EXPERIMENTAL PERFORMANCE AND ECONOMIC ANALYSIS OF NANO FLUIDS IN INCLINED SOLAR STILL EQUIPPED OF THE STEPPED ABSORBER WITH CORRUGATED FINS AND EVACUATED TUBE

Thesis Submitted for the Award of the Degree of

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in

Mechanical Engineering

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2022

Certificate

This is to certify that the work reported in the Ph. D. thesis entitled "***Experimental performance and economic analysis of nano fluids in inclined solar still equipped of the stepped absorber with corrugated fins and evacuated tube***" submitted in fulfillment of the requirement for the reward of degree of **Doctor of Philosophy (Ph.D.)** in the **School of Mechanical Engineering**, is a research work carried out by **Fale Samish Mahendra**, **41800851**, is bonafide record of his original work carried out under my supervision and that no part of thesis has been submitted for any other degree, diploma or equivalent course.

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Declaration

I, hereby declared that the presented work in the thesis entitled **"*Experimental performance and economic analysis of nano fluids in inclined solar still equipped of the stepped absorber with corrugated fins and evacuated tube*".** in fulfilment of degree of **Doctor of Philosophy (Ph. D.)** is outcome of research work carried out by me under the supervision **Dr. Sudhanshu Dogra**, working as **Assistant Professor**, in the **School of Mechanical Engineering** of Lovely Professional University, Punjab, India. In keeping with general practice of reporting scientific observations, due acknowledgements have been made whenever work described here has been based on findings of other investigator. This work has not been submitted in part or full to any other University or Institute for the award of any degree.

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ABSTRACT

In the present day, the water dilemma seems to be screaming for global catastrophe. According to the projections that were made public by the United Nations, it is anticipated that there would be a shortage of water for two billion people by the year 2025. At this time, illnesses brought on by a lack of access to clean water cause the deaths of 3.57 million people over the world each year. Therefore, to regulate this condition, researchers are developing advancements in current desalination technology to increase the output of fresh drinking water despite constraints like this automated process' comparatively poor operational efficiency. The need for desalination has, however, been borne by an ever-increasing demand due to resource depletion and rising population demands. Parts of the Asian Pacific region, such as India, China, and Japan, as well as global powers like Germany and the UK, have been heavily involved in the development of this technology, with the Middle East (with Saudi Arabia being the largest user of this technology for the treatment of seawater) and the USA seeing the most significant advancements. When treated water is released, it affects aquamarines in a bizarre way.

Desalination is the term for any process that purges water of extra salts and minerals, as well as the chemical conversion of seawater into potable water. Any commercial purpose, whether municipal, industrial, or otherwise may use these procedures. Diverse technologies have been used by scientists to investigate the majority of available disposal sources. The use of solar desalination technology is becoming increasingly popular as a consequence of its enormous supply of energy as well as its inexpensive installation costs.

The conventional methodology involving basin solar still is the most used method for ages and is hassle-free for aspects related to convenience and maintenance. The basin which is covered up with a see-through cover and contains saline water that is unveiled in presence of solar radiation is usually black stained to facilitate maximum radiation. Once water changes its state of form (due to evaporation), it is made to condense once its particulates come in contact with the cover. The leftover water is then distributed to the various facilities using the appropriate media, and the process is repeated until it is complete. Unfortunately, this simplified apparatus suffers from a

substantial lack of efficiency as a result of the released latent heat of condensation and the subsequent gradual increase in the temperature at which water evaporates. This is the most important drawback of the apparatus.

The research work has the following objectives:

1. Design and fabrication of modified inclined solar still with stepped absorber and evacuated tube.
2. Study the effect of Nano fluids, corrugated finned on stepped absorber and evacuated tube on the productivity of the fabricated inclined solar still.
3. Comparison of the performance for modified fabricated inclined solar still and conventional solar still.
4. Economic analysis of modified fabricated inclined solar still will be done.

In this research work, an inclined solar still having the stepped absorber with corrugated fins integrated with vacuum tubes is fabricated. In order to lessen the amount of heat that is lost from the water in the basin due to heat transfer, the basin of the solar still has an area of one square metre and is built of galvanised iron. For insulation, commercial plywood and polyurethane foam are used. The innermost part of the basin has been given a black paint job so that it can soak up the maximum amount of solar energy that is hitting the still. The 4 mm thickness plain glass is used which is placed at 22^o inclination as the approximately latitude of Nagpur (India). In the present study, the 5 steps are used as absorber having dimension of 1 step is 160mm x 1000mm x 30mm on which triangular corrugated fins are attached. The 5 vacuum tubes are used for experimentation having dimensions of 47mm inner diameter 58mm outer diameter and 1800mm long which is attached at the lower side of a basin and inclined at 45^o to the horizontal. Also, Al_2O_3 (Aluminium oxide) nanoparticles are used in the experimentation.

The experimentation is performed for five different cases, they are:

Case-1: Inclined solar still having stepped absorber with corrugated fins in winter season.

Case-2: Inclined solar still having stepped absorber with corrugated fins integrated with vacuum tubes in winter season.

Case-3: Inclined solar still having stepped absorber with corrugated fins in summer season.

Case-4: Inclined solar still having stepped absorber with corrugated fins integrated with vacuum tubes in summer season.

Case-5: Inclined solar still having stepped absorber with corrugated fins integrated with vacuum tubes in summer season by using aluminium oxide nanoparticles.

An inclined solar still that has a stepped absorber with corrugated fins integrated with vacuum tubes by using nanoparticles is the best basin condition of solar still to obtain maximum output, which is 5.2 L/m^2-day from the still, according to the results of the experiments that were conducted. This conclusion was reached as a result of the findings that were obtained.

As compared to inclined solar still having stepped absorber with corrugated fins in the winter season, 25.32% more fresh distillate output is obtained from an inclined solar still having a stepped absorber with corrugated fins in the summer season. Similarly, for an inclined solar still having stepped absorber with corrugated fins integrated with vacuum tubes in winter and summer seasons, 45.91% and 79.48% respectively more fresh distillate output is obtained as compared to an inclined solar still having stepped absorber with corrugated fins in the winter season. The highest percentage of fresh distillate output is obtained i.e., 100.16% for an inclined solar still having stepped absorber with corrugated fins integrated with vacuum tubes by using nanoparticles as compared to an inclined solar still having stepped absorber with corrugated fins in the winter season.

The TDS and pH values that were measured for the fresh distillate that was produced fall within the acceptable ranges that have been set by the WHO.

Also, an economic analysis for all the cases is done and found that the payback time is 299 days for inclined solar stills with stepped absorbers and corrugated fins, 281 days for inclined solar stills with stepped absorbers and corrugated fins integrated with vacuum tubes, and 277 days for inclined solar stills with stepped absorbers and corrugated fins integrated with vacuum tubes that use aluminum oxide nanoparticles.

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The research work is one of the major milestones in my journey of learning.I acknowledge with earnest gratefulness the blessing of Almighty for this work. Iwish to express my sincere thanks and sense of gratitude to my guide. ***Dr. Sudhanshu Dogra****, Associate Professor, School of Mechanical Engineering, Lovely Professional University, Phagwara, Punjabfor his esteemed guidance constant inspiration and encouragement and continued support throughout the tenure of this research study. The blessing, help,and guidance given by him from time to time shall carry me a long way in the journey of life on which I am about to embark. I am indeed, greatly indebted to them.*

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Fale Samish Mahendra

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NOMENCLATURE

A	=	Area, (m^2)
AMC	=	Annual maintenance cost, (Rs)
ASV	=	Salvage cost per year, (Rs)
CPL	=	Cost of distilling water per litre, (Rs)
CRF	=	Capital recovery factor
CS	=	Total cost of still, (Rs)
FAC	=	First annual cost, (Rs)
h	=	Overall heat transfer coefficient, ($W/m^2\ ^oC$)
h_{fg}	=	Latent heat of vaporization of water, (J/kg)
I (t)	=	Solar irradiation, (W/m^2)
i	=	Annual rate of interest
k	=	Thermal conductivity, (W/m °C)
m	=	Mass, (kg)
m	=	Mass flow rate, (kg/min)
m_{ew}	=	Hourly productivity, (kg/m^2h)
N	=	a lifetime of solar still, (year)
P	=	Partial vapour pressure (Pa)
S	=	Salvage value
SFF	=	Sinking fund factor
T	=	Temperature, (°C)
TAC	=	Annual Total Cost, (Rs)
TDS	=	Total dissolved solid

V = Fluid velocity, (m/s)

ΔT = Temperature difference, (°C)

η = Efficiency, (%)

SUBSCRIPTS

a = ambient

c = convection

e = evaporation

g = glass

I = liquid

p = absorber plate

th = thermal

w = water

i = vapour film

CHAPTER 1

INTRODUCTION

1.1 PREAMBLE

Water crisis in modern times appears to call out for catastrophic situations all over the world. As per estimates declared by UNO, approximately 2 billion people are estimated to suffer from water scarcity by 2025 [1]. Due to insufficient supply of water and water-related diseases, currently, 0.003575 billion people die every twelve months. The predicted tension of water on a country–level in 2040 is shown in figure 1.1 [2]**.** Hence, to get this situation under control, researchers are coming up with improvements in existing desalination technology to enhance the productivity of fresh drinking water despite limitations such relatively low operating efficiency of this mechanized process. However, the ever-depleting resources and consequently raising population demands have shouldered the need for desalination on an ever-increasing demand. With the major advancements happening in the Middle East (with Saudi Arabia being the largest user of this technology for the treatment of seawater) and the USA, parts of Asian Pacific countries such as India, China, and Japan along with global powers like Germany and UK have been heavily involved in the development of this technology [3]. However, the treated water when discharged has a surreal impact on the aquamarines. Firstly, the problems due to water scarcity and water pollution are discussed below. Also, solar energy status in India is discussed.

According to the Bureau of Indian Standards, drinking water is water used for human utilization for drinking and cooking purposes from any resource. Two major problems that impact every nation's ability to prosper economically are a lack of water and energy [4]. Water is a liquid of life, as there can be no life without water [5]. Water is readily available, but not in the quality or quantity which makes it practical to consume.

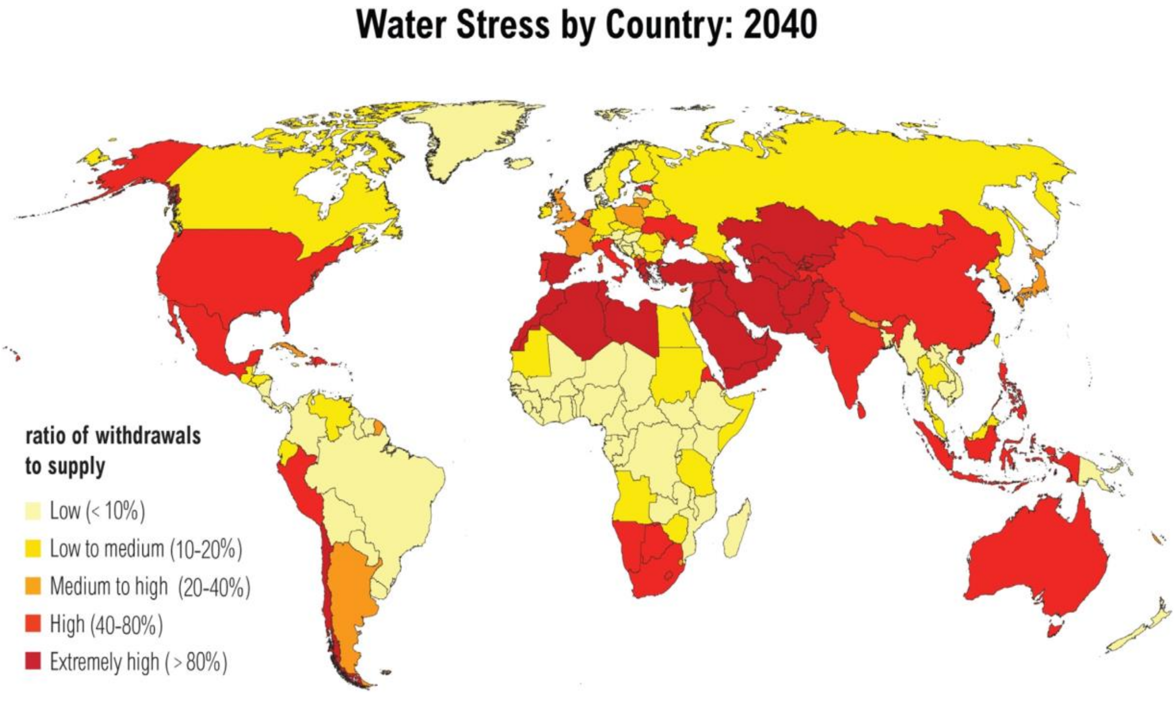


Figure 1.1. Projected water stress in 2040 [2].

1.2 WATER RESOURCES IN INDIA

Almost three-quarters of the surface of the planet is taken up by the seas of the globe. According to estimations provided by the UN, 75.2% of the world's freshwater is found frozen in the polar areas, while the remaining 22.6% is found as groundwater. There is approximately 2.7% of freshwater on Earth [6]. The following is a list of India's most important water resources:

- Surface Water
- Groundwater
- Rainfall

Table 1.1: India projected population and water availability per person [7]

Population (million)	**Year**	**Per Capita average annual water (m^3/Year)**
1027	2001	1820
1211	2011	1657
1463 (Projected)	2031	1367
1628 (Projected)	2051	1228

Source: Government of India, 2009 (NCIWRD Report, 1999)

Over the following decades, there will likely be a major rise in water consumption. Differences between water consumption and supply are getting worse. [8].

From above table 1.1, we can predict how much amount of burden is coming on the water sources. Now talk about today's problem, there is water available but not in a consumable state or phase [7]. Waterborne illnesses are a serious problem worldwide, but they are particularly acute in developing nations where the majority of the population lacks even the most basic access to potable drinking water, which exacerbates their poor health and has a negative impact both on their economy and their quality of life. Waterborne diseases such as cholera, typhoid, fever, malaria, amoebiasis, and dysentery can be caused by polluted or contaminated water. Water-related diseases kill more than 5 million people each year around the world [9]. Pollution sources have an effect on the quality of the water. These include sewage discharge, industrial discharge, run-off from agricultural fields, urban run-offs, and chemical substance percolation [5]. On July 21, 2017, the Indian government's Ministry of Health and Family Welfare responded in the Indian Parliament, stating that between 2014 and 2016, more than 44 million Indians became sick with enteric fever and viral hepatitis as a direct result of drinking water that was tainted.

Following table 1.2 shows the data on the number of deaths because of different diseases.

Table 1.2: Number of Deaths Because of Different Diseases [9]

Year	**Diseases**			
	Diarrhea	**Typhoid**	**Hepatitis**	**Cholera**
2014	1137	425	400	5
2015	1352	452	435	4
2016	1540	512	446	3
Average	1343	463	427	4

People are affected by waterborne diseases leads to an increase in their economic burden on them. Averagely calculated public expenditures are shown in table 1.3 below.

Table 1.3: Public Expenditure on Health (Source GOI: Ministry of Health)

Sr. No	Year	Public Expenditure on Health	Per Capita Expenditure on Health
1	2009-2010	72536	621
2	2010-2011	83101	701
3	2011-2012	96221	802
4	2012-2013	108336	890
5	2013-2014	112270	913
6	2014-2015	12160	973
7	2015-2016	140054	1112
8	2016-2017	178875	1397
9	2017-2018	213719	1651

1.3 WATER SCARCITY AND INSECURITY

Despite covering 70% of the planet, water is not abundant. Only 2.5% of all water is fresh [6]. The world's population will be composed of 9.7 billion people by 2050, and 3.9 billion people, or more than 40%, will live in river basins that are severely water-stressed [8].

Water resources are being strained by factors other than population growth. Extreme use is also observable. In the 20th century, the world's population quadrupled, yet water demand climbed by a factor of six. Water demand from manufacturing is expected to increase by 400% between now and 2050, while household is expected to increase by 130%. The growing amount of rivalry for limited access to this resource is seen in figure 1.2. This competition will only intensify as water supplies become increasingly scarce. There are an estimated 592 transboundary acquirers, which contribute to the shared international river basins that supply sixty percent of the world's surface fresh water. International cooperation and coordination must continue if there is to be enough water for human, economic, and environmental needs. Even though there have been hundreds of international water agreements signed over the years, it is not always clear how nations will cooperatively manage increasing resource pressure to prevent further water conflicts.

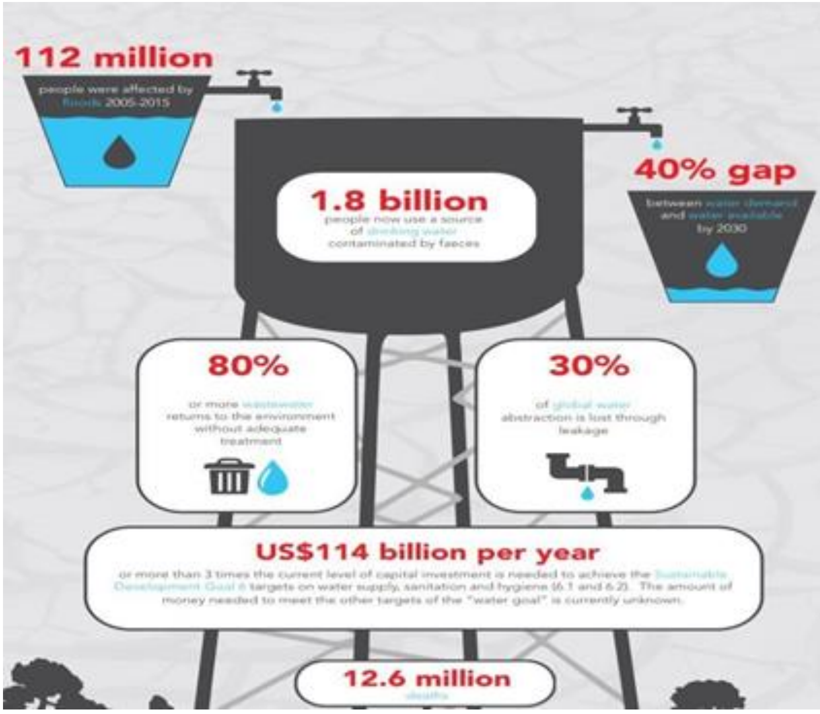


Figure 1.2. Global Water Scarcity [7]

Water scarcity may become worse during a drought. Drought has more negative effects than any other kind of disaster. In 2016, 411 million people were impacted by natural catastrophes, the majority of which were due to drought-related conditions (94%). Droughts are also the most expensive natural disasters, having a particularly negative impact on agriculture. Every year, droughts in the USA cost the agricultural industry an average of US$ 6 to 8 billion. More than 27 million metric tonnes of yearly grain output have been lost as a direct result of drought in China over the course of the previous two decades. There has been a 116% increase in drought-affected crop areas between the 1950s and the start of this century. Irrigated agriculture would have produced an estimated US $94 billion in global welfare gains if water had been secured for it in 2010. In addition, research suggests that increased water security might assist in maintaining food crop prices as well as production levels. The likelihood that annual global wheat production would fall below 650 million metric tonnes is reduced from 83 percent to 38 percent in the event that there is sufficient water security. (Source: www.unicef.org).

1.4 SOLAR ENERGY STATUS IN INDIA

In order to produce solar energy, a variety of constantly developing technologies are used, such as solar heating, photovoltaics for cell phones, solar thermal energy for boilers, solar architectures for buildings, molten salt power plants, and synthetic photosynthesis to use the radiant light and heat of the Sun.

India is experiencing rapid growth in solar power. India is the country with the fourth-highest global energy consumption, behind the US, China, and Russia [10]. Electricity is mostly generated from this solar energy. As of July 31, 2019, the nation had installed 30.071 GW of solar power. India is the nation in which the construction of solar power installations is the most cost-effective.

One of the eight goals that were included in the Prime Minister's National Action Plan for Combating Climate Change was for the Jawaharlal Nehru National Solar Mission to begin working towards a target of 20 GW capacity for the year 2022. This goal was completed four years earlier than it was anticipated to be completed. The goal for solar energy production was increased to 100 gigawatts in the year 2015 [11].

Solar energy is one of the most significant forms of renewable energy that India may utilise to supplement its existing energy sources and bring down the country's carbon emissions. Solar energy currently meets more than one percent of the world's demand for electricity. The country of India is in the enviable position of having abundant access to solar energy, which has the potential to create up to 500 trillion kilowatts of clean, renewable power [12].

Approximately 1.5×10^{18} kWh of solar energy is incident on the surface of the earth each year. From this Rajasthan is the largest state and Gujarat is the second largest state which receives the amount of solar radiation in India.

Although Rajasthan receives between 6 and 7 kilowatt hours (kWh) per square metre on a daily basis, Gujarat receives between 5.5 and 6 kilowatt hours (kWH) per square metre [10].

From May 26, 2014, when there were just 2,650 MW, there are now over 20 GW as of January 31, 2018, India increased its solar-generation capacity by an astounding 8 times. In 2015-2016, the country boosted its solar energy generation by 3 GW, more than 10 GW in 2017–2018, compared to 5 GW in 2016–2017. An average cost of solar power today is now 18% less than an expense of its coal-fired counterpart [13].

3.4 GW of solar energy is generated on roofs, 70% of which is used for business or industry. India is working to provide off-grid solar power to meet its country's local energy demands in addition to its extensive grid-connected solar photovoltaic (PV) effort [14].

The main policy adjustments that were made to support the solar and renewable energy industries are [15]

- Electricity Act 2003
- Tariff policy (2006)
- Integrated energy policy 2006
- National Action Plan on climate change
- Generation-based incentives for solar (2009)
- Jawaharlal Nehru National Solar Mission (2010)

Significant obstacles to the development and use of solar energy:

- Technological barriers
- Economic barriers
- Environmental barriers
- Social barriers

Till date advancement in a field of solar technology is as follow:

- Solar Photovoltaic
- Solar Thermal Powers
- Solar Heater
- Hybrid solar Plant

1.5 DESALINATION

Desalination is the term for any process that purges water of extra salts and minerals, as well as the chemical conversion of seawater into potable water. Any commercial purpose, whether municipal, industrial, or otherwise may use these procedures. Two streams of water are produced after the feed water has been treated in major desalination processes. Fresh water that has been treated and is potable but contains less salt and minerals (treated water or product water) Brine or concentrates with higher salt and mineral concentrations than the starting saltwater or feed water [16]. Two categories: Membrane and Thermal represent the most common approaches to achieving this.

