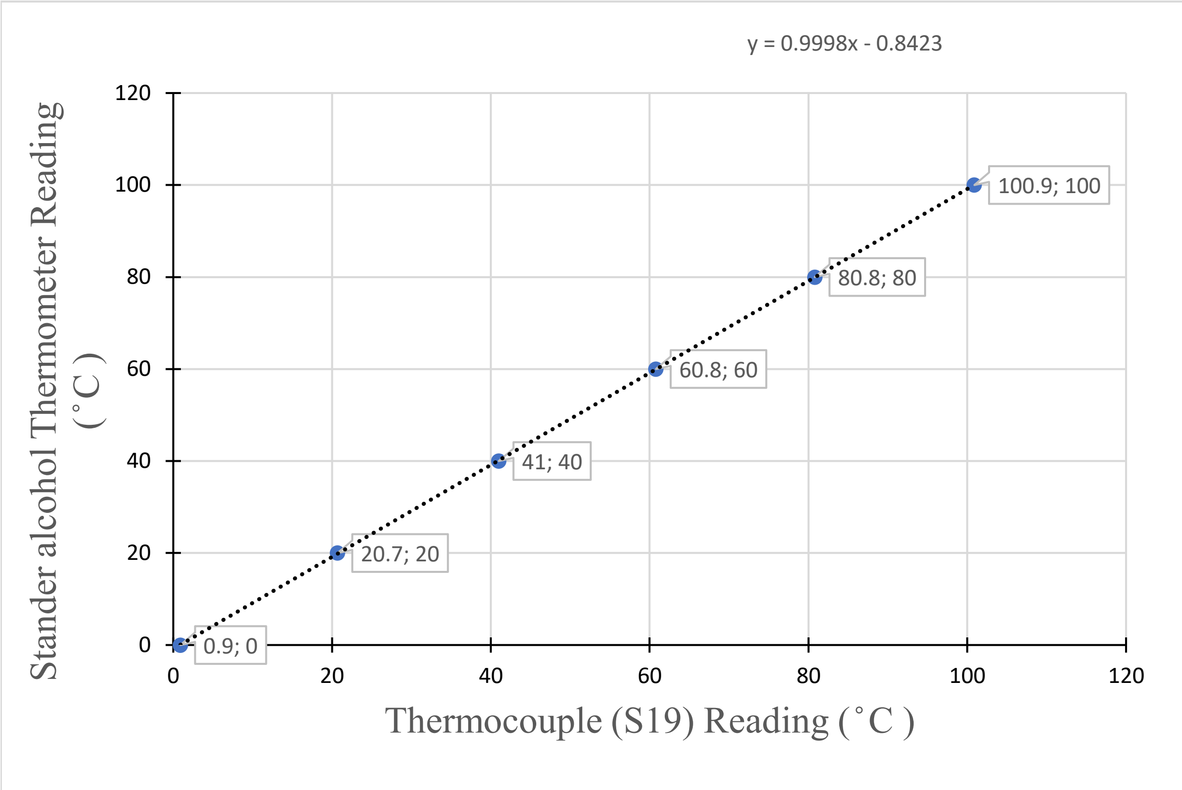


Figure A .19: Thermocouple (S19) calibration, ambient

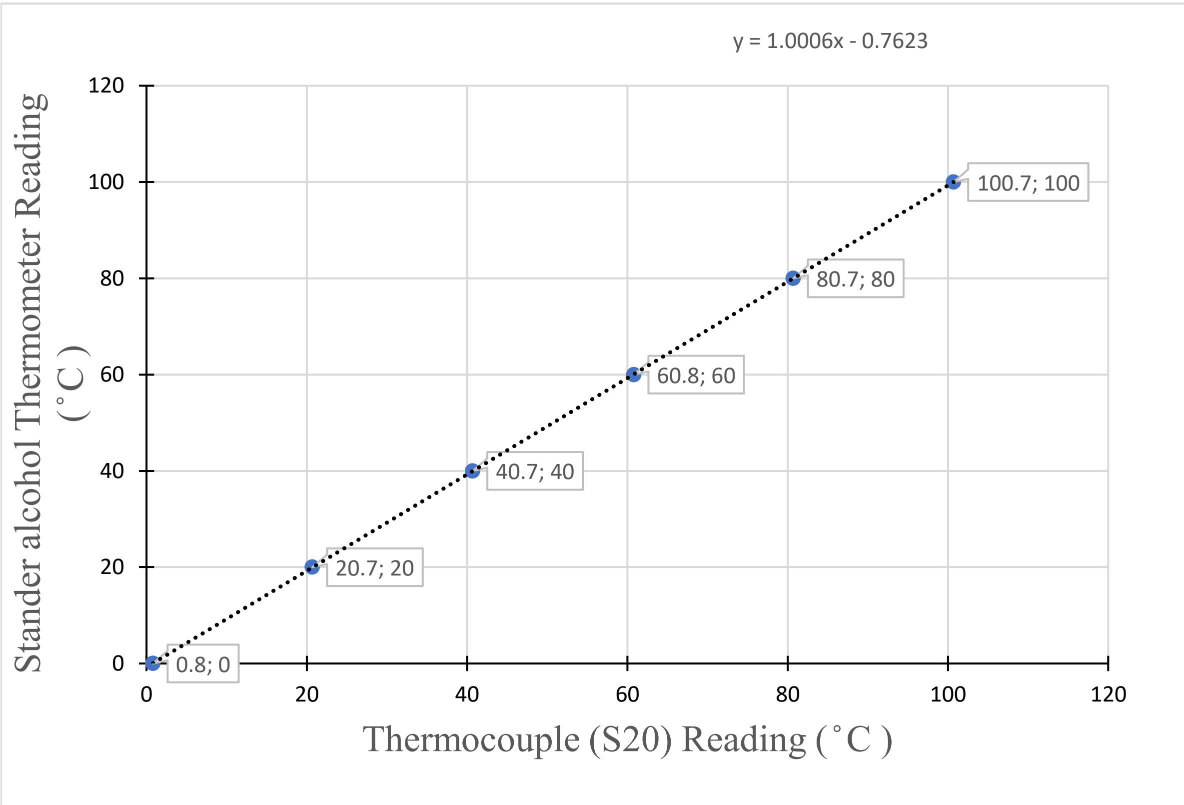


Figure A .20: Thermocouple (S20) calibration

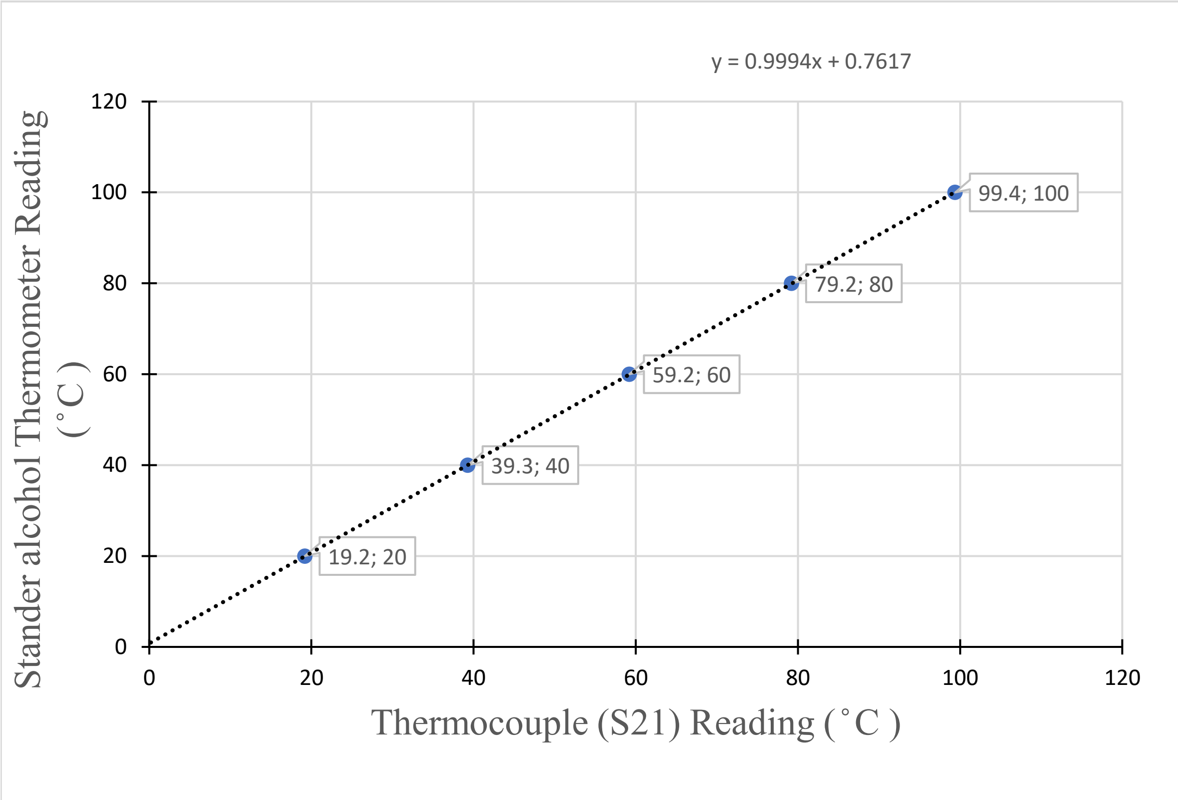


Figure A .21: Thermocouple (S21) calibration

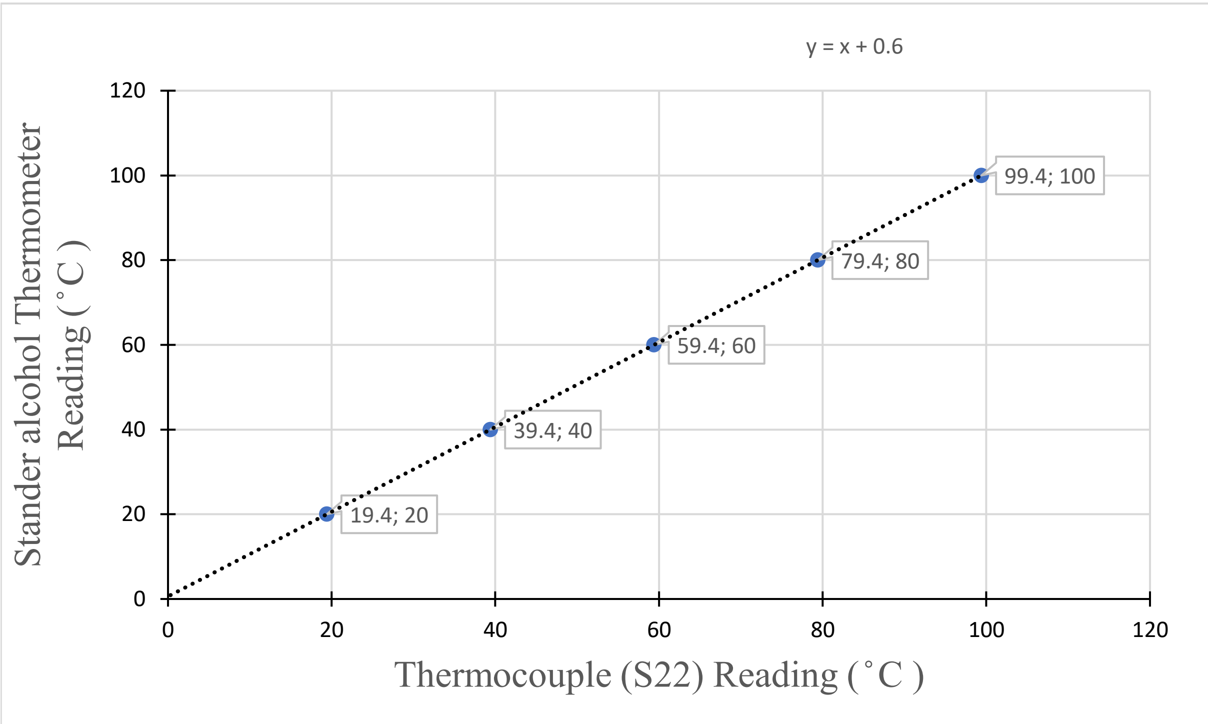


Figure A .22: Thermocouple (S22) calibration

Appendix – B –
Copper pipes Evacuation

For reducing the boiling point of the water trapped inside the copper pipes, the internal pressure should be less than the atmospheric pressure. For that particular reason, the 1 stage vacuum pump type (rotary vane) (as in fig. B1) was used to evacuate the inside air with the help of a low-pressure gauge as shown in fig. B.2. The evacuation process started at 1 atm, until the internal pressure reaches nearly zero and maintained for 24 hours under vacuum and connected to the gauge to ensure that there is no leakage.