1.5.1 Renewable Energy Desalination

The effects on the atmosphere's carbon content were observed as a result of a need to increase a productivity of a plants involved in this process and an adoption of fossil fuel-driven mechanized processes led to a technology's elimination and the use of renewable sources as the plants' fuel. In the vast majority of the gulf countries, this practice is prevalent. The following list of diverse sources is discussed:

a) Solar: The heat produced by a sun's rays are used extensively by plants.
b) Wind: Mechanical generators produce electricity with the aid of windmill plants.
c) Hydroelectric: Dams generate a lot of energy because of the large volume of water flowing through them.
d) Biomass: Energy produced by burning or otherwise decomposing waste, such as wood chips and cow dung cakes.

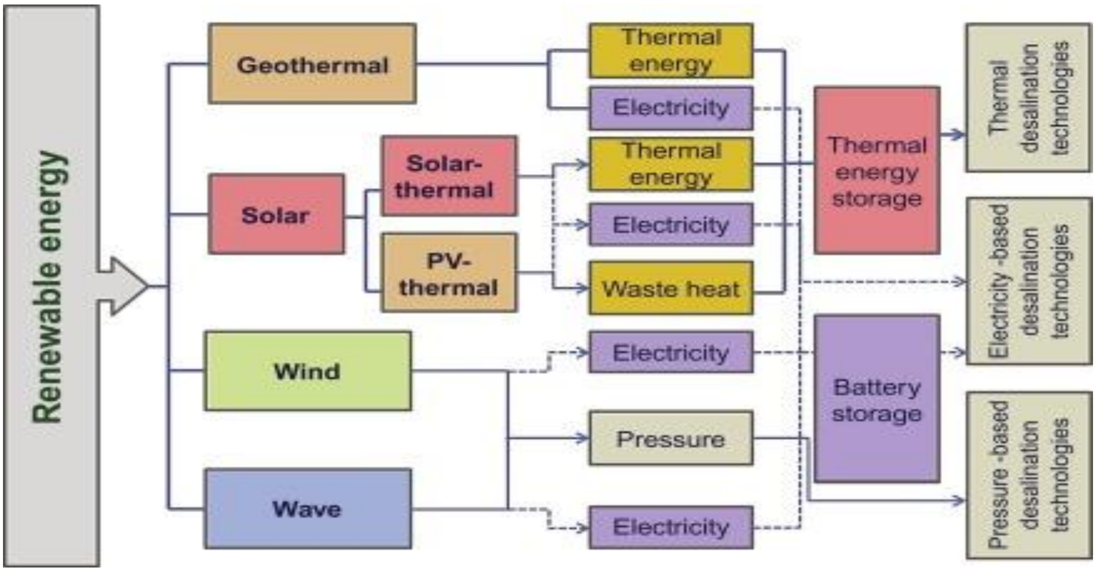


Figure 1.3. Technology for desalinating water combined with a storage system and renewable energy [17].

e) Geothermal: For a generation of electricity, energy is used beneath a earth's crust in a form of particulate/liquidate form.

Diverse technologies have been used by scientists to investigate the majority of available disposal sources. As a result of its large supply of energy and low installation costs, solar desalination technology is widely preferred over others.

1.5.2 Solar Desalination

The above-mentioned technique is broadly classified as the management of solar energy. As a result, it may mostly be divided into two distinct groups:

a) Direct: The absorption process and desalination take place in the same apparatus.

b) Indirect: Both absorptions of solar energy and desalination are done through different processes and systems.

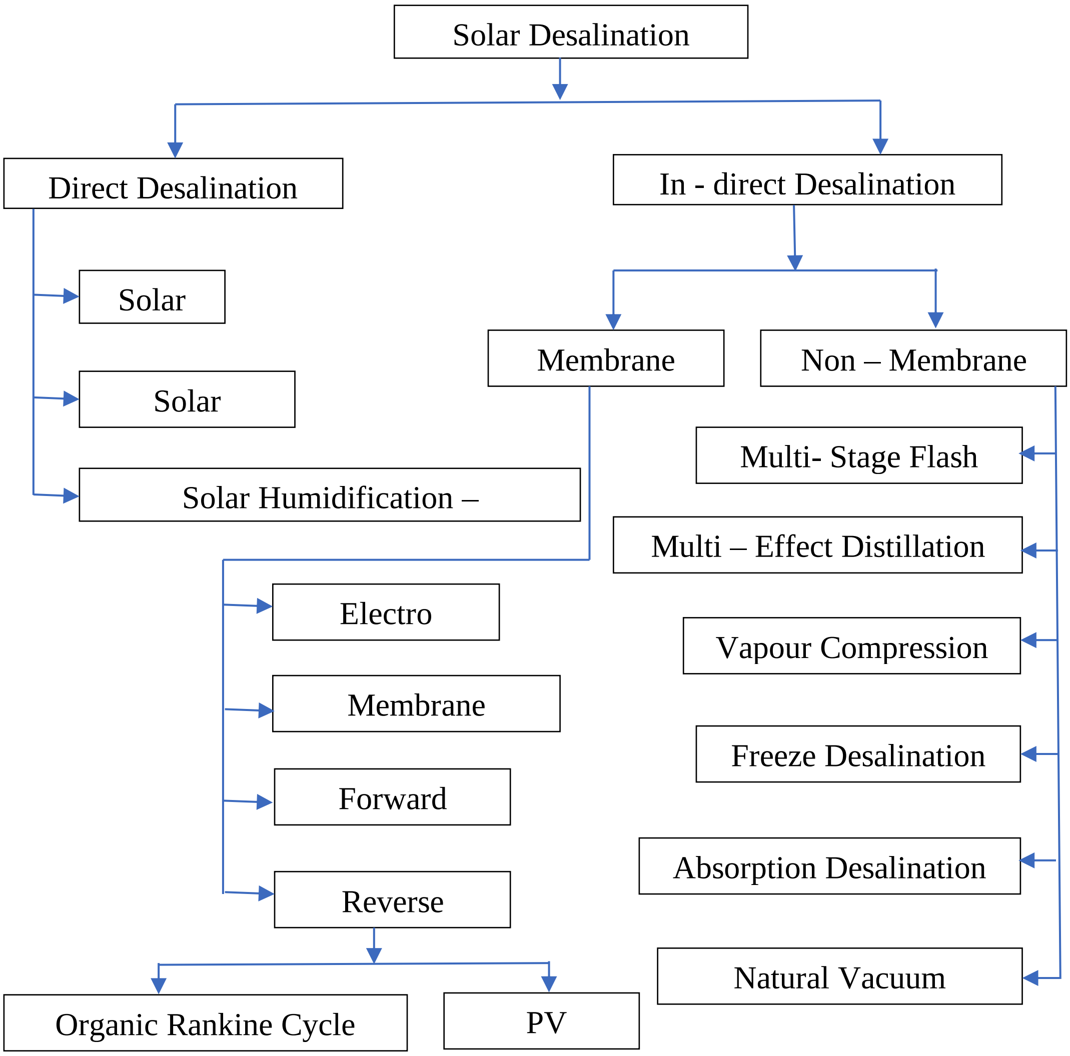


Figure 1.4. Stratification of different Solar Desalination Technologies [18].

The conventional methodology involving basin solar still is the most used method for ages and is hassle-free for aspects related to convenience and maintenance. The basin which is covered with a see-through cover and contains saline water that is unveiled in presence of solar radiation is usually black stained to facilitate maximum radiation [19]. Once water changes its state of form (due to evaporation), it is made to condense once its particulates come in contact with the cover. The leftover water is then distributed to the various facilities using the appropriate media, and the process is repeated until it is complete. Nonetheless, this reduced apparatus has a substantial number of drawbacks, the most notable one being its low efficiency, which is caused by the released latent heat of condensation and the subsequent gradual increase in the temperature at which water evaporates [20].

1.5.2.1 Solar Distillation

Depending on the type of solar distillation system, it can be passive or active, such as solar desalination or solar stills. When solar energy is used in the desalination process, it is provided to a desalination unit indirectly (e.g., through flat panel collectors, parabolic trough collectors, etc.). A desalination method appropriate for these applications and a solar energy harvesting technology is required. The direct sun harvesting desalination systems with the simplest and lowest cost are solar stills. To separate freshwater from salt water and leave concentrated brines behind, these devices use direct solar radiation. A single chamber houses both the evaporating and condensing components of the solar still. Latent heat is rejected to the air around the unit via the glass roof [17].

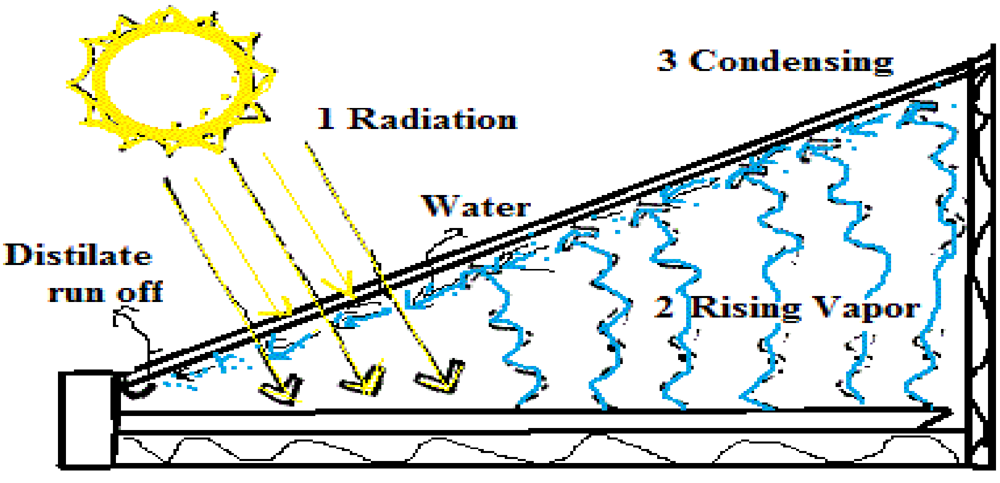


Figure 1.5. Solar Distillation [17]

Standard solar stills have an energy efficiency of 30% to 40%. Stills with an exterior condensing surface that was kept cold or at a lower temperature displayed an improvement in energy efficiency of up to 70%. Combining several effects into one system can improve both energy competence and a distillate produce. By splitting the distillation produced by the sun's radiation obtained by the unit, the energy competence of the solar distillation is determined. Membrane technology, multi-effect distillation at cold temperatures, humidifiers, dehumidifiers, or concurrent distillation and condensation are some further indirect solar desalination techniques. [17].

1.5.2.2 Multi-Stage Flash Distillation (MSF)

This method is predicated on the concept of flash evaporation, which describes the mechanism by which saltwater evaporates as a direct result of a decrease in pressure through a number of stages. Sequential regenerative heating, which involves warming the incoming saltwater with saltwater discharges in each flash container (effect or stage), achieves energy efficiency. Utilizing exterior heating elements such as reduced steam from power stations or steam produced from steam turbines, the saltwater is heated before it is injected. The heated seawater is then pumped into the flash-evaporating cylinders as the working pressures in the succeeding cycles fall. The normal number of stages for energy recovery and flashing in modern, large-scale MSF facilities is from 15 to 30. The size of the heat source that is accessible in the first stage determines the working temperature, which varies between 90 to 120 degrees Celsius (also known as that of the top brine temperature, or TBT). The plant often performs better when run at higher temperatures because of the greater number of stages. Since the produced water comes between two and ten parts per million, a post-treatment procedure is required to provide pipelines with water for drinking purposes (ppm) [17].

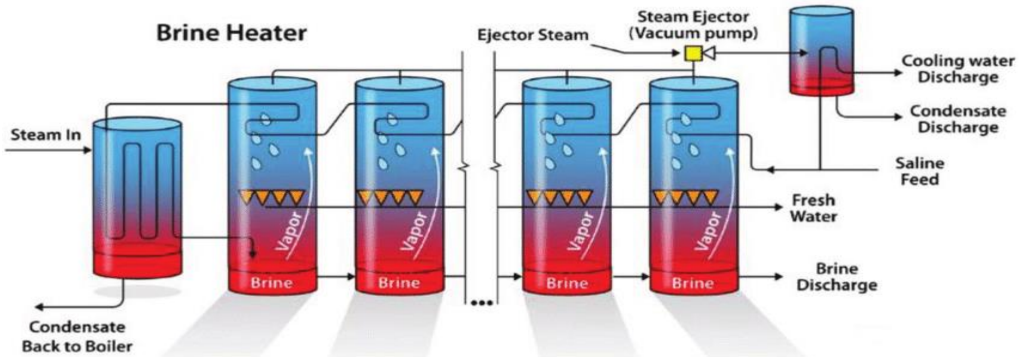


Figure 1.6. Multi-stage Flash Distillation (MSF) [21]

1.5.2.3 Multi-effect Evaporation/Distillation (MED)

The MED process, depicted in figure 1.7, is a most effective thermal desalination method at the moment from a thermodynamic perspective. similar to the MSF technique shown in figure 1.6. Numerous options exist for the MED process to increase energy effectiveness. In contrast to the MSF technique, which employs pre-heated seawater, the steam generated from a power plant warms the pipes in the initial evaporation chamber. They operate using a model of a double purpose power plant. In the succeeding effect, the fresh water vapour that has condensed in the first evaporation chamber is transferred via the condenser, which functions as the emitting surface. A brine left over from initial evaporation chamber is sprayed in a lower-pressure, lower-temperature evaporation chamber. Until an adequate temperature differential is present for freshwater evaporation, this process proceeds in successive effects [17] [21].

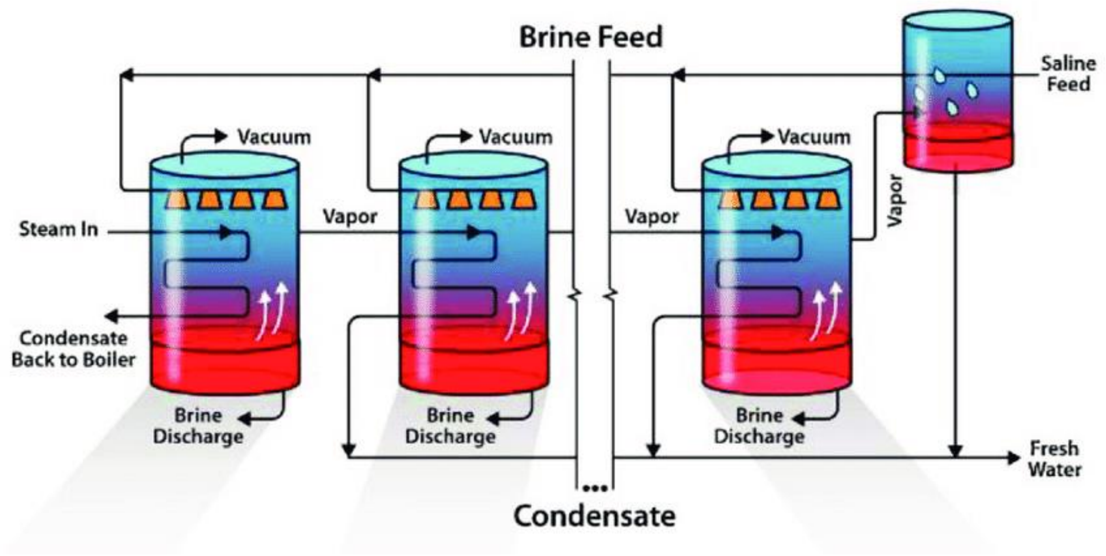


Figure 1.7. Multi-effect evaporation/distillation (MED) [17]

1.5.2.4: Vapour Compression

For small to medium-scale desalination plants, vapor compression works well. Compressed mechanically in a compressor or thermally in a steam ejector, the vapour that is produced in the final effect can be used as a source of heat in the initial effect. This can be accomplished by mechanical or thermal compression, respectively. As a result of the first effect, the vapour that is created is compressed, which results in an increase in steam pressure and temperature above those of the initial vapour. The compressor initially produces a vacuum in the evaporator in order to condense the vapour that was extracted from the evaporator into a pipe. More vapor is produced as a result of the boiling and partial evaporation of seawater that is sprayed on an exterior of a heated tube bundle. A thermo compressor, which is an opening at the steam jet of the steam-jet type of VCD unit, removes and creates water vapour from an evaporator to lower atmospheric pressure. A steam jet compresses the water vapour that was extracted. This combination condenses on a tube walls, producing a heat necessary for the saltwater that is applied to on other side of a tube walls in an evaporator to evaporate. It is expensive to construct a compressor for mechanical vapor compression, but an ejector is all that is required for thermal vapor compression [17]. This is the difference between the two vapor compression procedures. Compared to TVC, MVC compressors are considered to be less efficient and have higher operational and maintenance drawbacks figure 1.8.

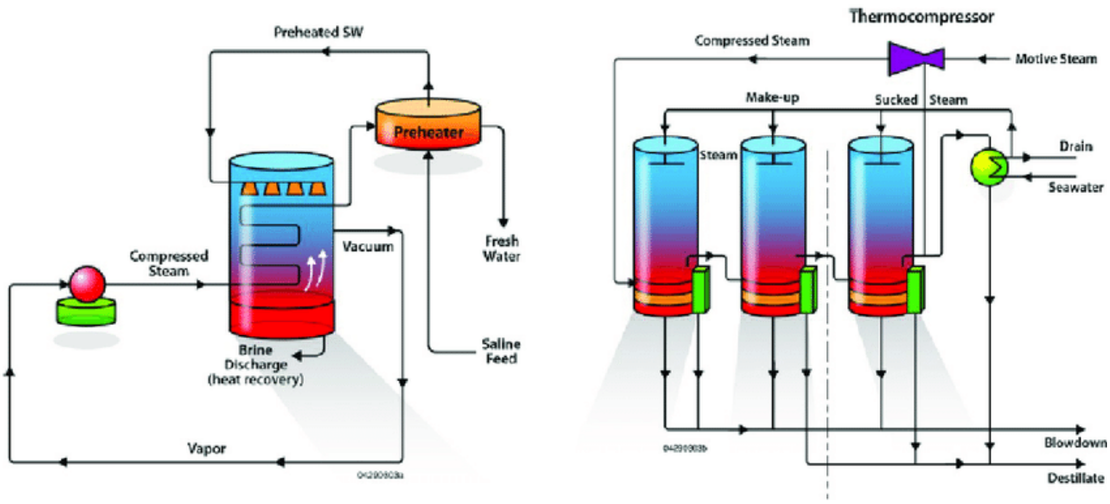


Figure 1.8. Vapour Compression [17]

1.5.2.5 Reverse Osmosis (RO)

The reverse osmosis method employs the semi-permeable barrier to separate the fresh water from the salty feed water in a non-phase change operation. While salts cannot enter through the barrier, water may. For fresh water to pass through the membrane, an extreme force that is greater than an electrolyte of a feed water must be applied. The amount of pumping necessary to generate the external pressure is dependent on a salt content of the input water. During this procedure, the feed water does not require any heating and does not go through any phase changes. Among the four parts of a RO plant, raw water is pretreated, high-pressure pumping is applied, membrane separation is carried out, and permeate is treated after separation. In the pre-treatment stage, big suspended particles, bacteria, and colloidal materials that could harm membrane operations are removed. Pretreatment procedures frequently include DE chlorination, multi-media filtering, coagulation, acid addition, and chlorination. Utilizing cleaning agents will also help to prevent fouling issues. Several factors determine the pretreatment method, including the characteristics of a feedwater, configuration and type of a membrane, and the recapture ratio. Mixing and re-carbonation with feed water are common methods of post-treating the permeate (freshwater) [17].

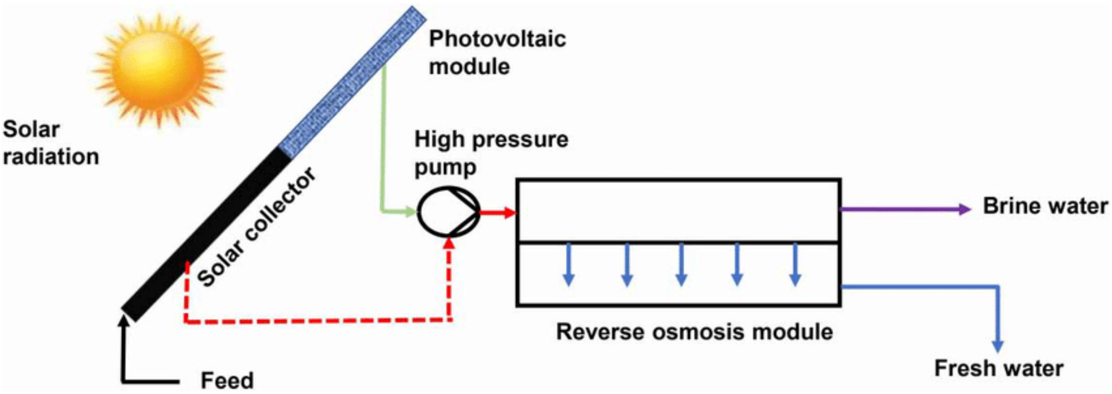


Figure 1.9. Reverse Osmosis (RO) [17]

1.5.2.6 Electro Dialysis (ED)

The ionic salts' migration toward the corresponding countercharge electrodes serves as the basis for this method's working theory. Concentrate and product streams are created in a cyclical manner by selective membranes that alternately allow passage of anions and captions. The cation-selective membrane prevents the anions from passing through, blocking their passage and trapping them in the brine stream. The anion-selective membrane allows the anions to pass through. The negative-charged cation-selective membrane traps cations travelling in the opposite direction like anion-selective membranes. Every cell pair in a standard ED system is made up of a membrane stack, demineralized flow spacers, anion transfer membranes, and concentrate flow spacers. The electrode storage compartments are located at the stack's opposing ends. Regular flushing is necessary to prevent scaling or fouling on the electrodes. "Feed-and-bleed mode" recycles concentrate streams and discharges them to trash or blow down. This is necessary because the brine and output streams flow differently. As the brine stream is 10 times faster than the diluted stream, pressure imbalances create concentrate recycling. ED units can remove 50–94% of source water's dissolved solids, up to 12,000 mg/L TDS. Voltage input, process design (number of stacks or stages), raw water quality, and membrane choice affect salt removal. Economic considerations typically place a cap on TDS removal. As the feed water TDS rises, ED costs rise as well. Similar to electrodialysis (ED), electrodialysis reversal (EDR) reverses the polarity of the electrodes on a regular basis to release ions that have accumulated on the membrane surface. By turning product streams into waste streams, this procedure lessens the impact of inorganic scaling and fouling. This procedure extends membrane life, enhances membrane and electrode cleaning, and does not call for the inclusion of chemicals [17].

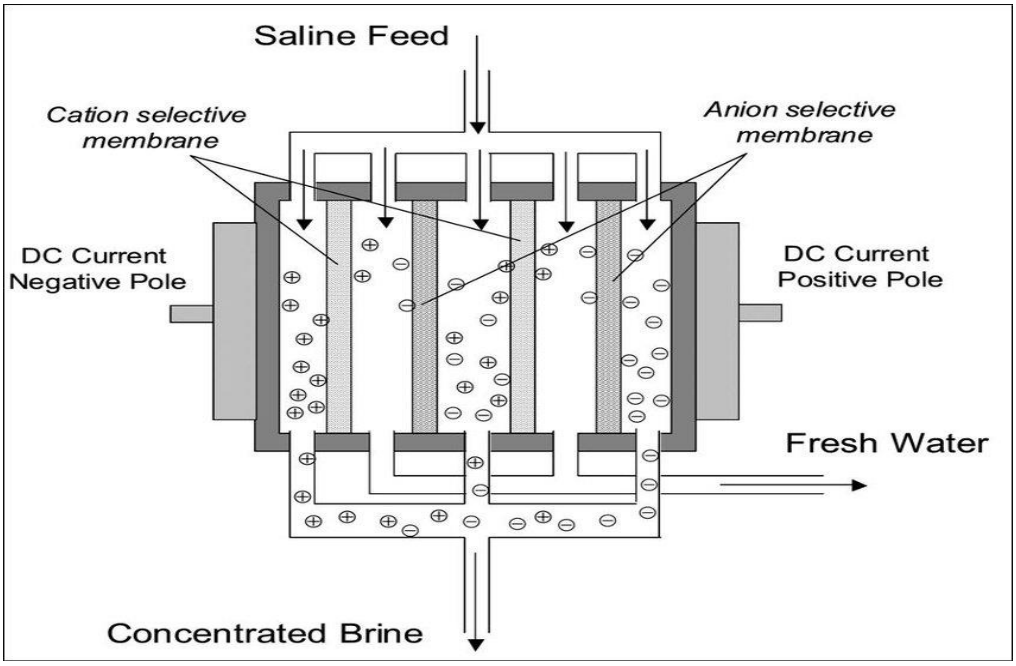


Figure 1.10. Electro Dialysis (ED) [17]

1.5.2.7 Membrane Distillation (MD)

Because it makes use of both the concepts of membrane separation and heat evaporation, the membrane distillation procedure is known as a hybrid procedure. Water vapours rise and diffuse across the membrane barrier and condense in the permeate flow on the cold side of the unit after the feed water (saline water) is heated by an external heat source, usually solar energy or industrial waste heat. Only a 10-

degree Celsius differential in temperature between cold (permeate or freshwater) and a hot (saline water feed) streams are needed for this process to create fresh water. The four most common variants of an MD process are called sweep gas membrane distillation (SGMD), vacuum membrane distillation (VMD), and direct contact membrane distillation (DCMD). Unlike AGMD, which provides an air gap amongst the condensation surface and membrane to increase energy competence, DCMD brings a membrane into straight contact with the liquid phases. In the VMD, a permeate side is held at the lower pressure by mechanical pumping in order to maximise a permeate flow. In a SGMD, the generated vapour is collected using a stripping or carrier gas. Of all of them, DCMD has the greatest penetration rate and best operational efficiency. For the AGMD, the permeate flux is rather low. VMD is appropriate for feed waters with volatile [22].

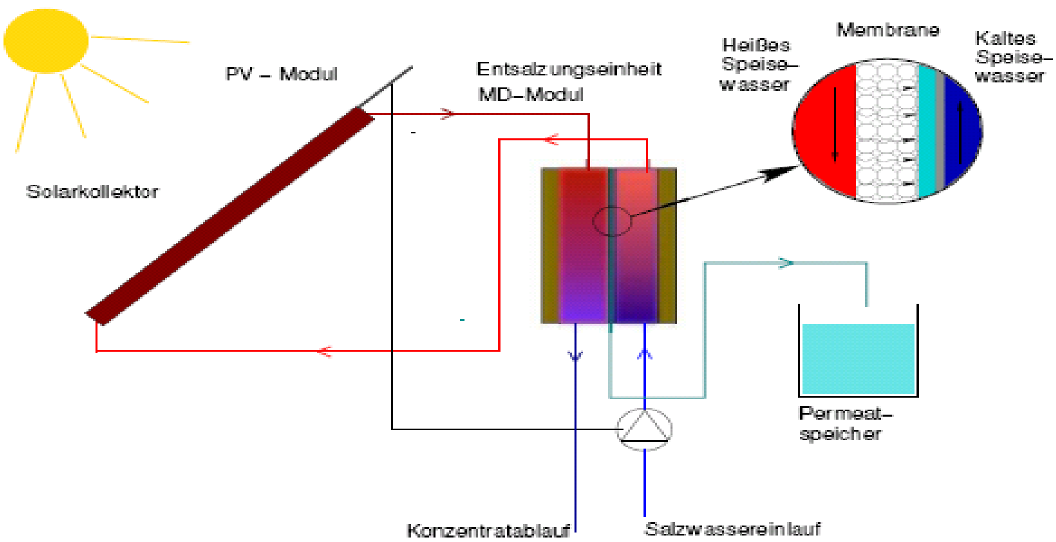


Figure 1.11. Membrane Distillation (MD) [22]

1.5.3 General Classification of solar still designs

The designs of solar stills are distinguished into 2 major categories i.e., Active and Passive stills altogether depending upon the process involved in the heat source used for the evaporation of saline water. Usually, solar heaters, Photovoltaic thermal hybrid solar collectors, and concentrators are used for this purpose. The classification of solar still is given in Figure 1.12.

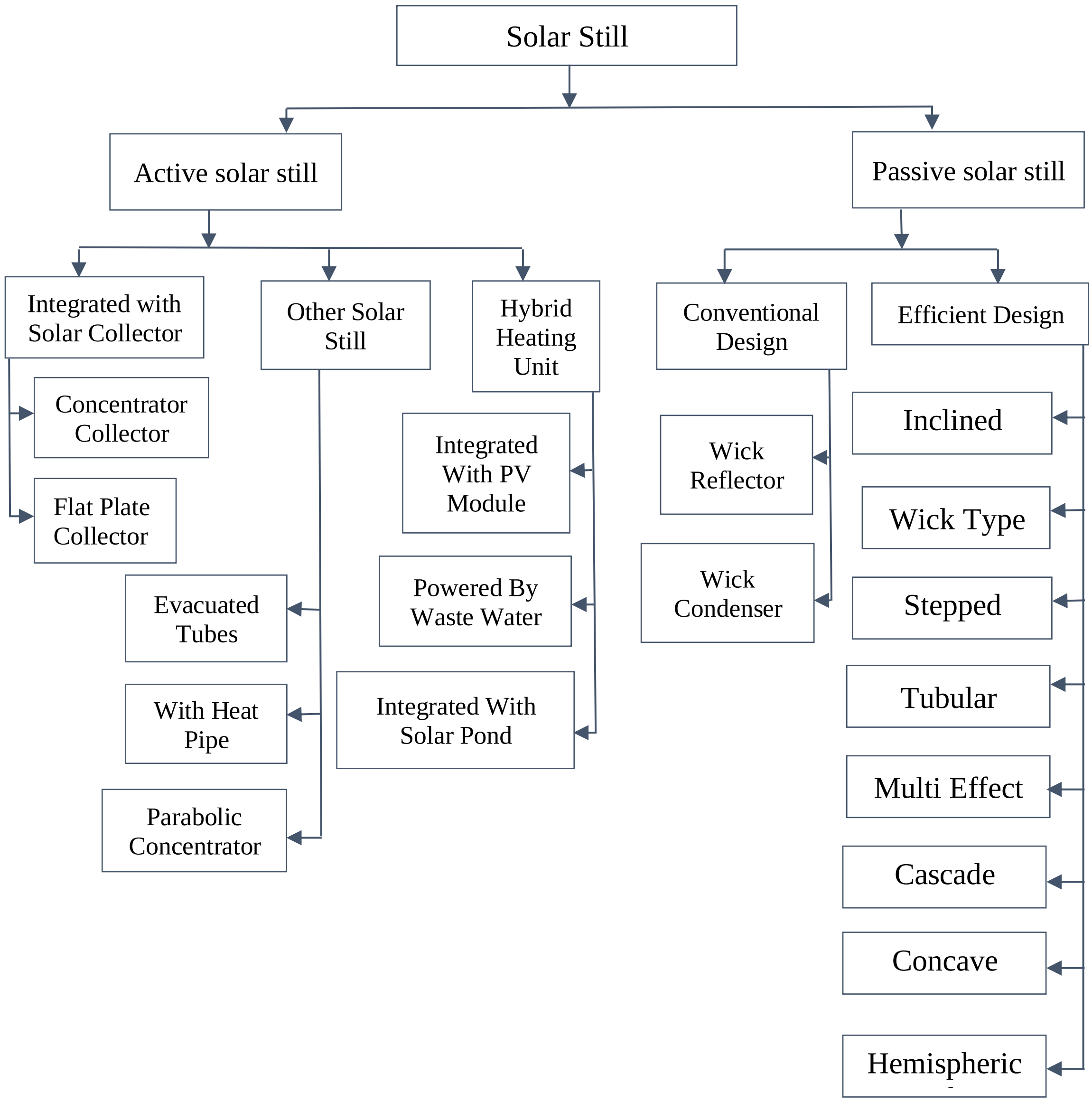


Figure 1.12. Classification of solar still [23]

1.5.4. Terminology used in solar still:

1. **Solar still:** A solar still is a piece of equipment that collects solar energy and then uses that energy to desalinate water. The process takes place within the solar still.
2. **Single basin:** The still in which a single tank is used to store brackish water, which after absorption of heat from solar rays gets converted into fresh water that still is known as a single basin solar still.
3. **Double basin:** A still in which two tank is used to store brackish water, which after absorption of heat from solar rays gets converted into fresh water that still is known as double basin solar still. In this still, one tank is placed on the lower

side known as the lower basin and another one is placed over that tank known as the upper basin.

4. **Single slope solar still:** Single slope solar stills are those in which there is just one sloped surface that is used to transfer solar rays in order to evaporate salty water and turn it into fresh water. These types of stills are referred to as single slope solar stills.
5. **Double slope solar still:** Double slope solar stills transfer sun rays to evaporate brackish water into fresh water.
6. **Productivity/ yield/ Output:** The fresh water obtained from still is measured, that measured quantity is known as productivity/ yield/ output.
7. **Effectiveness/ Competence/ Efficiency:** The ratio of fresh water obtained from still to the solar energy supplied to the brackish water is known as Effectiveness/ Competence/ Efficiency.

1.6 ORGANIZATION OF THE THESIS

- Chapter – 2 of the report deals with the literature review that has been carried out on the topic of the study. The problem statement is also defined in this chapter.
- A complete detail of the research methodology, design of experimentation, experimental set–up, experimental procedure, and data reduction techniques adopted is given in chapter 3.
- Results & discussion of the experimentation are presented and are discussed in chapter 4.
- Chapter 5 is the last chapter of the thesis and deals with the conclusion drawn from the analysis and scope for future work.

CHAPTER 2

LITERATURE REVIEW

Scientists had proposed the number of experiments using both active and passive methods for desalinating water using solar energy. The primary objective of this literature review is to provide a summary of previous investigations of this kind. The upcoming section is divided into four sub-sections.

1. The first section includes studies of the consequences of engrossing (absorbing) substances in the basin.
2. The second section presents a few literatures available on the consequences of reducing the temperature of the upper surface of the still
3. The third section illustrates how phase change material (PCM) affects still images
4. The fourth section is related to an economic analysis of solar still.

2.1 EFFECT OF ABSORBING MEDIUM IN THE BASIN

It is necessary to enhance the amount of heat transfer that occurs within the solar still in order to evaporate the water that is contained within the solar still. The next paragraphs will cover the many types of absorbent material that are employed.

2.1.1 Solar still with wick

Wick can be defined as porous solid material which is used to induce the capillary action of the liquid to reduce its vapor pressure. Due to reduction in vapor pressure, water evaporates at lower temperature. The different materials used as wick are jute fabric, woollen fabric, terry cotton, etc.

Kalidasa et al. [24] performed a dual-slant solar experimental analysis with specific energy-absorbing content. Light cotton fabric, sponge sheets, coir mate, and scraps of cotton are among the several energy-storing materials employed in experiments. Mild steel pieces are also used in the experiment. To increase productivity aluminium rectangular extended surfaces are used. On aluminium extended surfaces various covering materials are also placed and length wise and breadth wise studies were undertaken. From that, they found that light black cotton cloth is the most efficient absorbing material. The length wise arrangement of the aluminium fin covered with a cotton cloth is very efficient found.

Anburaj et al. [25] experimental research on tilted solar still with rectangular channels and edges on an absorber plate was carried out. The experimentation was undertaken in Tamil Nadu, India. For various inclinations (20^{o}, $30^{o,}$ and 35^{o}) the still was studied. On the absorber plate, several wick materials, including waste cotton bits, jute fabric, and black cotton textiles, are used. Likewise, for energy storage material mild steel pieces are used. Experimentation led them to discover that an inclination of thirty degrees, which yields 3.77 litres of water per day, is the optimal setting for output production. When utilised in its capacity as wick material, the black cotton fabric yielded a daily volume of 4.21 litres. The production of 4.27 l/day was achieved by including the pieces of mild steel as well as the clay pot.

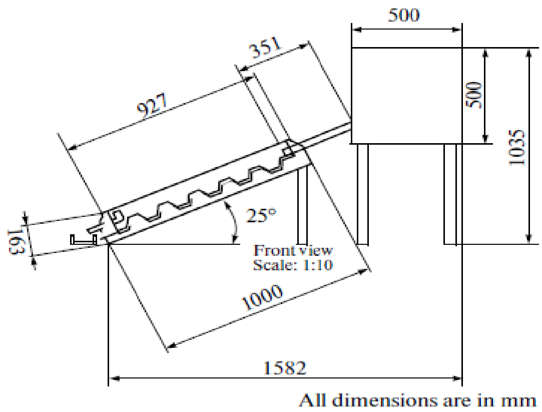


Figure 2.1. Diagram of tilted type solar still. Figure 2.2. Different basin materials used. [25]

Srivastava et al. [26] performed both theoretical and experimental research on a single-slope solar still equipped with a floating absorber surface. Black jute cloth is used as an absorber surface. The experimentation was carried out at Rewa, Madhya Pradesh, India. About 9 absorbers are floated on a surface of a water to cover a whole basin part. Some portion of jute cloth ate deep inside the basin water due to which capillary action takes place and jute cloth always remains wet. From experimentation, they found that 68 % higher yields were obtained during the pure day whereas 35 % was obtained when there was an overcast day. A 2 vertical mirror is placed above the improved still due to which 79% greater productivity was obtained from the improved still. In this improved still, there was no effect of water gravity in the still. So, this improved still is used at greater water gravity.

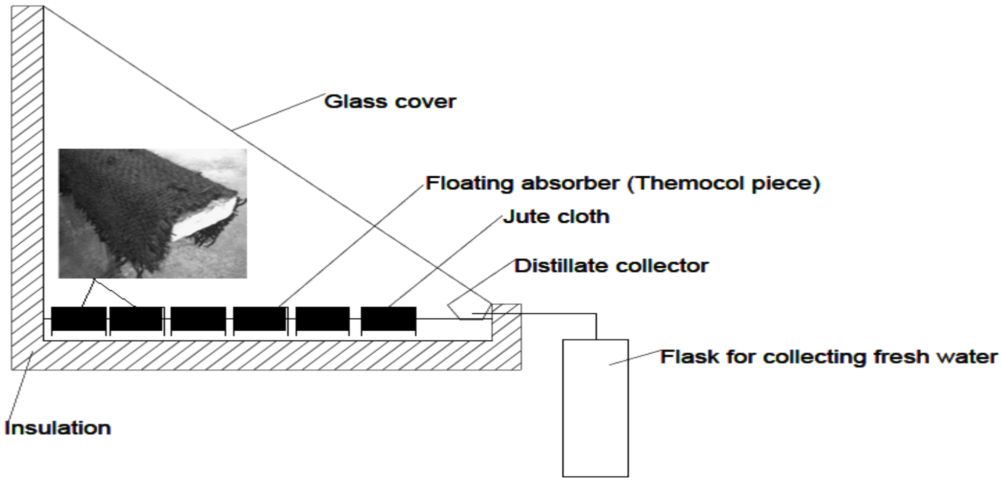


Figure 2.3 A Schematic diagram with modified solar still with blackened jute cloth [26]

Alaudeen et al. [27] did the experimental solar research using a tray-mounted stepped absorber plate and an inclined flat plate collector. The two basins were developed one was conventional and the other with a stepped absorber. The experimentation was done for different gravity of water inside the conventional still (2 cm, 3 cm, and 4 cm) while the same amount is kept inside the steeped type solar still (2 cm). Different wick materials such as rock, sand, wooden chips, sand, coal, and coconut coir were used also sponges are used to increase capillary action. The 1468 L/m^2 output were obtained for water gravity of 2 cm which was the highest output while 1150 L/m^2 were obtained for 4 cm water gravity which was the lowest. The 1305 L/m^2 were produced when the wick and sponge are used for 2 cm water gravity and 1280 L/m^2 were produced when the wick and sponge are used for 4 cm water gravity.

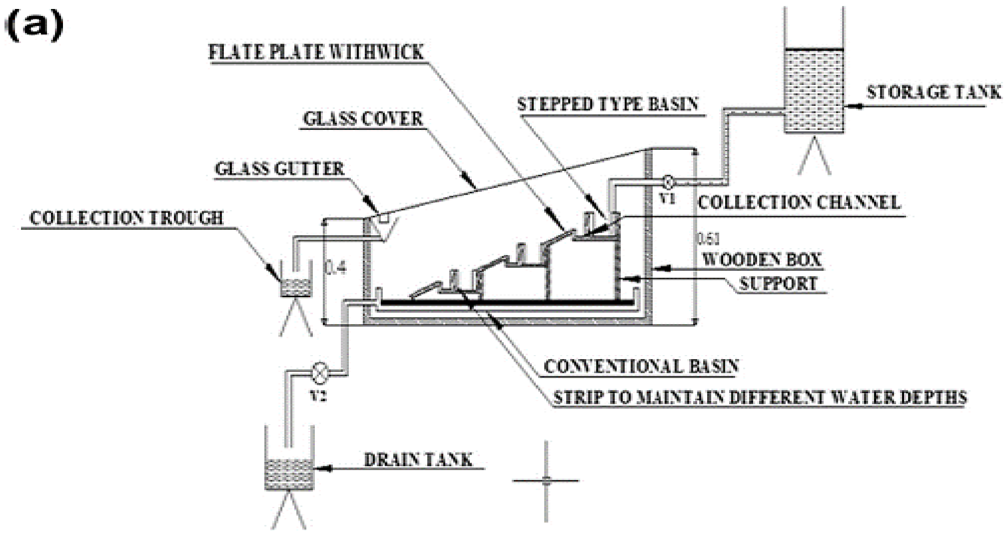


Figure 2.4. Sectional view of the stepped type solar still. [27]

Hansen et al. [28] by experimentation tested tilted solar still with a particular wick and absorber composition. Water coral hustle and timber tissue are taken as wick material in this polystyrene sponge experiment while four-sided stepped, flat platter, and cable web are taken as absorbers. The end result shows that the performance of water coral hustle with a stepped cable web absorber increases by 71.2 percent compared to a flat absorber and by 48.9 percent when water coral hustle with stepped wire mesh absorber increases compared to a step absorber.

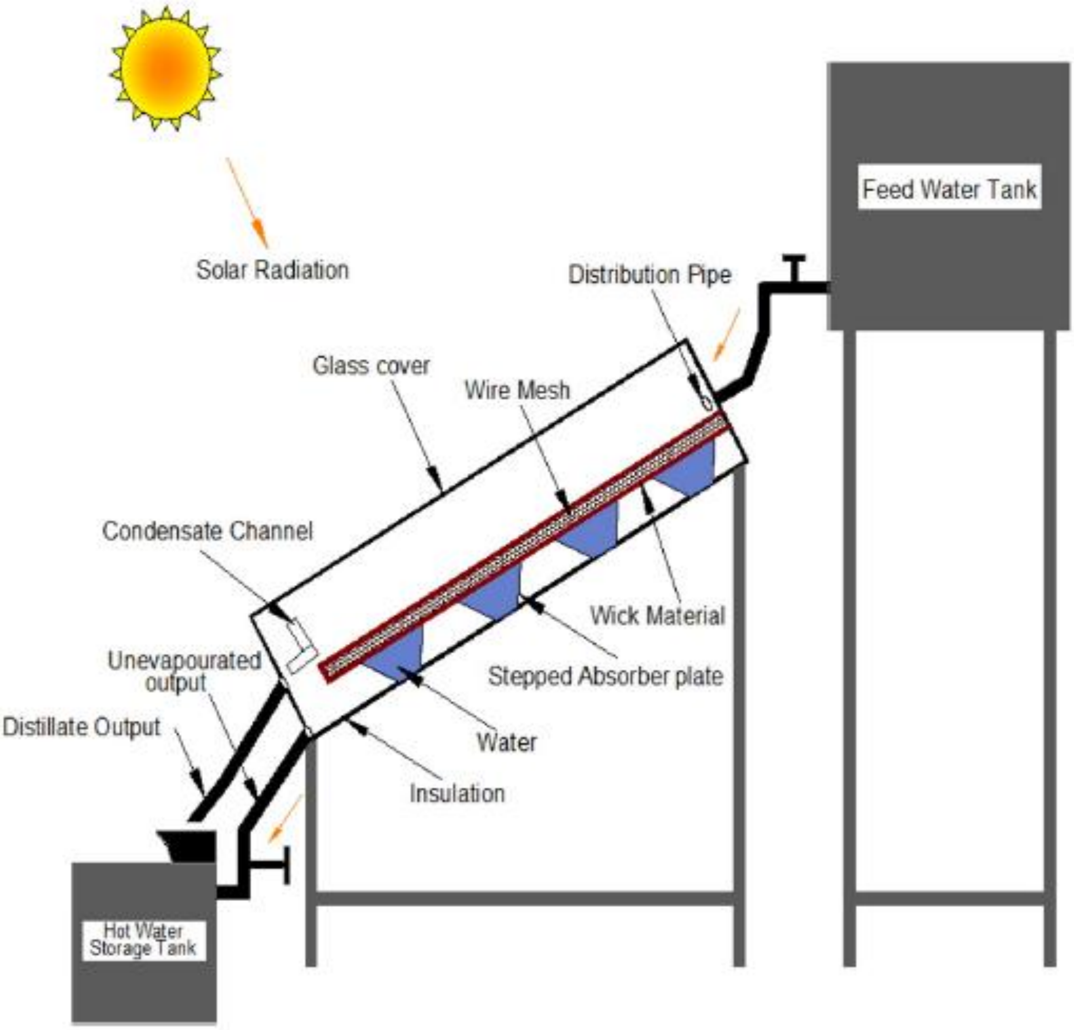


Figure 2.5. Demonstrating working of inclined type solar still. [28]

Omara et al. [29] performed the analysis on solar still in which wick and reflectors were used with a corrugated absorber. The conventional still was compared with the still in which a corrugated absorber, wick, and reflector was used. When compared to the typical method, the utilisation of a corrugated absorber resulted in a 55.36% increase in production. Also 90% output and 49.3% everyday competence increases as compared to conventional still when the wick material was placed over the corrugated absorber. When an interior reflecting surface is utilized with a corrugated absorber having wick material, the output and everyday competence is increased by 145.5% and 59% as compared to conventional still. The everyday competence obtained from conventional still was 33%.