1 Stage Vacuum Pump CE

Model	RS-1
Free air Displacement	2.5 CFM
Ultimate vacuum	5Pa
Voltage	220V/50HZ
Power	1/4HP
Oil capacity	220ml

Figure B.1: 1 stage rotary vane vacuum pump

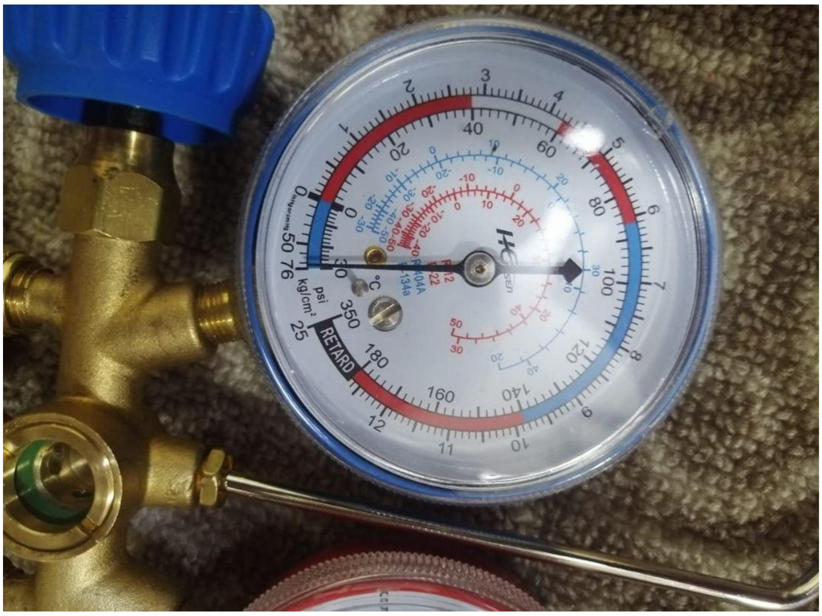


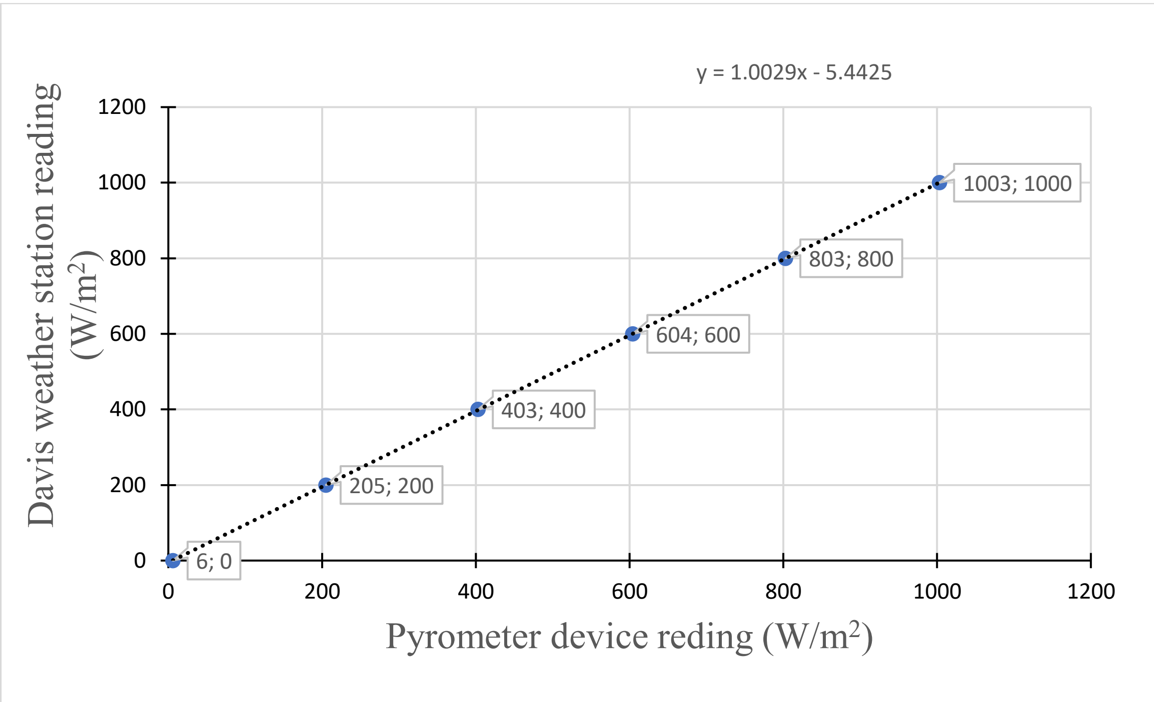
Figure B.2: low pressure gauge

A special mechanism was used to fill the pipes with water that maintain it under vacuum while filing. A small tank connected with special pipes supplied with proper connecters that connect perfectly to the copper pipes as in fig. B.3. The water sucked inside the copper pipes due to the pressure difference when the copper pipes valve opened.


Figure B.3 special feeding mechanism

Appendix – C –
Pyranometer calibration

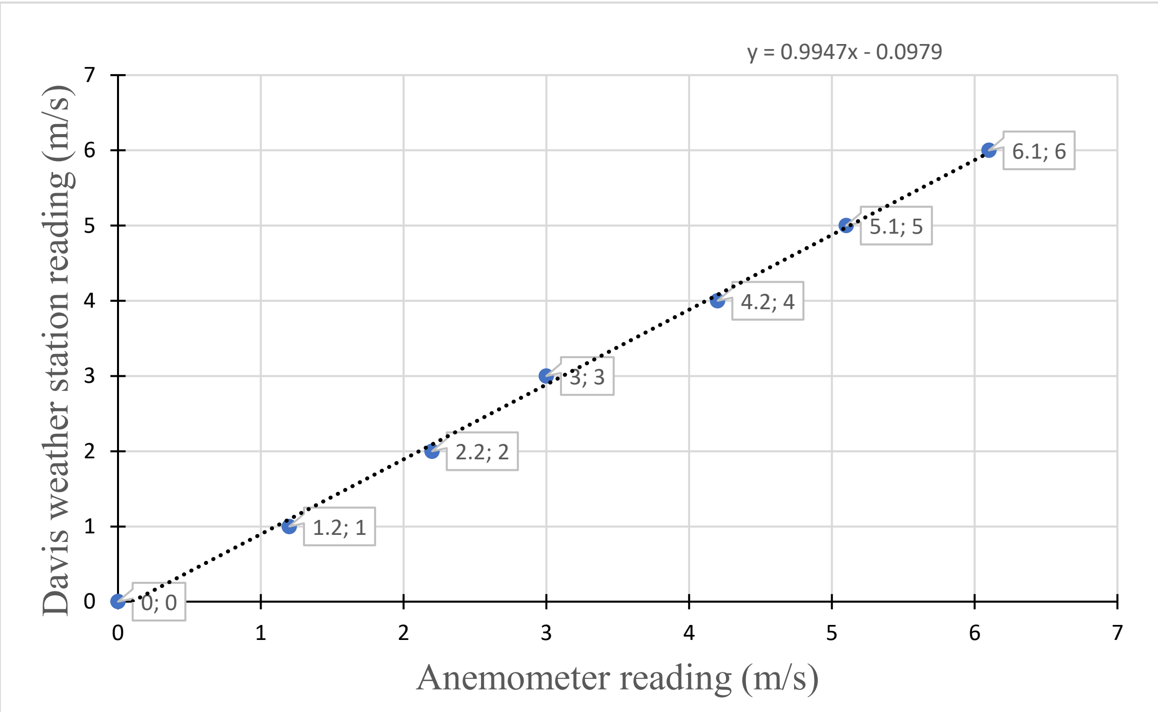
In this study a pyrometer was used to measure the global radiation. it used for being easy to use with an acceptable accuracy. The device could be easily calibrated with the proper instruments that had the accurate measurement standard. The Davis weather station in Najaf Engineering Technical College /Iraq was taken as a standard for calibrated the pyrometer. With a capability of sensing a solar radiation ranging from 0 – 1800 W/m² and accuracy of ±0.3%. Values ranging between 0 and 1000 W/m² was recorded for the calibration as in figure C.1.



C.1 Pyranometer calibration

Appendix -D
Anemometer calibration

The Anemometer used in all the experiments to measure the wind speed. It has been selected for being easy to use and handle during the experiment in all conditions. The Anemometer has been calibrated based on the readings of the Davis weather station located in the Najaf Engineering Technical College /Iraq with wind speed rang of 0.1 to 89 m/s and an accuracy of ± 5%.