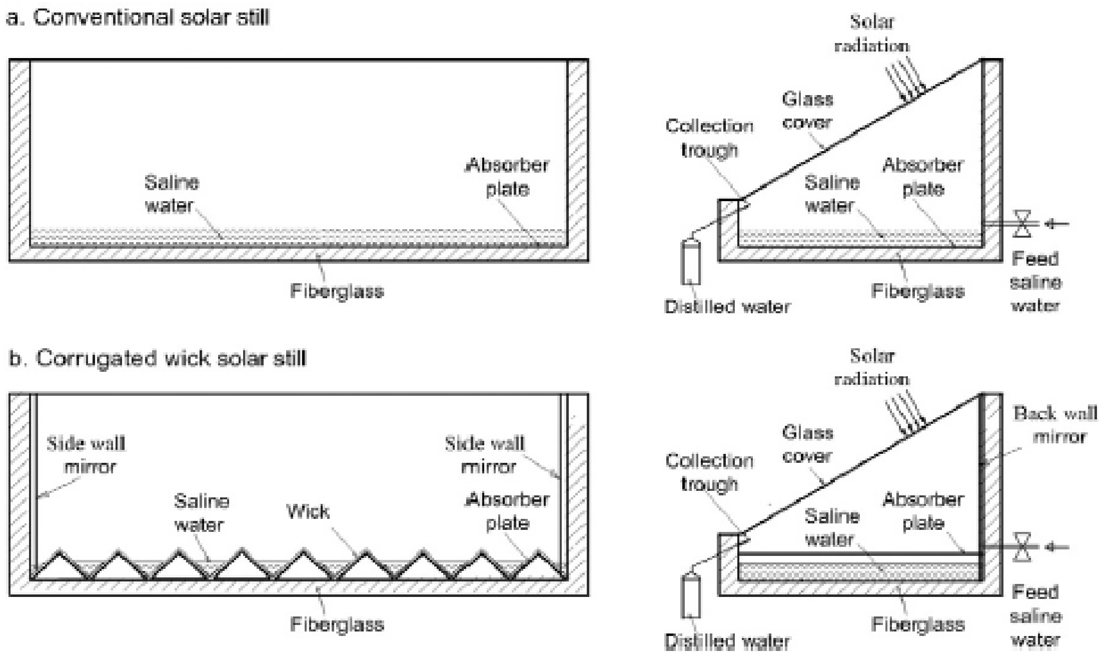


Figure 2.6 Cross-sectional view of solar stills. [29]

Agrawal et al. [30] experimentally and theoretically evaluated the performance of a single slope single basin solar still in which multiple "V-shaped floating wick" were applied as absorbers which were made up of thermocol as base and jute cloth was wrapped on that. The experiment was done in the city of Rewa for the period of summer and winter seasons. By using a V-shaped, the evaporative surface was increased by 26%. During experimentation when there was no cloud the distillation output obtained was nearly 6.20L/m^2 during springs and 3.23 L/m^2 in fall having a regular yield of 56.62% for springs and 47.75% for fall. Analytical results are compared with investigational one and established in very nearby i.e., less than 20% were found.

According to Table 2.1, jute cloth is the most used wick material followed by sponge, cotton fabric and wool. The maximum improvement in productivity is 85% for jute cloth while the lesser is for black cord fabric i.e., 12 percent.

Table: 2.1: Comparative study of different wick materials

Author	Year	Type of wick	Type of still	Increase in productivity (%)
Minasian et al. [61]	1995	Jute cloth	Single basin solar still	85
Kalidasa et al. [24]	2011	Jute fabric Coir mate Scrubber sheet Light black cotton fabric	Dual basin solar still	-
Anburaj et al. [25]	2013	Black cord fabric Jute fabric Cord chips	Tilted solar still	12
Srivastava et al. [26]	2013	Jute fabric	Single basin solar still	68
Rajaseeniva an et al. [62]	2013	Black cotton fabric Jute fabric Waste thread chips	Dual basin and single basin solar stills	85
Alaudeen et al. [27]	2014	Wooden chips Coconut coir	Conventional Solar still	16.36
Rajaseenivasan et al. [63]	2015	Black cord fabric Jute fabric	Dual basin solar still	-
Hansen et al. [28]	2015	Timber tissue Coral hustle Polystyrene	Tilted type solar still	71.2
Omara et al. [29]	2016	Double layer wick	Conventional Solar still	80
Agrawal et al. [30]	2019	V shaped floating wick (Black Jute)	Single-slope single-basin solar still	56.62
Saravanana et al. [64]	2020	Square shaped pyramid solar still	1. Polyester 2. Terry cotton 3. Jute cloth 4. Woollen fabric	33.1

2.1.2 Solar still with charcoal

Charcoal, also known as activated carbon, is a porous absorbent substance that is used to increase the amount of water that can be obtained from the distillation process.

Tris et al. [31] an experiment was carried out using a solar still of the basin type, combined with flat plate collectors that included various heat absorber materials. The various absorber material used in this experimentation were blackened rock-bed, charcoal, and black paint. After experimentation outcomes indicated that coupled of flat plate collector increases the output by 194% but there was 3 times increase in cost as compared to basin type. From different absorber materials, charcoal produces 11% to 18 % more than black paint and 23% to 92% more than blackened rock beds.

2.1.3 Solar still with baffles

Installing baffles on the absorber plate is yet another method that may be utilised to improve the quality of the distilled water.

Sathyamurthy et al. [32] The performance of a solar still with a semi-circular absorbers and baffles was experimentally investigated. Experiments were conducted in Chennai, India. An effectiveness of a solar still is affected by the quantity of barriers and the speed of the water flow. The 3 L/m^2 output and 38% competence of every day were obtained from still using a semi-circular absorber with baffles whereas 2 L/m^2 output and 32% competence were obtained when still was conventional. Distillate output as well as hot water was obtained from the present still. The temperature of the water coming from still was more when the baffle was used. The repayment time for the current still used in this experiment was less than associated with traditional still.

2.1.4 Solar still with gravels

Gravels, which are tiny stones, can be added to the solar still in order to boost the amount of sensible heat produced there. This is another strategy for increasing the output.

Shanmugan et al. [33] still conducting the analysis with sensible heat storage content on a single slope solar basin. White marble blocks, pebbles, black blocks, and iron scraps are some sensible energy storage materials used in experiments. The water which has to be distilled is supplied by a dripping arrangement. Due to greater specific heat capacity, calcium stones are best for sensible heat storage during the day and night time. The 43.67% total thermal competence were developed from this still.

Panchal et al. [34] examine the solar still that utilises blue metal stones and cow dung cake as the heat storing material. The state of Gujrat in India was the location of the experiments. Three sun stills of comparable design were constructed for the purpose of conducting an experiment. The first solar still was filled with blue metal stone, the second solar still was filled with cow dung cake, and the third solar still was a typical design (only blue paint at the base). In solar still having blue metal stones produces 35% more distillation yield as compared to conventional still. Similarly, solar still having cow dung cakes produces 20% more distillation yield as compared to conventional still. This led to the discovery that blue metal stones can store more heat than cow dung cake.

Velmurugan et al. [35] experiment was carried out on a solar still with a double slope and a single basin, heat storage material was utilised, and an external reflector was installed in order to increase the yield of the still. For that, they made the 3 still with similar dimension such as traditional still, containing warmth storage material and still with an exterior mirror. During experimentation, they compared the above mentioned 3 still and found that the still in which the reflector was utilize produces higher water temperature as well as distillate output during sunlight time but during decreasing sunlight time the still carrying heat storage material has maintain elevated temperature of the water as well as distillate output. The competence improvement for still having reflector is 62.97 percent higher than traditional but similarly still with warmth packing content has 23.08 percent more performance that of traditional still.

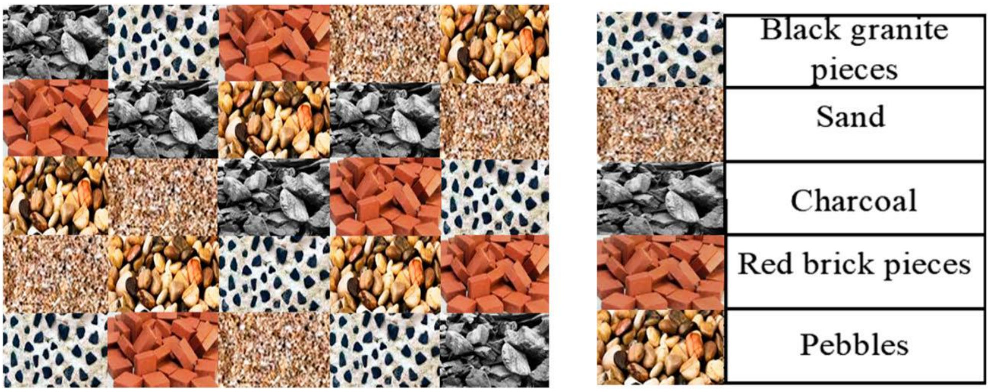


Figure 2.7. Schematic diagram for aligning of heat storage materials in the basin [35]

Nasri et al. [36] carried out an experiment on a solar still using a number of different absorber materials, including sand, gravel, and polyethylene. The geometry for the same was represented by figure 4. For the experiment the accumulating area used was $0.25m^2$. The experiment was done in the southern region of Algeria and the performance were compared for different absorber material. From the experiment they found that when gravel was used as an absorber it produces 5 L/m^2 of fresh water after that black polyethylene absorber produces 4.48 L/m^2/day and lastly sand absorber produces 3.84 L per m^2 per day of fresh water. As compared to sand, gravel produces 32.20% and black polyethylene produces 16.67% from this it was established that gravel has been found to be the best absorber and has maximum yield as differentiated with respect to another absorber. The effectiveness of the present still was nearly about 99.30 %.

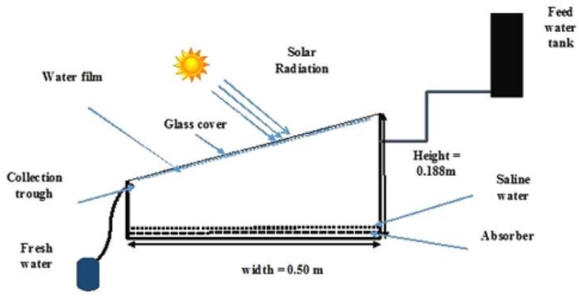


Figure 2.8. Photograph view of different absorbers. [36] Figure 2.9. Cross sectional view of the solar still. [36]

Table 2.2: Comparative study of different gravels

Author	Year	Type of gravels	Type of still	Increase in productivity (%)
Sakthivel et al. [68]	2008	Black sandstone chippings	Single basin solar still	52
Shanmugan et al. [33]	2012	White limestone Stepping stones Pebble Dark gravels Calcium chippings	Single basin solar Still	43.67
Panchal et al. [34]	2015	Blue metal stones and Cow dung cakes	Conventional solar still	35
Velmurugan et al. [35]	2019	Black granite pieces Sand Charcoal Red brick pieces Small rock	Single basin double slope solar stills	23.08
Nasri et al. [36]	2019	Gravel Black Polyethylene Sand	Conventional Solar still	99.30

2.1.5 Solar still with sponges

Sponges, organic polymer compound in the foam form, in the various shapes (cubical, pyramid, etc.) used to augment the capillary action of water and to increase the wetted surface area in the solar still due to their higher porosity.

Abdallah et al. [37] a solar still with a single slope was used to investigate the impact of a variety of absorbing materials. In this experiment "coated and uncoated porous media and black volcanic rocks" are used as heat storage material. For experimentation 4 different solar still of the same size were designed out of which 1 still contain the coated sponge, 2 still contains the uncoated porous sponge, 3 still contain the black volcanic rocks and the last was conventional still. The 28% total output was found from still having a coated sponge, while still having an uncoated sponge produces 43% total output. The highest total output was obtained from still having black volcanic rock and i.e., 60%.

Harris et al. [38] studied energy storage material having low cost in conventional still for rising the content of fresh water. For the experiment, sponges and salt balls with spherical shape are used as energy storage equipment. The 3.7 L/m^2 everyday output was obtained from still having a salt ball as energy storage material whereas 2.4 L/m^2 was obtained from still having sponges as energy storage material whereas 2.6 L per m^2 from single slope solar still. After every 14 days, the sponges have to be changed because the salts are sucked within the sponge's holes and the capillary action doesn't take place properly. The cost of water is maintained at a very low level even when spherical ball heat storage is used in single slope solar.

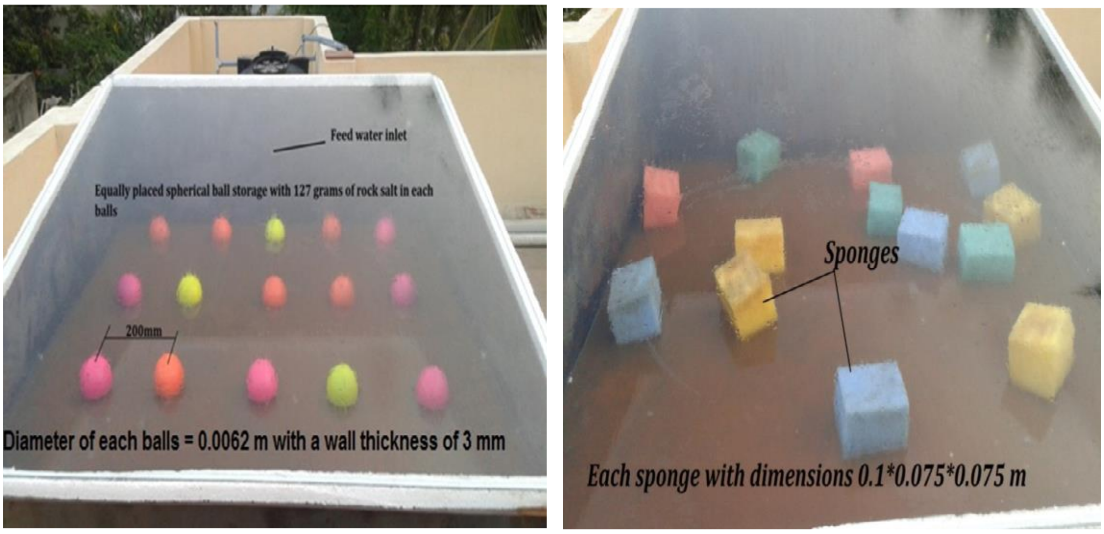


Figure 2.10. An Experimental setup of a conventional solar still with spherical ball salt heat storage and sponges. [38]

2.1.6 Solar still with sand

Sand is a granular material that is made up of very small particles of several minerals. Sand may be distinguished from one another not by its composition but by the size of its grains. Sand is grittier than silt and has granules that are more uniform in size than gravel. As a result of its great capacity for absorbing heat, it is frequently utilised as the absorbing medium in solar stills.

Sebaii et al. [39] sand is used as a heat absorber in a single sloped solar still that was calculated experimentally. A scientific model was created to test stills with and without storage substance. The 4.005L/m^2 per day output was obtained from still having 10kg of sand as heat storage with a competence of 37.8%, while 2.852L/m^2 per day was obtained from still without heat storage material with a competence of 27%. The overall yearly competence was 23.8% more in still having warmth storage material as associated with the still without warmth storage material.

2.1.7 Solar still with fins

Increasing the absorber's surface area improves the solar still's heat transmission area. Fins on the absorber plate improved solar still performance in a simple and effective way.

Omara et al. [40] experimentation was done on solar stills with both finned and corrugated absorber plate surfaces, and the results were analysed. For experimentation 3 still are developed. One was conventional still, the second was finned as an absorber surface and the third was a corrugated absorber surface. Results obtained from the second and third stills are compared with the conventional still. For 50 mm water gravity under still and 30 L & 50 L amount of water, the experiment was undertaken. From the results, they find that, relative to traditional still, more yield is obtained in finned and corrugated. For 30L of saline water, 40 % more yield was obtained for finned type solar still and 21 % more yield was obtained for corrugated still. 47.5% competence were obtained for finned still, 41 % competence were obtained for corrugated still and 35 % competence were obtained for conventional solar still.

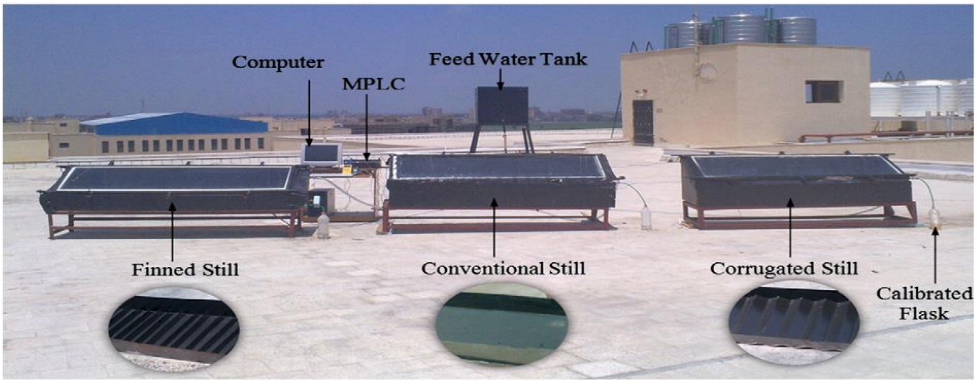
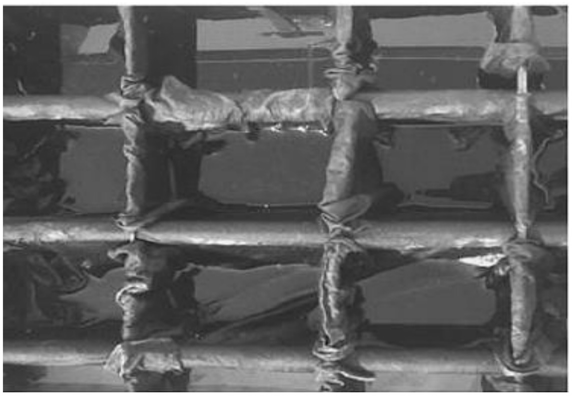


Figure 2.11. Schematic view of absorbing materials in the solar still. [40]

Agrawal et al. [41] single slope solar experimental study with an extended porous surface between winter and summer seasons. Old cotton rags that have been blackened and used for testing are used to create a porous extended surface that is submerged in the bathwater just partly. They found that improved still gives 56% more productivity during day time and 48 % more during 24 hours as compared to conventional still for February month. Similarly, 23 % more productivity during day time and 15 % more during 24 hours as compared to conventional still for may month. A 7.5L/m^2 output were obtained from this improved still during the month of May which was the maximum. The yield of still becomes lowers as the water gravity within the basin rises.



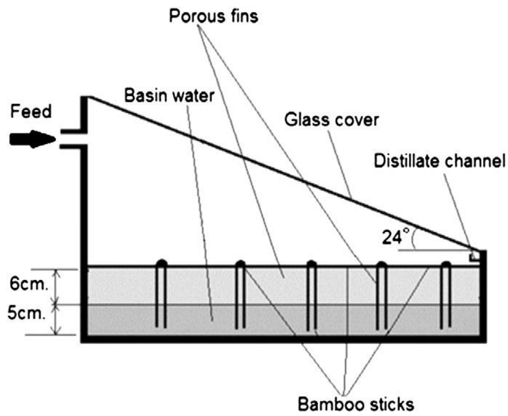
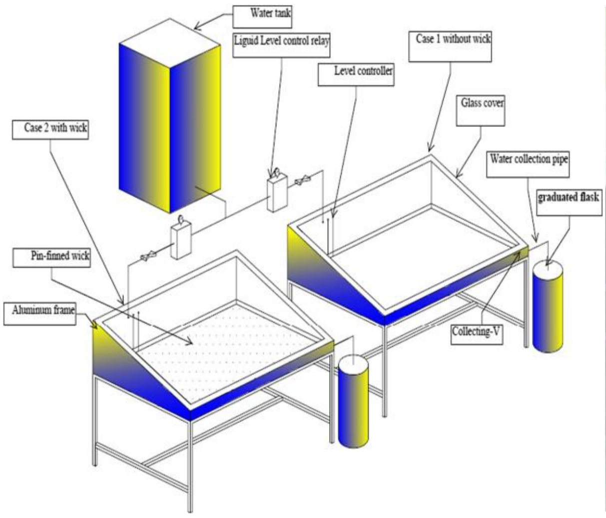


Figure 2.12. Photograph of the porous fins. [41]   Figure 2.13. Photograph of the porous fins [41]

Alaian et al. [42] experimented with employing pin-finned wick as an absorber to study the effects of solar still. Two types of stills were constructed in order to carry out the experimentation: one was a conventional still, and the other was a pin-finned absorber. A competency of 55 percent is achieved in the still by employing the pin-finned wick. During experimentation, 23% more productivity was obtained when this system was used. A number of additional measurements, such as the temperature of a glass surface or the temperature of the water, are also taken into consideration. The amount of distillate produced adjusts in accordance with the variation in the ambient temperature.