D.1 Anemometer calibration

Appendix -E

Publications

- Zahraa Abdulkareem Jaafar, Hassanain Ghani. Hameed, Ridha Hasan Hussein, Experimental Investigation of a Single Slope Solar Still Performance- Evaporation Process Enhancement, (IOP Conf. Series: Materials Science and Engineering 928 (2020) 022096) (Scopus Proceeding conference).
- Zahraa Abdulkareem Jaafar, Hassanain Ghani. Hameed, Experimental Investigation of a Single Slope Solar Still Performance- Evaporation Process Enhancement Using Evacuated Pipes, (acceptable)

- Zahraa Abdulkareem Jaafar, Hassanain Ghani. Hameed, Effect of utilization of wick on single slop solar still performance، (submitted)

- Zahraa Abdulkareem Jaafar, Hassanain Ghani. Hameed, Experimental Investigation of a Single Slope Solar Still Performance- Condensation Process Enhancement, (submitted)

الخلاصة

تمثل المياه النقيه مايقارب 1 % من الماء حول العالم لذا تعاني بعض المناطق النائية والصحاري من شحة في مياه الشرب ،ولهذه الضرورة توجه الباحثين لاجراء العديد من المحاولات لانتاج المياه النقيه وكان التقطير الشمسي احداها. يعتبر المقطر الشمسي الحل المناسب لمشكلة شحة المياه العذبة بسبب انخفاض الكلفة وسهولة التصنيع كما انه لا يحتاج لمصدر طاقة سوى الطاقة الشمسية. معدلات انتاج المقطر الشمسي منخفضة اذا ما قورنت باحتياجات الانسان اليومية، لذا كان اساس بحثنا هو دراسة تأثير تحسين العمليات الرئيسية (عملية التبخير و عملية التكثيف) التي تتحكم في انتاجية المقطر الشمسي . تم تحسين هذه العمليات بطرق مختلفة وقد اجريت العديد من التجارب للتحقق من فاعلية هذه الطرق في الكلية التقنية الهندسية /نجف في العراق بموقع (32.1 شمالا ، 44.19 شرقا) . تضمنت هذه التحسينات استخدام استخدام فتائل الحديد المغلون وخزان صمم ليكون جامعا للطاقة الشمسية وانابيب من النحاس مفرغة من الهواء اضافة الى استخدام قنوات المياه للتبريد. تم تحسين اداء المقطر الشمسي بشكل كبير بتحسين عملية التبخير او التكثيف حيث تم تحسين معدلات الانتاج بنسبة 44.83 % عند استخدام خزان تجميع الطاقة الشمسية ، بينما بلغت نسبة التحسين حوالي 86.65 % و 72.53 % و 151 % عند استخدام فتيل مغلون قياس شبكته 25 * 25 ملم و 50 * 50 ملم وعند دمجهم معا ، على التوالي. كما تم استخدام الانابيب النحاسية المفرغة باقطار 7 و 15 ملم وبنسب تعبئة للمياه بلغت 50% و 100 %، حيث بلغ الحد الاقصى للتحسين 90.09 % باستخدام الانابيب النحاسيه بقطر 15 ملم و المملوءة بنسبة 50 % من الماء،جميع هذه النتائج مقارنة مع المقطر الشمسي الاعتيادي الذي يعمل في نفس الوقت .كما تم تحسين عملية التكثيف في هذه الدراسة باستخدام قنوات مائية (شكل U وشكل N) على الغطاء الزجاجي الامامي لتقليل درجة حرارته باستخدام ثلاث معدلات تدفق للماء 1 و 1.5 و 2 لتر\دقيقة .تم تحسين اداء المقطر بنسبة 56% و 45.71 % عند استخدام قنوات تبريد المياه بشكل U و N على التوالي بمعدل تدفق مياه 2 لتر \ دقيقة.

جمهورية العراق

وزارة التعليم العالي والبحث العلمي

جامعة الفرات الاوسط التقنية\ كلية الهندسة التقنية – النجف

دراسة تأثير تعزيز عمليات التبخير- التكثيف على اداء مقطر شمسي تقليدي

رسالة مقدمة الى

قسم هندسة تقنيات ميكانيك القوى

كجزء من متطلبات نيل درجة الماجستير في تقنيات الحراريات في هندسة ميكانيك القوى

تقدم بها

زهراء عبد الكريم جعفر

بكالوريوس في هندسة تقنيات السيارات

اشراف

الاستاذ المساعد الدكتور

حسنين غني حميد

كانون الثاني - 2021