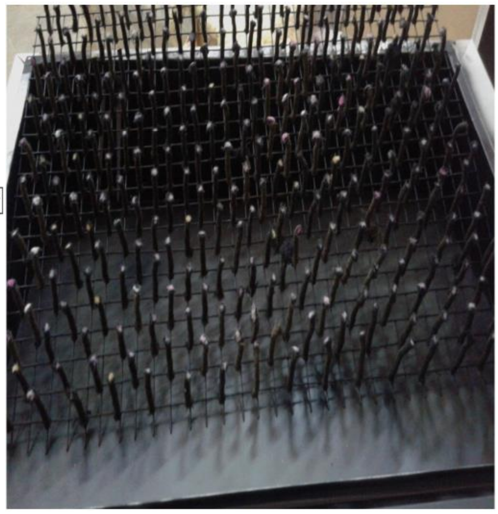


Figure 2.14. Schematic of the experimental test unit. [42] Figure 2.15. Pin-finned wick elements. [42]

Gnanaraj et al. [43] conducted the experiment on single basin double slope solar still for improving the productivity of distillate fresh water for that some internal and external modification has been done. For the period from March to May 2018, this experiment was undertaken in Villianur, Pondicherry. The internal modification which done was still coupled with corrugated finned, still enclosed with black granite for heat storage, and stilled with wick material similarly external modification was done by incorporating reflectors. One basin is made by utilizing all the above modifications. After experimentation, they found that during the day time basin with a reflector and corrugated finned has speedy growth of water temperature. Although still with black granite has greater water temperature during evening and night time. Conventional still produces 1.88L/m^2-day of distilled output, similarly, corrugated fin still produces 2.995 L/m^2-day, black granite still produces 3.21L/m^2-day, still having wick material produces 2.69 L/m^2-day, still in which reflector was incorporated produces 3.655L/m^2-day and the still in which all the internal and external modification were done produces 5.13L/m^2-day. When all the modification was used the efficiency of that still were 171.43% higher than that of conventional still followed by 93.93% for still having reflector after that 69.84% for black granite still, still with corrugated fins has 58.47% and still in which wick material was used had 42.33%.

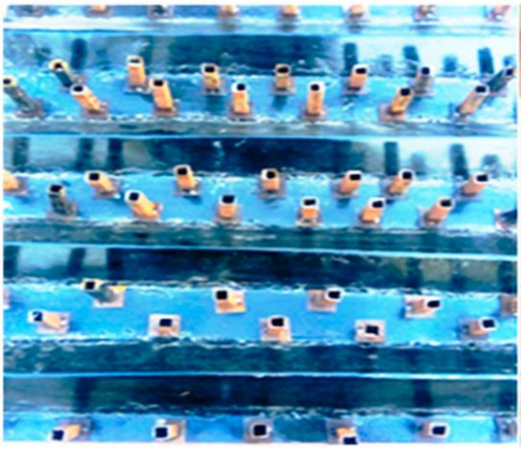
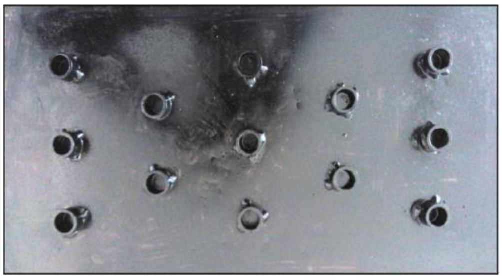


Figure 2.16. Finned Corrugated basin. [43]   Figure 2.17. Black cotton wrapped fin. [43]

Jania et al. [44] the experiment was carried out on a solar still with a double slope and a single basin. The absorbers for the experiment were fins with hollow circular and square cross section area fins. The experiment was performed in the Valsad city, Gujarat, India. In this experiment, square hollow fin (20mm height, 25mm side length, and 2mm thick) and circular fin (20mm length, 25mm diameter, and 2mm thick) and is joined on mild steel plate (300mm×600mm×2 mm) and uses as an absorber for water desalination. The depth of water was varied i.e., 10 mm, 20 mm, and 30 mm were used for both an absorber plates. From that, they found that when the circular fin was used as an absorber the distilled output obtained were 54.22 % for 10 mm, 38.49 % for 20 mm, and 43.86 % for 30 mm water depth as weighed up against a square fin absorber. The everyday yield for circular fin was 26.86% for 10 mm, 19.52 % for 20 mm, and 25.32 % for 30 mm depth of water were achieved. Circular fin having 10 mm water depth produces 1.4917 L/m^2-day distilled output and a square fin having 10mm water depth produces 0.9672 L/m^2-day distilled output. From this, it indicates that as the depth of water was less the productivity was more.



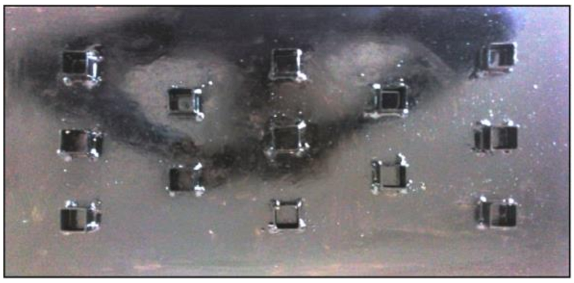


Figure 2.18. Circular finned absorber plate of mild steel. [44] Figure 2.19. Square finned absorber plate of mild steel. [44]

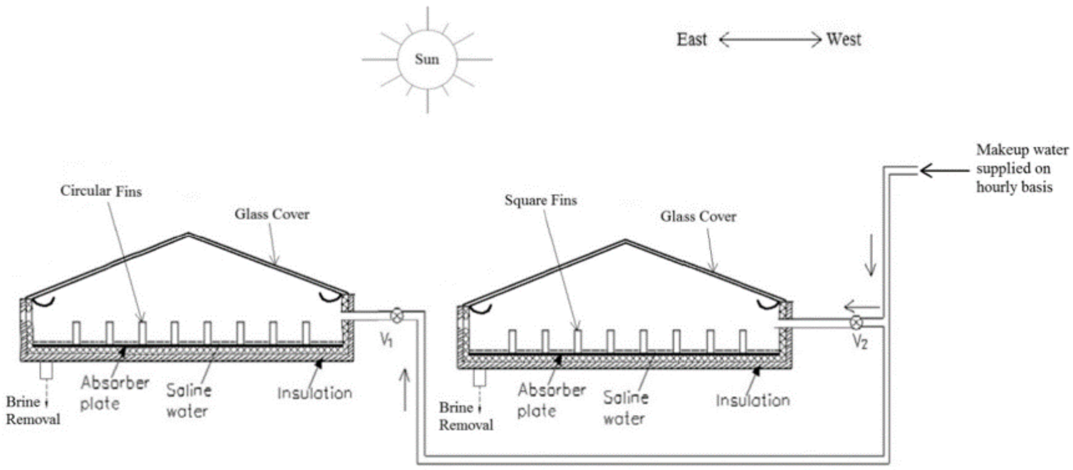


Figure 2.20. Schematic diagram for the layout of experimental setup. [44]

Khaled et al [45] study was carried out, both theoretically and experimentally, on solar stills that had inside mirrors and fins. The experimentation was performed in Jordan. From model results, they found that when the interior mirror was placed on the south, east, and west side the competence was increased by 13 % in June, 20 % in April, 28% in September, 33 % in October, 37 % in January, and 46 % in December. While the average monthly competence increases by 29.1% and output were increased by 3.014 L/day·m^2. From experimentation, they also found that if fin were added alone there was no change in output but if they added with an interior mirror both output and competence were increased tremendously.

2.1.8 Solar still with Nano particles:

Nanoparticles are solid particles having the diameter in the range of 1 – 100 nm. They have been utilised during the previous two decades, and they are surely a novel approach among other methods, in order to increase the performance of solar stills in terms of the amount of fresh water they produce. The capacity of nanoparticles to provide the needed thermo-physical qualities, which may be accomplished by varying the particle size, shape, and concentration, has awarded them with a place as one of the primary research foci in the solar still.

Kabeel et al. [46] experimental analysis of solar still integrating exterior condensers and nano fluids was carried out. The experimentation was performed in Kafrelsheikh city, Egypt. The vaporization and condensation amounts increase with the use of fan. During the daytime when fan was operating at the speed of 1350 rpm a yield was augmented by 53.22 % as associated to the conventional still. In a similar vein, the production was raised by 50.24 percent when the fan was operating at the same speed between the hours of 11 am and 3 pm in comparison to a traditional still. When nano fluids are used with an exterior fan the output of still were increased by 116 % and when nano fluid are used without the external fan the output were increased by 76 %. This shows that nano fluids increased the productivity of still.

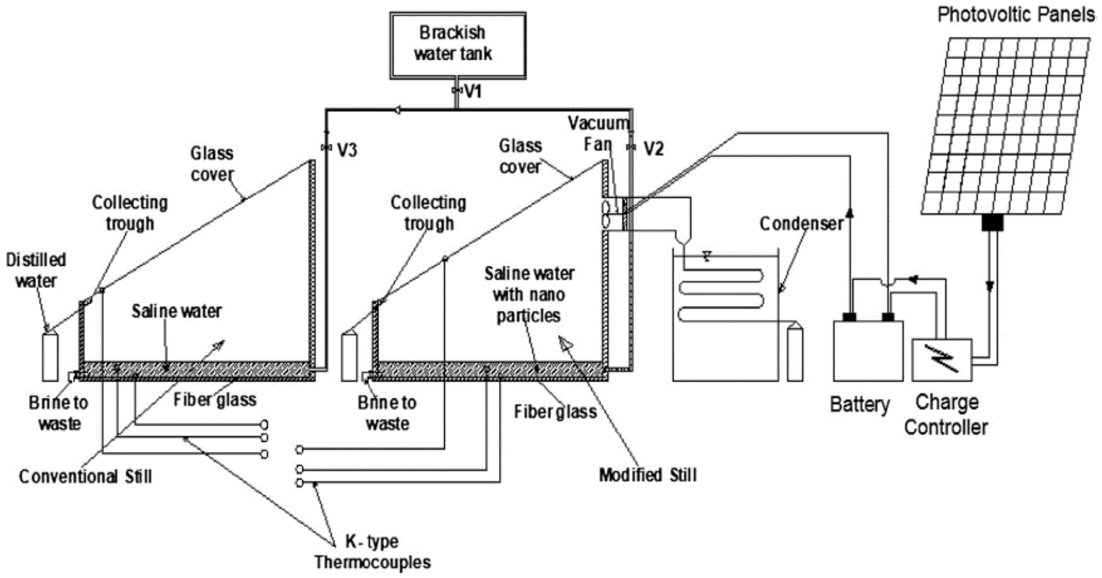


Figure 2.21. Schematic diagram of the experimental setup. [46]

Kabeel et al. [47] performed the traditional solar experimental investigation which was still adjusted by nanoparticles and equipped with vacuum. The nanoparticles used in the study are copper oxide and aluminium oxide. Experimentation was done for different mass concentration of nanoparticles which varies from 0.02% - 0.2 % at a period of 0.02%. They found that when copper oxide is used as nanoparticles with fan to provide a vacuum the efficiency obtained were 133.64% and when vacuum fan are not used the efficiency obtained were 93.87 % more as compared to conventional still. Similarly, when aluminium oxide is used as nanoparticles with fan for vacuum, the efficiency obtained were 125 % and when fan has not used the efficiency obtained was 88.97 % more as compared to conventional still. This indicates that copper oxide increases productivity.

Elango et al. [48] comparative research on a single basin single solar slope also performed with separate nanoparticles. Nanoparticles of "Aluminium Oxide, Zinc Oxide, and Tin Oxide" are being utilised for the purpose of comparison in this investigation. For doing experimentation 2 similar size still were developed in which one still has only plain water while the other is having nanoparticles. From experimentation, they found that 29.95% more output were obtained when Aluminium oxide is used as nanoparticles as compared to plain water. Similarly, when Tin oxide were used as nanoparticles the output obtained was 18.63% more than plain water and for Zinc oxide, 12.67% more output was obtained. Due to its greater thermal conductivity than other nanoparticles, aluminium absorbs more radiation, increasing the temperature differential between seawater and glass covers. This shows that thermal conductivity plays an important role in distillate output in still. The 2.8 years were required for repayment when nanoparticles are used, which were much lesser than plain water.

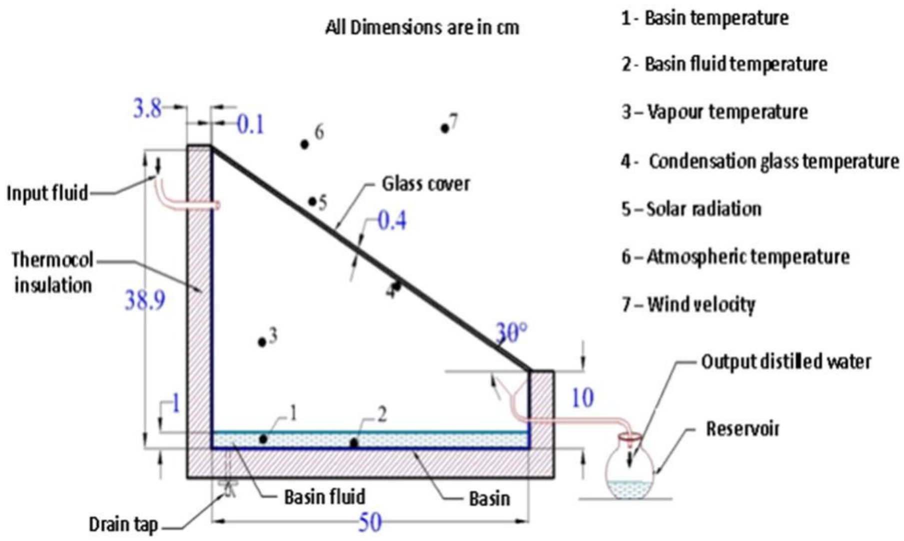


Figure 2.22. Schematic diagram of single basin single slope solar still. [48]

Sahota et al. [49] a consequence of the solar nanoparticles still having a double slope were studied. Al_2O_3 were used as nanoparticles in the experiment. The 3 different centralizations of nanoparticles were used in this study. The 30kg and 80kg mass of water was used for doing experimentation. For liquid, the logical utterance was designed for the given studied. The results were compared for still having nanoparticles and without nanoparticles. In comparison to the situation when nanoparticles were not present, the yield increased to 12.2% for 35 kg of water and 8.4% for 80 kg of water when 0.12% of Al_2O_3 was employed.

Modi et al. [50] examined a solar still with a single slope and a double basin, performing side-by-side comparisons with and without nanoparticles. An experimentation was done in Gujrat, India. For doing experimental work two still was made of the same size. During experimentation, the mass of nanoparticles Al_2O_3 was varied i.e., 0.01%, 0.05%, 0.10% & 0.20%. The efficiency of still were increased by the use of nanoparticles as compared to without nanoparticles. The distilled output for mass 0.01% of Al_2O_3 gets 17.6%, for 0.05% gets 12.3%, for 0.10% gets 7.2% and for 0.20% gets 2.6% as compared to still without nanoparticles. It was observed that with the increase in particle concentration of Al_2O_3, a decrement in the efficiency of still has occurred.

Sathyamurthy et al., [51] experimentation and study were carried out employing fumed silica nanoparticles in black paint for the stepwise solar still layers. The concentration of nanoparticles varies from 10-40% and it is found that when the concentration of nanoparticles increased from 20% there is no effect on the output. Throughout the course of the investigation, it was discovered that increasing the concentration of the nanoparticles to 10% resulted in a 27.2% increase in production in comparison to using regular black paint. In a similar manner, the output was boosted by 34.2%, 18.3%, and 18.4% correspondingly when 20%, 30%, and 40% concentrations of nanoparticles were utilised in comparison to regular black paint.

Panchal et al., [52] nanoparticles were used in the experimental research that was carried out on the stepped solar still. The Magnesium oxide and Titanium oxide of different concentration was used for experimentation. The range of nanoparticles concentration used for experimentation was 0.1% to 0.2%. From the results it was found that for magnesium oxide with 0.1% concentration, 33.33% more fresh water was obtained, whereas for 0.2% concentration 45.38% was obtained. Similarly for Titanium oxide with 0.1% concentration 4.1% fresh water was produced and for 0.2% concentration, 20.4% was produced. In comparison to titanium oxide, magnesium oxide has a higher thermal conductivity and a lower specific heat capacity, both of which contribute to a larger production of fresh water from a still.

2.1.9 Solar still with Evacuated tube

The Evacuated or Vacuum tubes are used in a number of rows of parallel transparent glass tubes, through which the water circulates and absorb heat generated by tubes. Due to cylindrical shape, sunlight is always perpendicular to the evacuated tubes and performed well in the low intensity of sunlight, in the morning or late in the afternoon, or when shaded by clouds.

ShivKumar et al. [53] an investigation into the theoretical workings of a single solar slope still that was combined with vacuum tube and forced mode functions was carried out. For 0.006 kg/s quantity movement of water, 3.47 L of everyday output was obtained from the still when the gravity of the water in the still were 0.01 m. But the best output was found when the quantity of movement is 0.006 kg per sec having gravity of water in still was 0.03 m. The 3.9 L of everyday output was obtained with 33.8 % energy competence and 2.6 % exergy competence. They also found that more output was obtained in forced mode as compared to natural mode.

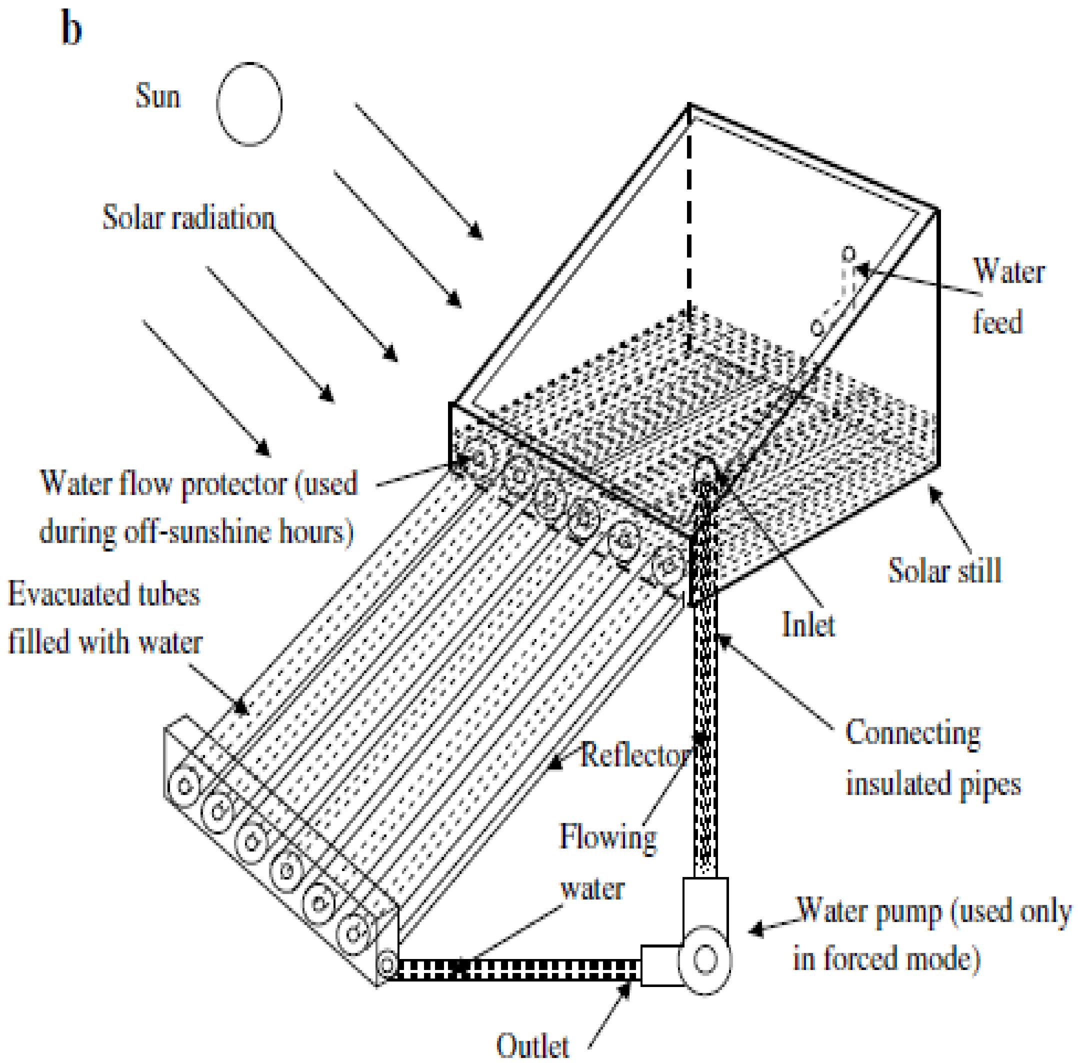


Figure 2.23. An Illustration of EISS solar still in forced mode. [53]

Panchal et al. [54] experimentation with a vacuum tube and a double basin single slope solar still. In this experiment, black granite gravel was also used. The experimentation was done in Gujarat, India. The experiment makes use of four distinct styles of dual basin stills: a straightforward dual basin still, a dual basin still that incorporates a vacuum tube, a dual basin still that makes use of black granite gravel, and a dual basin still that combines all three of these design elements. They discovered that still's vacuum tube coupling enhanced competences by 56%, while the still's vacuum tube coupling and the presence of black granite gravel increased competences by 65%. After experimentation, they said that vacuum tube augmentation was very efficient as compared to other passive augmentation techniques. According to financial examination, 195 days were required to repay the cost of the product.

Figure 2.24. Photograph of experimental setup. [54]

Panchal et al. [55] have tested double basin solar stills with evacuated tubes and solid fins. The 2cm water-filled 3cm mild steel extended surface is utilised for experiments. In March 2018, a double basin solar still connected with an evacuated tube was tested. In April 2018, a solid-extended tube was tested. They observed that a double basin solar still combined with an evacuated tube with an enlarged surface yielded 25% more fresh water than one without. This method boosted daytime and off-set yield.

Badran et al. [56] experimented with a pyramid roof solar still, evacuated tube, and flat plate collector. Evacuated tube vs. flat plate collector. This experiment delivered hot water to the solar still by connecting the outlet side of an evacuated tube and flat plate collector to the intake side. A flat plate collector augmentation produces 2.485L of fresh water as differentiated to conventional still which was higher than 7.62%, similarly evacuated tube augmentation produces 2.615L of fresh water as differentiated to conventional still which was higher than 13.25%. From this, it was clear that evacuated tube augmentation had higher efficiency than “flat plate collector” augmentation and traditional still.

Figure 2.25. Experimental setup of the project [56]

Panchal et al. [57] carried out the test using a single basin passive solar still that was linked with a vacuum tube. The experiment was carried out in the Indian state of Gujrat between the months of July 2011 and June 2012 inclusively. During this time span, they discovered that a solar still equipped with a vacuum tube produced 4.994 L of distillate, which was 97.6% more than what could be gotten from a conventional still. It was also determined that the vacuum tube augmentation approach was more effective than other passive ways such as the application of flat plate collectors, parabolic collectors, and solar ponds. This was one of the conclusions that was reached as a result of the research that was conducted.

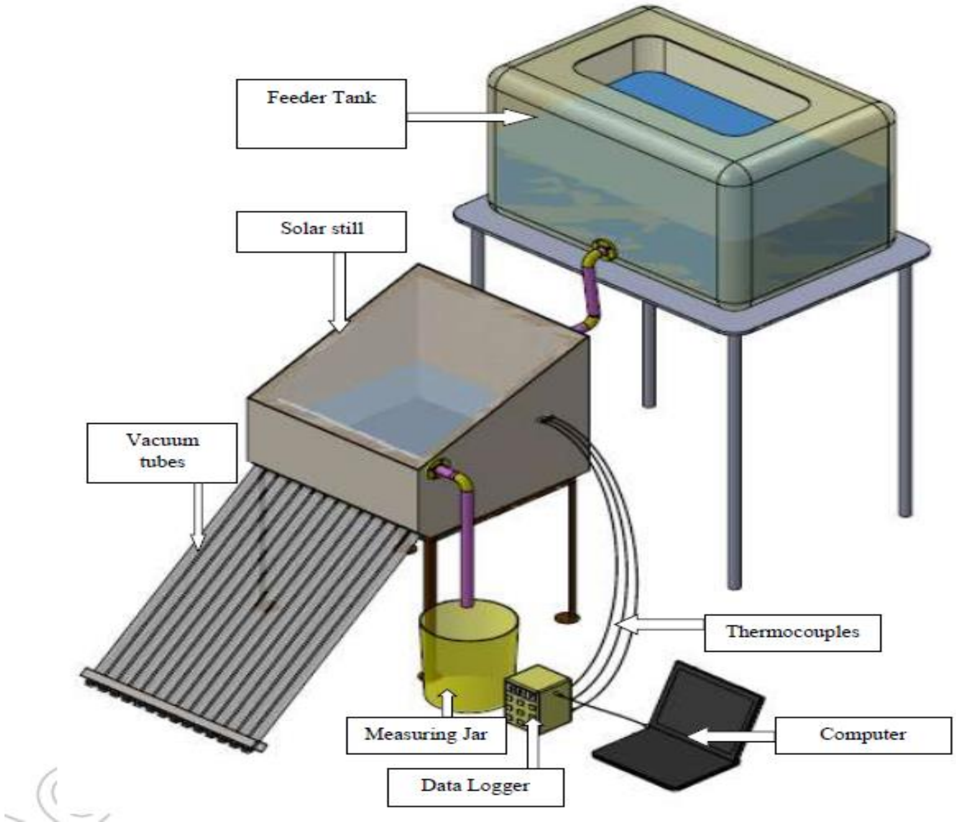


Figure 2.26. Schematic arrangement of single basin passive solar still with vacuum tubes [57]

Shehata et al. [58] investigated on a single slope solar system with an ultrasonic humidifier and evacuated solar collector. Egypt was the location of the testing. They created a model with a 1 m × 1 m dimension for experiments. To increase the vaporisation capacity, 6 ultrasonic humidifiers were utilized. The ultrasonic humidifier gets the power from a solar panel having a capacity of 280 W. for supplying hot water to the still, evacuated solar collector were attached in the experiment. Experimentation was done for 3 months of summer having the identical climatic conditions. Phase change materials were used in 4 different cases in the experiment: solar stills with phase change materials, ultrasonic humidifiers, and phase change materials, evacuated solar collectors and phase change materials, and solar stills with phase change materials, evacuated solar collectors, and ultrasonic humidifiers. After experimentation, they found that when the height of the water was 25 mm in the basin the everyday yield obtained were 5.34 L per day for still with phase change material and when the height was 35 mm the everyday yield obtained were 7.4 liters per day for a still with an ultrasonic humidifier and an evacuated solar collector. The daily production was increased by 25% for a water height of 25 mm and 44% for a water height of 35 mm in the basin by employing an ultrasonic humidifier in conjunction with an evacuated solar collector.

Patel et al. [59] performed a series of experiments on a solar still equipped with three basins, a vacuum heat pipe, a corrugated sheet serving the function of an absorber, and a sensible heat storage medium. Experiments used granite and pebbles as heat storage materials because of their high density. The experiment was carried out in three distinct settings: a conventional triple basin sun still; a triple basin solar still including pebbles; and a triple basin solar still containing granite. Typical triple basin sun still as compared to a conventional triple basin sun still, the triple basin solar still that used granite to collect the sun's rays generated 180% more distillate, whilst the triple basin solar still that used pebbles to collect the sun's rays produced 169% more distillate. Distillate was generated at a rate of 17.5 kg/m^2/day by the standard triple basin sun still with vacuum heat pipe and pebbles, while the traditional solar still with vacuum heat pipe and granite produced 19.0 kg/m^2/day.

Panchal et al [60] experimentation and study were carried out on a solar still equipped with vacuum tubes and calcium stones as the sensible heat storage medium. The experiment was performed in the Gujarat, India. For experimentation $1m^2$ area of a basin with fourteen vacuum tubes were used. For the purpose of conducting experiments, three distinct types of stills were constructed: the first was a traditional solar still, the second was a traditional solar still with vacuum tubes, and the third was a traditional solar still with vacuum tubes and calcium stones. For performing experimentation ground water were used. From experimentation, they found that when traditional solar still with vacuum tubes were used 5.09 L yield were obtained and when traditional solar still with vacuum tubes and calcium stones 5.31 L were found. After comparison, they found that 113.52 % yield were increased when traditional solar still with vacuum tubes were used as compared to traditional still and 104.68 % were increased when traditional solar still with vacuum tubes and calcium stones as compared to traditional still. The amount of time needed to recoup costs was calculated to be 237 days for standard solar stills that use vacuum tubes.

Table 2.3: Comparative study of different absorbing material

Author(s) and experiment location	Year	Still Type	Absorbers used	Findings
Minasian et al. [61], India	1995	Single basin solar still	Wick	When wick type solar still coupled with conventional solar still produces 85 percent more output over traditional solar still whereas 45 percent more output was developed from wick type solar still coupled with conventional solar still over to only wick type solar still.
Kalidasa et al. [24], India	2011	Dual basin solar still	1. Aluminium members 2. Jute fabric 3. Coir mate 4. Scrubber sheet 5. Light black cotton fabric 6. Waste cotton chips	The light black cotton fabric is the most efficient absorbing material. The length wise arrangement of the aluminium fin covered with cotton cloth are very efficient found.
Anburaj et al. [25], India.	2013	Tilted solar still	1. Black cord fabric 2. Jute fabric 3. Cord chips	The 4.21 L/day were obtained when the black cotton cloth is used as wick material. By adding the mild steel pieces and clay pot the output of 4.27 l/day was obtained.
Srivastava et al. [26], India	2013	Single basin solar still	Jute fabric	The 68 % higher yield were obtained during the pure day whereas 35 % was obtained when there was an overcast day. The79% greater productivity were obtained from the improved still when 2 vertical mirrors were placed.
Rajaseenivaan et al. [62], India	2013	Dual basin and single	1. Black cotton fabric 2. Jute fabric	For all the absorber material, 85 percent more yield were produced from

		basin solar stills	3. Waste thread chips 4. Clay pot -facing up 5. Clay pot -facing down 6. Mild steel pieces	the double basin still over the single basin still.
Alaudeen et al. [27], India	2014	Conventional Solar still	1. Stepped Absorber 2. Rock 3. Sand 4. Wooden chips 5. Coal 6. Coconut coir	Maximum productivity of 1468 per m^2 was obtained for 2 cm water depth and the lowest production of 1150 L per m^2 was obtained for 4 cm water depth.
Rajaseenivasan et al. [63]	2015	Dual basin solar still	1. Black cord fabric 2. Jute fabric 3. Cord parts 4. Steel sections	The 2.072% energy competence was obtained when mild steel chunks were used in the double basin still, whereas for single still 1.412% competence was increased.
Hansen et al. [28], India.	2015	Tilted type solar still	1. Smooth absorber 2. Paced absorber 3. Wire- mesh absorber 4. Timber tissue 5. Coral hustle 6. Polystyrene	The performance of water coral fleece with stepped wire mesh absorber increases by 71.2 percent compared to a flat absorber and by 48.9 percent when water coral fleece with stepped wire mesh absorber increases compared to a step absorber.
Omara et al. [29], Egypt	2016	Conventional Solar still	Corrugated absorber Plate	The 145.5 percent more distilled water produces from corrugated solar still with wick over traditional still.
Agrawal et al. [30], India	2019	Single-slope single-basin solar still	V shaped floating wick (Black Jute)	It is found that maximum daily productivity is 6.20 L/m^2 in summer and 3.23 L/m^2 in winter having efficiencies of 56.62% and 47.75% respectively.
Saravanana et al. [64], India	2020	Square shaped pyramid solar still	1. Polyester 2. Terry cotton 3. Jute cloth 4. Woollen fabric	From the result it was found that 9.4%, 20.9%, and 33.1% more yield was produced for woollen fabric wick material as compared to jute, Terry

				cotton, and polyester respectively.
Okeke et al. [65], Nigeria.	1990	Single basin solar still	Charcoal and coal	The 1.21L per m^2 per day output was obtained from still having an effectiveness of 16.5%.
Tris et al. [31], Turkey	1996	Single basin solar still	1. Black dye 2. Charcoal 3. Darkened rock bed	The 18 percent and 92 percent more output were obtained from still when charcoal was used as compared to the black paint and blackened rock bed respectively.
Sebaii et al. [66], Egypt.	2000	Single basin solar still	Baffles	The 20% everyday output of fresh water increases by using the baffle plates as an absorber in the still.
Sathyamurthy et al. [32], India.	2015	Semi-circular through solar still	Baffles	The 3 L/m^2 output and 38% competence of everyday were obtained from still using a semi-circular absorber with baffles
Nafey et al. [67], Egypt.	2001	Single basin solar still	1. Black elastic with dissimilar width 2. Black chippings with dissimilar width	The output increases by 20% when the still having black rubber of 10mm and the quantity of water was 60 l/m^2
Sakthivel et al. [68], India.	2008	Single basin solar still	Black sandstone chippings	The still with black granite produces 52% competence which was 8% more as compared to traditional still.
Shanmugan et al. [33], India	2012	Single basin solar Still	1. White limestone 2. Steppingstones 3. Pebble 4. Dark gravels 5. Calcium chippings 6. Iron crumbs	The 43.67% total thermal competence were developed from this still.
Panchal et al. [34], India	2015	Conventional solar still	Blue metal stones and Cow dung cakes	The 35 percent as well as 20 percent more yield were produced by the still containing blue metal stones and cow dung cake respectively as equated to reference still.

Madhu et al. [69], India	2018	Tilted solar still	1. Baffles 2. Polyester sheet 3. Rubber sheet	The results show that 57.1% more output was obtained from still containing polyester sheet as sensible heat storage material and 59.5% more output was produced from still containing rubber sheet as sensible heat storage material as compared to traditional still not containing any sensible heat storage material.
Velmurugan et al. [35], India	2019	Single basin double slope solar stills	1. Black granite pieces 2. Sand 3. Charcoal 4. Red brick pieces 5. Small rock 6. Exterior Mirror	It is observed that during bright sunshine external reflectors accelerate the production rate while during decline sunshine hours higher production is obtained from heat storage material. It also observed that the efficiency of a still with energy storing material was 23.08 percent more than traditional still while the efficiency with reflectors was 62.97%.
Nasri et al. [36], Algeria.	2019	Conventional Solar still	1. Gravel 2. Black Polyethylene 3. Sand	The 5 L per m^2 of fresh water is obtained from gravel, after that black polyethylene absorber, produces 4.48 L per m^2 per day and lastly, sand absorber produces 3.84 L per m^2 per day of fresh water. The effectiveness of still was nearly about 99.30%.
Raj et al. [70], India	2019	Single basin solar still	1. Stone chips 2. Sand stones 3. Calcium oxide	As compared to traditional solar still the 19.8% more fresh water was obtained from still containing stone chips, 18.41% more was obtained from still containing sand stones, and 26.98% more was obtained from still containing calcium oxide.

Sharshir et al. [71], Egypt	2020	Single basin solar still	1. Exfoliated graphite flake 2. Wick 3. Carbon foam	The everyday yield was increased by 51.8% obtained for still containing exfoliated graphite flakes, and carbon foam with the wick as compared to traditional solar still.
Hijleh et al. [72]	2003	Single basin solar still	1. Black scrubbers 2. Black coal 3. Black steel 4. Yellow scrubbers	By using the scrubber dices the output was improved in the range of 18% to 273% as compared to the still without scrubber dices.
Abdallah et al. [37]	2009	Single basin solar still	1. Uncovered metal wiry scrubbers 2. Covered metal wiry scrubbers	The highest total output was obtained from still having black volcanic rock and i.e., 60%.
Arjunan et al. [73], India.	2011	Single basin solar still	Scrubbers	The 35.2% more output was obtained from still having a sponge of 5mm thickness as compared to traditional still. The performance of the still were improved by using the sponges as absorbing material.
Harris et al. [38], India.	2016	Single basin solar still	1. Sphere-shaped ball with saline rock 2. Scrubbers	The 3.7 L/m^2 everyday output was obtained from still having a salt ball as energy storage material whereas 2.4 L/m^2 was obtained from still having sponges as energy storage material and 2.6 L per m^2 from traditional still.
Sebaii et al. [39], Egypt.	2009	Single basin solar still	Beach Soil	The overall yearly competence was 23.8% more in still containing heat storage material as equated to the still lacking warmth storage material.
Velmurugan et al. [74]	2008	Single basin solar still	1. Scrubber 2. Wick 3. Extended Surface	When extended surfaces were used as absorber surfaces the output increase by 45.5%, when the wick was used as absorber surface the output increases by 26.6% and when sponges were used as

				absorber surfaces the output increases by 15.3%.
Omara et al. [40], Egypt.	2011	Single basin solar still	1. Extended surface 2. Ribbed cloth	For 30L of saline water, 40 % more yield and 47.5% competence were obtained from finned type solar still
Agrawal et al. [41], India	2013	Single sloped solar still	Porous Fins	A 7.5L/m^2 output were obtained from this improved still during the month of May which was the maximum.
Panomwan et al. [75], Thailand.	2013	Single basin solar still	Extended surface	A 15.5 % output was increased from the improved solar still as compared to the conventional solar still.
Alaian et al. [42], Egypt.	2016	Single basin solar still	Pin-finned wick	When the pin finned wick is used in still, a 55 percent competence and 23% more productivity was obtained.
Elshamy et al. [76], Egypt	2018	Tubular solar still	Semi- circular Corrugated absorber Plate	The 25.9% increase in thermal competence was obtained from a tubular still with a semi-circular corrugated absorber plate.
Gnanaraj et al. [43], India	2019	Single basin dual slant solar stills	1. Finned grooved 2. Blacken granite 3. Wick 4. Exterior mirror	The everyday yield of 5.13 L per m^2 and 171.43% were obtained from the still when all the modifications were done in this research as compared to the traditional still.
Jani et al. [44], India	2019	Single basin twofold slope solar still	Rounded and four-sided cross-sectional hollow fins	The everyday yield of 1.4917 L per m^2 were obtained from still having circular fins whereas 0.9672 L per m^2 was obtained for square fins.
Khaled et al. [45], Jordan	2020	Conventional Solar still	1. Extended surface 2. Interior mirror	The average monthly competence increases by 29.1% and output were increased by 3.014 L/daym^2.
Panchal et al. [77], India	2020	Single basin solar still	Porous Fins	The 42.3% more output was obtained by the use of porous fins on the absorber plate.

Panchal et al. [78], India	2020	Traditional solar still	Inclined and vertical extended surface	The 26.77% more output was produced from still having inclined fins as compared to traditional still
Kabeel et al. [46], Egypt	2014	Single basin solar still	Nano fluids	When nano fluids are used with an exterior fan the output of still were increased by 116 % and when nano fluid are used without the external fan the output were increased by 76 %.
Kabeel et al. [47], Egypt	2014	Conventional solar still	1. CuO 2 Al_2O_3	The maximum increase in productivity of the modified still is achieved when using the cuprous oxide–water nano fluid (133.64% and 93.87% higher than the productivity of the conventional still with and without operating the fan throughout the daytime).
Elango et al. [48], India	2015	Single basin solar still	1. Al_2O_3 2. ZnO 3. Fe_3O_4 4. SnO_2	The 29.95% more output were obtained when Aluminium oxide is used as nanoparticles as compared to plain water.
Sahota et al. [49], India.	2016	Dual slant solar still	Al_2O_3	When 0.12% of Al_2O_3 were used the yield obtained was 12.2% for 35kg of water and 8.4% for 80 kg of water as compared to still without nanoparticles.
Modi et al. [50], India	2019	Single slant double basin solar still	Al_2O_3	The use of Al_2O_3 increases the yield of fresh water by 17.6% as compared to still without Al_2O_3.
Sharshir et al. [79], Egypt	2019	Pyramid solar still with evacuated tube	1. Copper oxide 2. Carbon black	The modified solar still was having 50% daily efficiency which was increased to 61% for modified solar still with copper oxide and 64.5% for modified solar still with carbon black.
Panchal et al. [52], India	2019	Stepped Solar still	1. Magnesium oxide 2. Titanium oxide	The magnesium oxide with 0.1% concentration has 33.33% more fresh water,

				whereas for 0.2% concentration 45.38% was found.
Nazari et al. [80], Iran	2019	Single slope solar still	Copper oxide	When 0.08% of copper oxide nanoparticles were used in solar still with a thermoelectric cooling channel 81% more output of fresh water was found.
Shafieian et al. [81], Australia.	2020	Conventional Solar still	Aluminium oxide	The efficiency was increased by 17.4% and 18% more when nanoparticles was used in the summer and winter season respectively.
Behura et al. [82], India	2020	Single slope solar still with V corrugated absorber	Copper oxide	When nanoparticles were used the output was increased by 62.74% as compared to traditional still.
Dsilva et al. [83], India	2020	Conventional Solar still	Titanium oxide and latent heat storage material.	The 88% more output were obtained from still when energy storage material with nanoparticles were used as compared to traditional solar still.
Sathyamurthy et al. [51], India	2020	Conventional Solar still	Layered using fumed silica nanoparticle	When 20% concentration of nanoparticles were used the output was increased by 34.2% as compared to ordinary black paint.
ShivKumar et al. [53], India	2014	Single slope solar	Evacuated tube	The everyday output of 3.47L/m^2 was obtained from the basin when it is integrated to the vacuum tube.
Panchal et al. [54], India.	2015	4 Dual basin solar still	Blacken granite gravel	The 56% competence were increased when still was coupled with vacuum tube whereas 65% competences increase when the still was coupled with the vacuum tube and having black granite gravel.
Panchal et al. [55], India.	2018	Double basin solar still with Evacuated tubes	Solid fins.	When the extended surface was used in double basin solar still integrated with an evacuated tube the yield of fresh water was increased

				by 25 % as compared to the still without extended surfaces.
Badran et al. [56], Jordan	2018	Pyramid-roof-type solar still	1. Flat Plate Collector 2. Evacuated Tube	It is observed that when the still is connected to a flat plate collector the water yielding is increased by 7.62% and when it is connected to an evacuated tube collector it is 13.25% as compared to the conventional one.
Panchal et al. [57], India	2019	Single basin passive solar still	Evacuated tube	The distilled output obtained from the solar still with vacuum tube was 4.994 L which was 97.6% more than the conventional still.
Shehata et al. [58], Egypt	2020	Single solar still	1. Evacuated tube 2. Ultrasonic humidifier	By using the ultrasonic humidifier coupled with an evacuated solar collector the everyday yield was upgraded by 25 % for 25 mm water height and 44 % for 35 mm water height in the basin.
Bhargva et al. [84]	2020	Solar still integrated with vacuum tube and heat exchanger	Evacuated tube	From experimentation, it was found that for 4 cm water depth 7.39 Liter per m^2 per day was found and the everyday efficiency was 30.5% was obtained which was 138.9% more as compared to traditional solar still for the same water depth.
Patel et al. [59], India	2020	Triple basin solar still with vacuum heat pipe	1. Corrugated absorber 2. Pebbles 3. Granite	The 180% distillate output were found more from triple basin solar still with granite as compared to traditional triple basin solar.
Panchal et al. [60], India	2020	Conventional Solar still	1. Evacuated tube 2. Calcium stone	The 113.52 % yield were increased when traditional solar still with vacuum tubes were used and 104.68 % were increased when traditional solar still with vacuum tubes and calcium

				stones as compared to traditional still.
Saw et al. [85], Malaysia	2020	Triangular shaped glazing solar still with vacuum tube	Evacuated tube operated in natural mode	The 60.5% average competence was found from solar still having vacuum tubes.
Saadi et al. [86], Algeria.	2018	Conventional Solar still	Stepped absorber coupled with Multi Tray evaporator	The 47.18% to 104.73% more fresh water was produced from stepped solar still having multi tray evaporator as compared to traditional solar still.
Shyora et al. [87], India	2019	Conventional Solar still	Stepped absorber	The 23.88% more fresh water was obtained from stepped solar still as compared to traditional still.
A. E. Kabeel et al. [88], Egypt	2019	Stepped solar still	1. Phase change material 2. Internal reflector 3. Graphite 4. Vacuum tube	The 13.6 L/m^2 to 13.62 L/m^2 day everyday freshwater was found when stepped solar still with internal reflector coupled with the vacuum tube and phase change material with graphite are used
Sharshir et al. [89], Egypt	2020	Stepped double slope solar still	1. Linen wick 2. Carbon black	The 80.57% fresh water yield were increased when linen wick and carbon black nanoparticles were used in the still as compared to traditional solar still.
Katekar et al. [90], India	2020	Conventional Solar still	Stepped absorber	The 147.93% more output was obtained from still having a stepped corrugated absorber as compared to traditional still.
Vignesh Kumar Ramalingam et. al. [91]	2021	Inclined solar still	Stepped absorber	When compared to a normal solar still, the inclined solar still with heat storage materials increased production from 28 to 69.5%, whereas the inclined solar still with wick material increased output from 82.25 to 144.5%.

A. Mohandass Gandhi et.al. [92]	2021	Stepped solar still	Nano particles	When a 30% SiO_2/TiO_2 coating was employed, the stepped solar still efficiency, which was 49.21%, raise.
Mohamed Abdelgaied et al. [93], Egypt	2022	Stepped solar still	1. CuO nanoparticles coated absorber surface 2. Interior mirrors 3. Phase change materials	The thermal efficiency of the stepped solar still by using an absorber plate coated with copper oxide nanoparticles, interior mirror, and PCM is increased by 136.6%.
A. S. Abdullah et.al. [94]	2022	Tray solar still	1. Flat absorber. 2. Finned absorber. 3. Jute. 4. Copper oxide nanoparticles mixed with PCM.	When phase change material comprising nanoparticle and electrical heaters were used in the finned tray solar still simultaneously, the daily water yield was increased by 196% compared to the conventional sun still.
Masoud Sobhani et.al. [95]	2022	Conventional solar still	1. PVC insulation box 2. Sliding absorber 5. Air stones	By employing air stones in the solar still, the fresh quality yield and efficiency were raised by 34.7% and 8.8%, respectively.

2.2 EFFECT OF COOLING OF GLASS COVER OF STILL

In the solar still, one of the most significant criteria is the temperature of the upper surface of the glass. The new distillate that is produced by the still is collected from the inside of the glass cover, where the condensation of the water that has been evaporated has been collected. The studies that have been conducted by so many researchers in order to lower the temperature of glass by chilling it are going to be addressed in the following part.

Arunkumar et al., [96] carried out a semi-circular solar still engineered comparative analysis both with and without the flashing of cold water on the glass surface. For experimentation 1100 mm x 1100 mm x 250 mm size semi-circular still was fabricated. For cooling the surface of the glass, the tank was attached in which cold water was present and placed at a particular gravity head so that identical water was supplied at the glass cover. The 0.01l/min of water are allowed to drift over the glass surface. From experimentation, they revealed that the competence of semi- circular still rises from 34% to 42 % when the upper portion were cooled by a continuous supplied of cold water.

Abdullah et al., [97] performed the experimental study on solar still in which stepped type absorbers were used and temperature reduction of the upper surface was done. In experiments, conventional still and stepped solar still were compared. A 0.5 m^2 absorber plate area is used for conventional and stepped solar still. The 5 steeped were made as an absorber in solar still. The water in the basin was warmed up by employing the utilisation of a solar air heater. A layer of aluminium pieces was positioned beneath the absorber plate in order to both boost and maintain the maximum yield. A water which was supplied over the top cover for reducing temperature having 0.03 kg/s movement. From experimentation, it was found that as compared to conventional still when stepped absorber still are used the production of water increases i.e., 112 % more output were obtained.

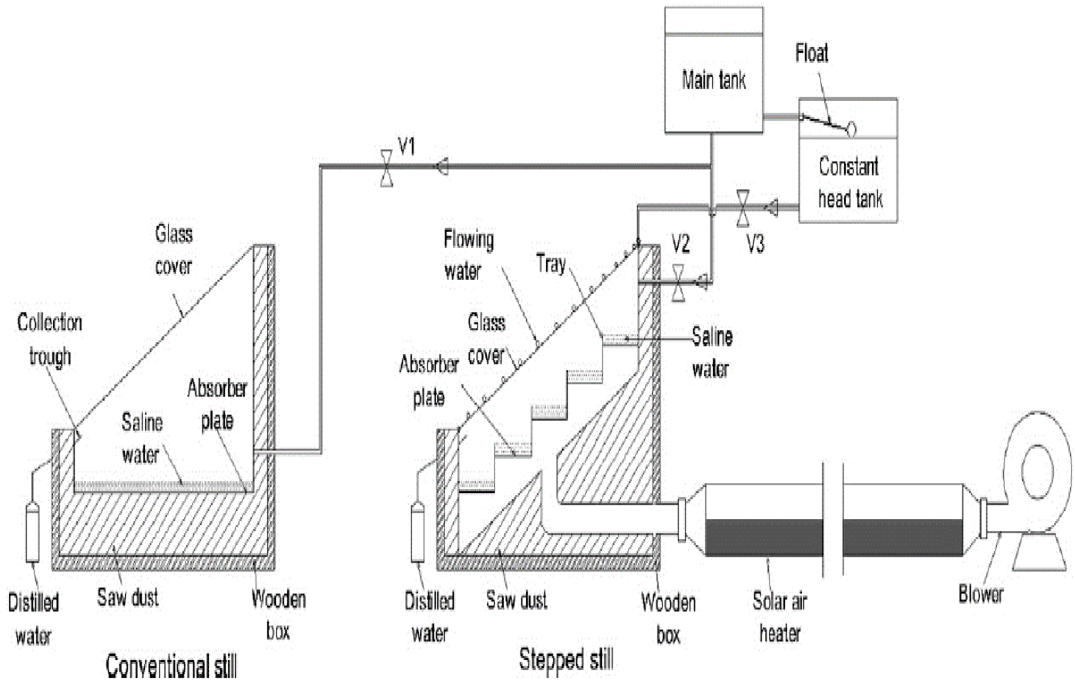


Figure 2.27. An Illustrative Diagram of the experimental setup. [97]

Aneesh et al. [98] the theoretical analysis was carried out on a single solar basin still in which upper portion cooling were done using an air cooler. To lower the water temperature which was supplied over the cover surface for cooling it, an evaporative cooler was used by the researcher. The 1.5 m/s permanent water was supplied over the upper surface. In this study 2 different techniques were used by the researcher for reducing the temperature of the upper portion: 1) from the desert cooler the cold water utilized 2) the normal water was used having a surrounding temperature. The temperature of the water which was flowing over the upper portion increased, by absorbing heat from that surface, and then that water was again supplied to the desert cooler. After experimentation researcher observed that when water from the desert cooler were used the yearly output was increased from 41.3 % - 56.5 %. Similarly, when water at surrounding temperature were used the yearly output increases from 21.8% - 30.1%.

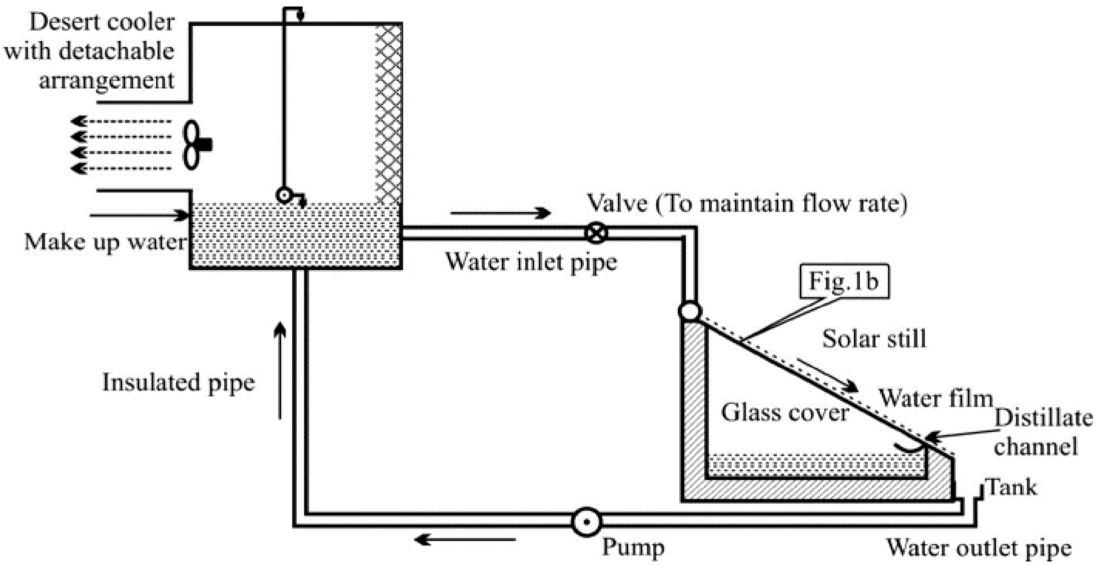


Figure 2.28. Schematic illustration of a solar still coupled to a desert cooler. [98]

Mord et al. [99] performed the experimental study on solar still having double slope which were integrated with a flat plate collector in which the upper shield was cooled. For experimentation rectangular still were fabricated having dimension 1.7 m x 0.7 m. For various gravity of water, the yield of the still were studied. The 800 ml/hr of water was supplied for cooling the upper portion of the glass in a still. The cooling water was supplied on a discontinuous basis i.e., for 5 min the water was supplied, and for the next 5 min the water was stopped. The 7.80 L per m^2 per day production are obtained from traditional still when the cooling water are supplied. When the still is used together with the flat plate collector and the upper half of a glass is chilled, a collection rate of 10.06 litres per square metre per day is attained. They observed that when the density of the water and the thickness of the glass surface were raised, the still's capacity fell. This was a surprising finding.

Srither et al. [100] by chilling the top surface we were able to successfully complete an experimental investigation on a freestanding triple basin still. Throughout the course of the experiment, a comparison of three different stills was carried out. The first still was a standard triple basin solar still, the second still was a triple basin sun still with temperature reduction in the top half, and the third still was a triple basin solar still that was attached to a parabolic dish collector. The 300mm x 360mm x 330mm still was fabricated for experimentation. The 20ml/s, 25ml/s, 30ml/s, 35ml/s, and 40ml/s where different flow rates of water were studied. From experimentation, they found that a 40ml/s flow rate of water produces maximum yield. As a result of lowering the temperature in the top part, there was a 32.8% increase in the overall yield.

Mousa et al. [101] studied on solar still having phase change material, cooling of the upper surface of the still, and integrated to a flat plate collector. Three different types of modification were done i.e., solar still with upper surface cooled, solar still with upper surface cooled integrated with exterior flat plate collector and solar still with upper surface cooled combined with phase change material and flat plate collector. They used 3 different PCM for experimentation. The consequences of hot water circulation rate, the mass of phase change material, the flowrate of cooled water, solar irradiation, atmospheric temperature, and speed of wind had been studied. They found that when the intensity of solar rays was increased from 200 – 700 W/m^2 the yield was increased from 0.9 ml/min – 3.4 ml/min for solar still with upper surface cooled, 2.35 ml/min – 10 ml/min for solar still with upper surface cooled integrated with flat plate collector and 3 ml/min – 11.9 ml/min for solar still with upper surface cooled integrated with phase change material (as sodium acetate trihydrate) and flat plate collector. The 2.4 times yield were increased by adding an exterior flat plate collector with phase change material. When the quantity of cooled water circulation was increased from 0 kg/s – 10 kg/s the yield was augmented from 1 ml/ min - 2.14 ml/min for solar still with upper surface cooled, 1 ml/min - 6.65 ml/min for solar still with upper surface cooled integrated with flat plate collector, and 1 ml/min - 7.5 ml/min for solar still with upper surface cooled integrated with phase change material (as sodium acetate trihydrate) and flat plate collector. Further, when a circulation of hot water was increased from 0 – 0.1 kg/s the yield was augmented by 2.4 ml/min – 6 ml/min for solar still with upper surface cooled integrated with flat plate collector and 4 ml/min – 7.4 ml/min for solar still with upper surface cooled integrated with phase change material (as sodium acetate trihydrate) and flat plate collector. The 1.8 times more yield had been obtained for solar still with upper surface cooled integrated with flat plate collector as compared to solar still with upper surface cooled and 2.3 times had been obtained for solar still with upper surface cooled integrated with phase change material and flat plate collector using sodium acetate trihydrate as phase change material as compared to solar still with upper surface cooled.

Table 2.4: Comparative study of various upper surface cooling technique

Author(s) and experiment location	**Year**	**Still Type**	**Flow rate**	**Findings**
Arunkumar et al. [96], India.	2012	Hemispherical solar still	0.01 L/min	The competence of semi- circular still rises from 34% to 42 % when the upper portion were cooled by a continuous supplied of cold water.
Arunkumar et al. [102], India.	2013	CPC-TSS	0.01 L/min	When the air was allowed to pass over the top surface of the CPC-TSS, the yield was increased by 40% and when water was allowed to pass over the top surface of CPC-TSS, the yield was enhanced by 43 %.
Hasan et al. [103], Jordon.	2013	Single slope solar still	0.6 L/min	The output of water production was depending on the surrounding temperature, solar rays' intensity, and movement of cold water over the surface.
Abdullah et al. [97], Egypt	2013	Stepped solar still	0.03 L/s	As compared to conventional still when stepped absorber still are used the production of water increases i.e., 112 % more output were obtained.
Aneesh et al. [98], India	2014	Single basin solar still	1.5 m/s	The yearly output was increased from 41.3 % - 56.5 % when water from the desert cooler was used. The yearly output increases from 21.8% - 30.1% when water at surrounding temperature were used.
El-Samadony et al. [104], Egypt	2014	Stepped solar still	0.045 - 0.085 L/s	The everyday distillate output increases by 8.2% when the movement of cold water takes place over the glass cover.
Suneesh et al. [105], India	2014	V type solar still	0.15 L/min	The "V" type solar still produced an average output of 4.6L/m^2 when the temperature of the upper surface was lowered by spraying cold water on it.
Mord et al. [99], Egypt.	2015	Dual slant solar still	0.8 L/hr	The 10.06 L per m^2 per day was collected when the still was connected to a flat plate collector and the upper portion of the glass was cooled.

Arunkumar et al. [106], India.	2016	CPC-pyramid solar still	0.01 L/s	The output of 7.7 L per day was obtained while still attached to the solar pyramid are the composite parabolic concentrator-concentric tube-shaped solar.
Srither et al. [100], India.	2016	3 basin solar still	0.02, 0.025, 0.03, 0.035, and 0.040 L/s.	The 40ml/s flow rate of water produces maximum yield. The total yield was increased by 32.8% when the temperature of the upper portion was reduced.
Mousa et al. [101], Jordon.	2020	Single slant solar still with flat plate collector	0 L/s - 10 L/s	The yield was augmented by 2.4 ml/min – 6 ml/min for solar still with upper surface cooled integrated with flat plate collector and 4 ml/min – 7.4 ml/min for solar still with upper surface cooled integrated with phase change material (as sodium acetate trihydrate) and flat plate collector.

2.3 EFFECT OF PHASE CHANGE MATERIAL (PCM) IN THE BASIN

Thermal energy storage systems are able to store energy in the storage medium by either heating or cooling it. In the future, the energy that was stored can be used to generate electricity, provide heating, or provide cooling. Latent heat storage materials are responsible for the absorption and release of heat whenever a material goes through a phase change. Latent heat storage technologies, such as PCM, have been shown to be perfect for use in solar stills due to the fact that they are able to retain anywhere from 5 to 14 times more heat than sensible heat storage. As a result, a number of researchers have utilised various PCM in solar stills, which are mentioned in the next section.

2.3.1 Solar still with Lauric acid

Lauric acid, also known as dodecanoic acid, is a 12-carbon saturated fatty acid that has many characteristics with medium-chain fatty acids. It has a little scent of soap or bay oil and is a dazzling white, powdery substance.

Hamadani et al. [107] lauric acid was used as a phase transition material in an experiment on solar still. For experimentation, 2 different solar stills were designed having an area of $1m^2$. Below the solar still, phase change material was placed. It was discovered that increasing the amount of material that changed phase and decreasing the amount of water in the still enhanced the daily production as well as the efficacy of the solar still. The maximum output of 2.63 L/m^2 per day was achieved during experimental work.

2.3.2 Solar still with Myristic acid

Myristic acid has a 14-carbon backbone and is a saturated long-chain fatty acid. Butter fat, coconut oil, and palm oil all naturally contain myristic acid.

Shukla et al. [108] conducted research and studies on solar stills including phase transition materials such as myristic and lauric acid. For the purpose of storing the heat energy, the phase change material was positioned on the lower side of the still. As a result of having a better capacity for energy storage, the output of the experiment that employed lauric acid as the phase transition material was found to be boosted by 36%.

2.3.3 Solar still with Stearic acid

A saturated fatty acid with an 18-carbon chain is stearic acid. Octadecanoic acid is known by its IUPAC name. It has the chemical formula $CH_3(CH_2)_{16}CO_2H$ and is a waxy solid.

Ajeetkumar et al. [109] using phase change material as steric acid the tubular solar still has been examined experimentally. The 0.77m^2 absorber area was used in the experimentation. For measuring the temperature of the solar still, copper thermocouples were used. From experimentation, they found that the everyday competence of fresh water was 21.87 %.

2.3.4 Solar still with Paraffin wax

The soft, colourless material known as paraffin wax is made of a combination of hydrocarbon molecules with between 20 and 40 carbon atoms and is generated from petroleum, coal, or oil shale. The majority of paraffin wax is found as a white, odourless, tasteless, waxy solid with a density of roughly 900 kg/m^3 and a typical melting point of between 46 and 68 °C. It is not water soluble.

Sathyamurthy et al. [110] using paraffin wax as a phase change medium, and an experiment was done to examine the effects of water mass on a triangle solar still. Comparisons were made between phase transition materials that were still present and those that were not. The still's ability to produce fresh water declines as the volume of water there rises. A still with phase change material produces 5.5L/m^2 of fresh water per day, according to testing, whereas a still without phase change material only produces 3.5L/m^2. When compared to a traditional still, a phase transition material still produced 35% more output.

Rajasekhar et al. [111] conducted an experiment on solar cells that still included a mix of nanoparticles and phase-change materials. Al_2O_3 and paraffin wax were employed as phase transition materials in the experiment. Phase change materials that are still present and those that are not were compared. The output of stills was found to be boosted by 45% when nanoparticles and phase change material were employed. Similar results were obtained by simply using phase change material and not any nanoparticles, which resulted in an output of 40%, as opposed to 38% when using both phase change material and no nanoparticles.

Shalaby et al. [112] A single-basin solar still with material that changes phase and a v-corrugated absorbers was tested experimentally. Paraffin wax was the phase-change substance employed in the experiment. Both phase change material and no material were used in the experiment. After testing, it was discovered that using phase material in the still caused production to increase at night and drop during the day by 7.4% and 72.7%, respectively. The daily production obtained was 12% higher when phase change material was utilized in a single-basin solar still with a v-corrugated absorber than when phase change material was not employed. When 25kg of water were used, the daily output was about 11.7% higher than when wick and phase change material were still present.

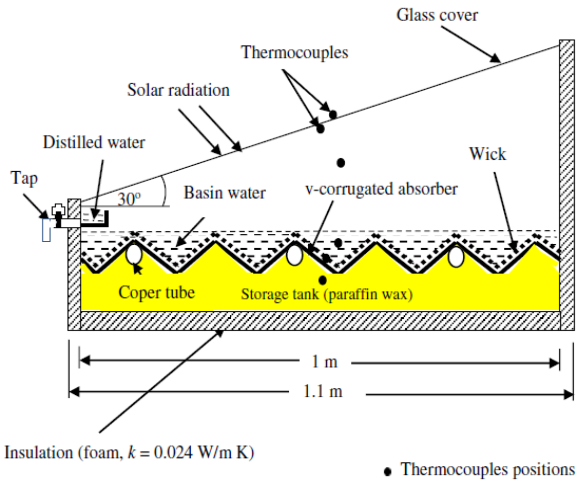


Figure 2.29. Single slope single basin solar still [112]

Table 2.5: Comparative study of various PCM used in still

Author(s) and experiment location	Year	Still Type	PCM Used	Findings
Hamadani et al. [107], India.	2012	Single slant solar still	Dodecanoic acid	The greatest daily production of 2.63 L/m^2 was attained. The efficacy was raised by 30 to 35%.
Shukla et al. [108], India.	2014	Single slant solar still	Myristic and Dodecanoic acid	A 35 - 40 % effectiveness were increased when Myristic acid were used.
Ajeetkumar et al. [109], India.	2015	Tube-shaped solar still	Octadecanoic acid	An everyday competence of fresh water was 21.87 % were found when Stearic acid are used.
Dashtban et al. [113], Iran.	2011	Stepped solar still	Paraffin wax	An everyday output from still having phase change material was 6.7 L per m^2 and from still without phase change material was 5.1 L per m^2. In comparison to still having no phase change material, the output will be 31% higher with it.
Sathyamurthy et al. [110], India.	2014	Pyramid solar still	Paraffin wax	The still with phase change material produces 5.5 L/m^2/day of fresh water, whereas the still without phase change material produces 3.5L/m^2/day. The 35 % more output was produced from still having phase change material as compared to traditional still.
Arunkumar et al. [114], India.	2015	Concentrator supported solar still	Paraffin wax	The output was augmented by 26% when the phase change material was used.
Chaichan et al. [115], Iraq.	2015	Concentrator supported solar distiller	Paraffin wax	The 307 % output was increased by using the phase change material and solar tracking system.
Rajasekhar et al. [111]	2015	Single slant solar still	AL_2O_3 with paraffin wax	When nano particles are used with PCM the output of still were increased by 45 %. When the still without nanoparticles and only PCM the output were 40% while the still without PCM and without nano particles the output obtained were 38%.
Shalaby et al. [112], Egypt.	2016	Single basin solar still	Paraffin wax	During the daytime 7.4% of output decreased while during night time 72.7% of output

				increased when phase material was used in the still.
Kabeel et al. [116], Egypt.	2016	Improved single slant solar still	Paraffin wax	The 9.36 L/m^2/day output were obtained from upgraded still coupled with hot air injection and having phase change material, whereas traditional still produces 4.5 L per m^2 per day.

2.4 STUDIED RELATED TO ECONOMIC ANALYSIS OF SOLAR STILLS

Kabeel et al. [117] utilizing phase change material, an experimental study was conducted focusing primarily on the performance of a solar still. Paraffin wax was used as a phase-change material during tests. For testing, two different solar stills with the same area of 0.615 m^2 were built. For testing, 17.5 g of paraffin wax were used in one still. Through experiments, they found that distillate is produced at a rate of 7.54 L per m^2 per day in a still containing phase change material as opposed to 4.51 L per m^2 per day in a still without phase change material. Phase-change materials were used, which resulted in a 60% increase in overall still productivity. Phase change materials reduced the cost of producing one liter of distillate water from $0.03 to $0.032, respectively.

Joshi et al. [118] created a research project using a heat exchanger and a single slant solar still. In this experiment, exergo-economic and enviro-economic analyses of the cost of producing fresh water and energy were completed. A single slope solar still with a partly, fully, and totally covered flat plate collector was compared to three distinct variations. The final instance included a flat plate collector with a single slope solar still. It cost 0.22 Rs/kg to produce fresh water using a solar still, a partly covered flat plate collector, and a 2% interest rate. Similar to this, the cost of manufacturing using an uncovered flat plate collector and a 2% interest rate is 1.20 Rs/kg. Flat plate collectors that were partially covered were preferred in the solar stills above.

Panchal et al. [119] studied the financial and exergy examination on triangular pyramid solar still coupled to incline solar still having baffles. For different water depths, experimentation was done. They discovered that when an inclined sun still was combined with a pyramid solar still, the output distillation increased. When the depth of water was raised from 0.02 m to 0.05 m during the alongshore phase, the exergy rose. The reimbursement period increases from 5.6 months – 11.4 months when triangular pyramid solar still was used only and it will increase to 6.3 months when they are coupled to inclined solar still for retailing price of distilled water was 5 Rs/kg. The 1533 L/ year was obtained from triangular pyramid solar still when the depth of water was 0.02 m while 2744.8 L/year was obtained from three-sided pyramid solar still coupled with inclined solar still for the same depth of water.

Bait et al. [120] performed an experimental on tube-shaped solar still coupled with dual slant solar still. The exergy enactment, enviro-economic, and economic analysis were done. The obtained outcomes were distinguished with the traditional solar still having the same dimension. The 405.04L/m^2 yearly output were obtained for the conventional still, whereas the 549.77L/m^2 yearly output were obtained from the upgraded solar still. For passive solar still, the hourly exergy competence was 7% and total exergy competence was 30% were found, similarly for active solar still the hourly exergy competence was 11% and total exergy competence was 41% were found. The financial examination revealed that the cost of fresh water production is less when the interest rate is 5% and the duration of 30 yrs. For simple solar still, the production cost of fresh water was 0.018 $/L whereas for modified still 0.036 $/L were found. For passive solar still, the reimbursement duration was 7.7 yrs. and for active solar still was 21 yrs. having 5% interest rate and the trading price of fresh water was 0.04 $/L.

A.F. Mohamed et al. [121] the performance of a solar still was experimentally tested utilizing basalt stone as an absorber material, and a thermo-economic analysis was performed. The consequences of different sizes of stone i.e., 1 cm, 1.5 cm, and 2 cm, and the absorbency of spongy absorber were studied. Two still were fabricated for experimentation one was conventional and the other was modified, and their result were compared. After experimentation, they concluded that the modified solar still produces 0.901L/m^2 output with augmentation of 19.81% for 1 cm size of stone as distinguished to traditional still, for 15 mm size of stone the 1.005L/m^2 output were found and augmentation of 27.86 % were found as compared to conventional still. Similarly for 2 cm size stone 1.075L/m^2 were obtained with augmentation of 27.86% as compared to conventional still. The highest everyday thermal competence was 22.6% developed for 2 cm size stone with augmentation of 32.07%. From economic analysed they obtained that the cost of production of fresh water per liter was 0.017 $/m^2. liter for 2 cm size of the stone, whereas for conventional still, the cost of freshwater production per liter was

0.020$/m^2$. liter. So, it was revealed that the size of the stone had a great impact on fresh water production and their enactment.

Naseer et al. [122] studied on upgraded solar still coupled with a solar collector. For upgrading the yield, 2 different modifications were done in conventional solar still. In 1st modification, a revolving hollow pipe were used inside the solar still to increase the vaporization area and decrease the boundary layer thickness. The hollow tube was revolved for 3 different speeds i.e., 0.5 rpm, 1 rpm, and 3 rpm. The 2nd up gradation was done for increasing the temperature of the water inside the basin, an exterior solar collector was coupled with upgraded solar still. After experimentation, they concluded that, as the speed of rotation was decreasing the yield from still were increased and the maximum yield was obtained when the speed was 0.5 rpm. The production was enhanced to 5.5 L/m^2 when the rotating hollow pipe inside still were connected to the exterior solar collector. The yield obtained was 1.4 L/m^2 when the conventional still was paired with an external solar collector. By utilizing this modification, the yield was improved by 292 %. A liter of fresh water produced by a modified solar still cost 0.048 dollars, compared to 0.049 dollars for a normal still.

2.5 RESEARCH GAP

From the above literature review the following research gap is found:

1. As per the literature reviewed, very few experimental investigations have been conducted for the use of Nano fluids having stepped absorbers in the inclined solar still.
2. According to the literature review, very few experimental studies on the corrugated fins on stepped type absorbers in the inclined solar still have been done.
3. According to the literature research, there haven't been many experimental experiments to look at the impact of an evacuated tube with a stepped absorber in an inclined solar still.
4. Only a few experimental studies employing corrugated finned on stepped type absorbers, evacuated tubes, and nano fluids have been done to evaluate the economic analysis of inclined solar stills, according to the literature study.

2.6 RESEARCH OBJECTIVES

The research work has the following objectives:

1. Design and fabrication of modified inclined solar still with stepped absorber and evacuated tube.
2. Study the effect of Nano fluids, corrugated finned on stepped absorber and evacuated tube on the productivity of the fabricated inclined solar still.
3. Comparison of the performance for modified fabricated inclined solar still and conventional solar still.
4. Economic analysis of modified fabricated inclined solar still will be done.

Now, the experimental set-up was designed and fabricated. The details are discussed in the next chapter.

CHAPTER 3

EXPERIMENTAL SET- UP, OPERATING PROCEDURE AND DATA REDUCTION

This chapter deals with the design and fabrication of the experimental set-up used to generate sufficient data. By adjusting various parameters over a wide range, a large amount of data was created. In this chapter, we also discuss the instrumentation and data collection, and reduction techniques used.

3.1 RESEARCH METHODOLOGY

Step-by-step descriptions of the research methodology

Step 1: Determining the Research Problem: The research topic, "**Experimental performance and economic analysis of nano fluids in inclined solar still equipped of the stepped absorber with corrugated fins and evacuated tube**," has already been completed as the first stage**.**

Stepped with corrugated fins are utilized as absorber plates for the experimental work, it has been determined. Nanoparticles (Aluminum Oxide) and evacuated tubes are also employed.

Step 2: Review of the Literature With the most recent research articles published to date, the second step—the review of the literature—has been finished and is continually being updated. This informs us of the gaps and developments in solar desalination systems around the world**.**

Step 3: Research Objectives: After findings the gaps from the literature review, the research objectives are framed and finalized.

Step 4: Creating the experimental setup It entails fabricating the entire experimental setup. It contains:

Fabrication of the Solar Still Basin: Galvanized Iron (GI) sheet has been used to build the solar still basin for the experimental setup.

Stepped Absorber plate: Galvanized iron (GI) sheet was chosen as a stepped absorber plate for the experimental set-up.

Corrugated fins: The triangular-shaped corrugated fins that have been selected for investigation were created using galvanised iron (GI) sheet as the primary material.

Glass Cover: White, 4 mm-thick glass is used to cover the top of the solar still.

Evacuated Tube: The two concentric tubes made of borosilicate glass having dimension 1800 mm long, 47 mm inner diameter and 58 mm outer diameter has been taken for experimentation.

Nano Particles: For the experimental set-up Aluminium Oxide has been taken as nano particles.

Step 5: Measuring Instrument: The following are the instrument used for measuring different parameters. It includes

PT 100 thermocouple and Temperature Indicator: PT 100 thermocouple is used to find out temperature of the atmosphere, Basin water, Glass cover, and Absorber plate. A total of 12 thermocouples are used.

Solar Meter: It is used to measure the hourly solar irradiation, which is used to find the efficiency of the still.

pH and TDS Meter: A pH metre is a piece of equipment that is utilised in the process of determining the quality of water. One type of measuring device is called a TDS metre, and its purpose is to determine the amount of solid material that has been dissolved in water.

Collecting Jar: The collecting jar is a glass or plastic container with a narrow neck, used for collecting the yield water. It is employed to calculate the solar still's hourly yield.

Step 6: Data Collection: When the product has been manufactured, measurements will be taken to collect data on the temperature of the absorber plate, the environment around it, the water in the basin, the glass, and the amount of solar radiation. The hourly yield of the still, as well as its overall efficiency, will be determined with the use of this information.

Step 7: Data Analysis and Processing: To obtain the best outcome possible, data analysis and processing will be done after all the cases' data have been collected.

Step 8: Data interpretation through graphs: Following data processing, graphs will be created to present the findings in a more arranged manner.

Step 9: Cost Analysis: Cost analyses will be completed for each case after reviewing the entire process and determining the desired outcomes in terms of efficiency.

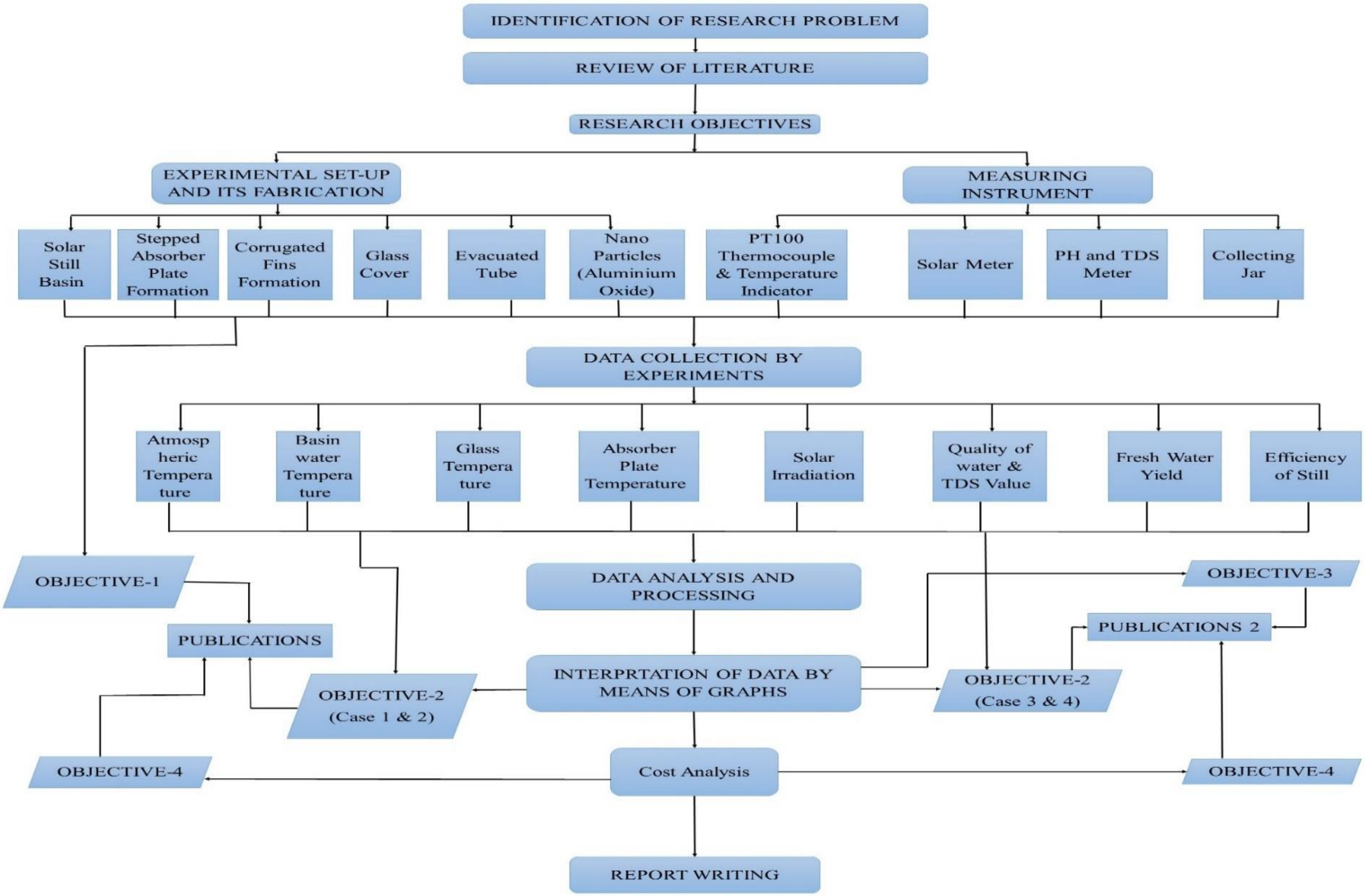


Figure. 3.1. Flow Chart of Research Methodology

Step 10: After receiving all of the results, the report authoring process will be completed.

3.1.1 Methodology for Objective 1

The objective consists of designing and developing modified inclined solar still with a stepped absorber, corrugated fins, and evacuated tube. For this purpose, a geometrical parameter of [57] is adopted for an evacuated tube. The 0.4cm thickness of the glass cover is decided as per the study undertaken [123] and the inclination of the glass cover is taken as 21.1458^{o} N approximately equal to 22^{o} N (equal to the latitude of Nagpur) from the study [57].

3.1.2 Methodology for Objective 2

The following improvements were recognized as best suited for increasing distillate output from inclined solar stills with single slopes. They are

1. Stepped absorber with finned corrugated basin in the still.
2. Nano particles in the inclined solar still.
3. Evacuated tube coupled to incline solar still.

So, three different conditions will be studied to evaluate inclined solar stills.

They are:

Condition I – Inclined solar still having stepped absorber with corrugated fin.

Condition II – Inclined solar still having stepped absorber with corrugated fin integrated with vacuum tubes.

Condition III – Inclined solar still having stepped absorber with corrugated fin integrated with vacuum tubes by using Nano particles.

For the above conditions, the performance of inclined solar still will be studied. In order to determine the yield of the inclined solar still with these improvements, we will apply the above methodology.

Efficiency of still

The evaporative heat transfer to sun irradiation on the absorber plate ratio, which can be calculated as follows, is what determines the thermal or energy efficiency of a solar still. This ratio may be calculated as follows: [4], [90], [124], [125].

$$\eta_{th} = \frac{\Sigma\, m_{ew}\, h_{fg}}{3600\, A_p \Sigma\, I\,(t)} \tag{3.1}$$

Where h_{fg} is the latent heat of vaporization of water and given by

$h_{fg} = 3.1615(10^6 - 761.6\ T_i)$, When $T_i > 70^oC$ (3.2)

$h_{fg} = 2.4935\ (10^6 - 947.79\ T_i + 0.13132\ T_i^2 - 0.0047974\ T_i^3)$, When $T_i < 70^oC$ (3.3)

A_p = Area of absorber plate (m^2).

I (t) = solar radiation(W/m^2).

T_i = Mean temperature of glass and water (^{o} C).

The freshwater productivity (m_{ew}) may be computed using the formula

$$m_{ew} = \frac{h_{ew} A_w (T_w - T_g) 3600}{h_{fg}} \quad (3.4)$$

Where h_{ew} is the computed heat transfer coefficient for evaporation between water and the interior of the condenser glass cover:

$$h_{ew} = \frac{(16.28\ x\ 10^{-3})\ h_{cw}\ (P_w - P_g)}{T_w - T_g} \quad (3.5)$$

A_w = Area of water (m^2).

T_w = Temperature of water (^{o} C).

T_g = Temperature of glass (^{o} C).

A glass cover and water's convective heat transfer coefficient (h_{cw}) is determined empirically,

$$h_{cw} = 0.884\ [(T_w - T_g) + \frac{(P_w - P_g)(T_w + 273)}{(268.9\ x\ 10^3 - P_w)}]^{1/3} \quad (3.6)$$

Partial Vapour pressure of Water (P_w)

$$P_w = e^{[25.317 - \frac{5144}{T_w}]} \quad (3.7)$$

Partial Vapour pressure of glass (P_g)

$$P_g = e^{[25.317 - \frac{5144}{T_g}]} \quad (3.8)$$

3.1.3 Methodology for Objective 3

The comparison of modified inclined solar still will be carried out with conventional solar still for similar conditions. The comparison will be done between the inclined solar still having stepped absorber plate with evacuated tube and Nano particles with the inclined solar still having stepped absorber plate having finned surface with evacuated tube and Nano particles.

3.1.4 Methodology for Objective 4

The production rate of distilled water as well as the time required to repay the cost of still will be studied. For this, the different equations were taken from [118], [124], [125].

Table 3.1: Different Parameters for Economic Study

Sr. No.	Considered Criteria	Formulations	Inferences
1	First Annual Cost (FAC)	FAC = CS x CRF	Where: CS = total cost of still
2	Capital recovery factor (CRF)	$\mathrm{CRF} = \frac{\mathrm{i}\,(1+\mathrm{i})^{\mathrm{N}}}{(1+\mathrm{i})^{\mathrm{N}}-1}$	Where: i = interest rate N = number of years
3	Annual Operating and maintenance cost (AMC)	AMC = 15% x FAC	
4	Sinking fund factor (SFF)	$\mathrm{SFF} = \frac{i}{((1+i)^{N}-1)}$	
5	Annual salvage value (ASV)	ASV = SFF x S	Where: S = salvage value and it is taken as 10% of capital cost
6	Annual total cost (TAC)	TAC = FAC + AMC – ASV	
7	Cost of freshwater per liter	$CPL = \frac{TAC}{L}$	Where: L= Yearly fresh water output.
8	Net payback period	$\eta_p = \frac{\ln\left(\frac{CF}{CF-(\,AFCx\,i)}\right)}{\ln\,(1+i)}$	Where: CF = cash flow and calculated as below CF = yearly yield x selling price

3.2 DESIGN CALCULATIONS

Dimensions for solar distillation are given as: -

Distilled water output per day = 4 - 5 kg/day

Period of incident solar energy = 8 hours

The base design, also known as the base area, is where the unclean water was contained and stored for the distillation process. The base is formed like a square. The base area is the square form in the top perspective.

3.2.1 Amount of solar energy required:

$Q_{required} = m \times h_{fg}$

Evaporation occurs when the temperature reaches to 100°C from the steam table @100^{0}c.

$h_{fg} = 2257 \times 10^3$ J/Kg

$Q_{required} = 5 \times 2257 \times 10^3$

$Q_{required} = 11.285 \times 10^6$ J/day

It is believed that the sun always produces the same amount of energy. The radiation from the sun weakens as it travels through space, and by the time it reaches the edge of the Earth's atmosphere, it is less strong still. The incidental solar energy in the city of Nagpur is approximately 480 W/m^2.

Period of 8 hours:

$Q_{incident} = 480$ W/m^2

$Q_{incident} = 480 \times 8 \times 60 \times 60$

$Q_{incident} = 13.824 \times 10^6$ J/ day

Now the area of the base required:

$A = Q_{required} / Q_{incident}$

$= 11.285 \times 10^6 / 13.824 \times 10^6$

$= 0.816$ m^2 = Approx 1 m^2

As the Solar radiation is not consistent throughout the day, the base area is taken more (1m^2) than required (0.816 m^2) to absorb more amount of radiation and to obtain the required amount of distillate.

Hence, L = 1m and W= 1m.

3.2.2 Flat Plate Absorber

The basin is having the length of 1m and a width of 1m, therefore the basin area is 1 m^2 and the flat plate absorber is placed at the bottom side of the solar still basin. Consequently, the flat absorber plate's area is

Area of Flat absorber plate = Length x width

= 1 x 1

$= 1\ m^2$

The flat plate absorber is having 1 m^2.

3.2.3 Stepped Absorber plate

In experimentation the 5 steps are used having the dimension of 5 steps is 800mm x 1000mm x 150mm. Therefore, the area of the stepped absorber is

Area of stepped absorber for 5 steps = (Length x Width) + (Height x Width) + Flat Absorber Area (Length x Width)

$$= (0.8 \times 1) + (0.15 \times 1) + (0.2 \times 1)$$

$$= 1.15\ m^2$$

Since the area of the stepped absorber is more as compared to flat plate absorber, the heat transfer is also greater in the stepped absorber than in the flat plate absorber. Additionally, with stepped absorbers as opposed to flat absorbers, there is less space amongst the glass cover and the absorber plate, which causes the water to evaporate more quickly.

3.3 EXPERIMENTAL SET-UP

3.3.1 Experimental Setup Description

As shown in figure 3.1, a single-basin, single-slope glass inclined solar still with a stepped absorber and a corrugated fin integrated with vacuum tubes is made for experiments. Commercial plywood and PuF are used as insulating materials in the still's basin, which has a surface area of 1 m^2 and is composed of galvanized iron. In order to maximise amount of solar energy that is absorbed by a still, an interior of a basin is painted a dark colour. The 4 mm thickness plain glass [123] is used which is placed at 22^o inclination as the latitude of Nagpur (India) [57]. In the present study the 5 steps are used as absorber having dimension for 1 step is 160mm x 1000mm x 30mm on which triangular corrugated fins are attached. The 5 vacuum tubes are used for experimentation having dimension of 47mm inner diameter 58mm outer diameter and 1800mm long which is attached to the basin's lower side and inclined at 45^o to the horizontal [57]. At the lower portion, the tube is supported with a rubber bush to prevent it from breakage. For the measurement of the ambient temperature, the temperature of the water, the temperature of the inner glass cover, and the temperature of the absorber plate, this configuration needs a total of twelve thermocouples.

An experimental set up is fabricated and all the equipment's were taken to NIT Polytechnic College, Nagpur, Maharashtra, India (21.1458° N, 79.0882° E). In order to get more sun insolation, a solar still was positioned with a south and a north facing directions. From morning 9:00 to afternoon 5:00 on each day, the experimental procedures were observed. The temperature of the air, the absorber plate, the water in the basin, the glass, the dispersed radiation, and the collected water were all likewise monitored every hour. The ambient air temperature, the temperature of the glass, the temperature of the water in the basin, and the temperature of the absorber plate were all measured with a thermocouple once per hour. Using a solar meter, the amount of sun radiation was simultaneously measured. The rate of water desalination was calculated hourly using a collecting jar.

Figure 3.2. Photographic View of Experimental Setup

Figure 3.3. Schematic diagram of experimental setup without evacuated tube

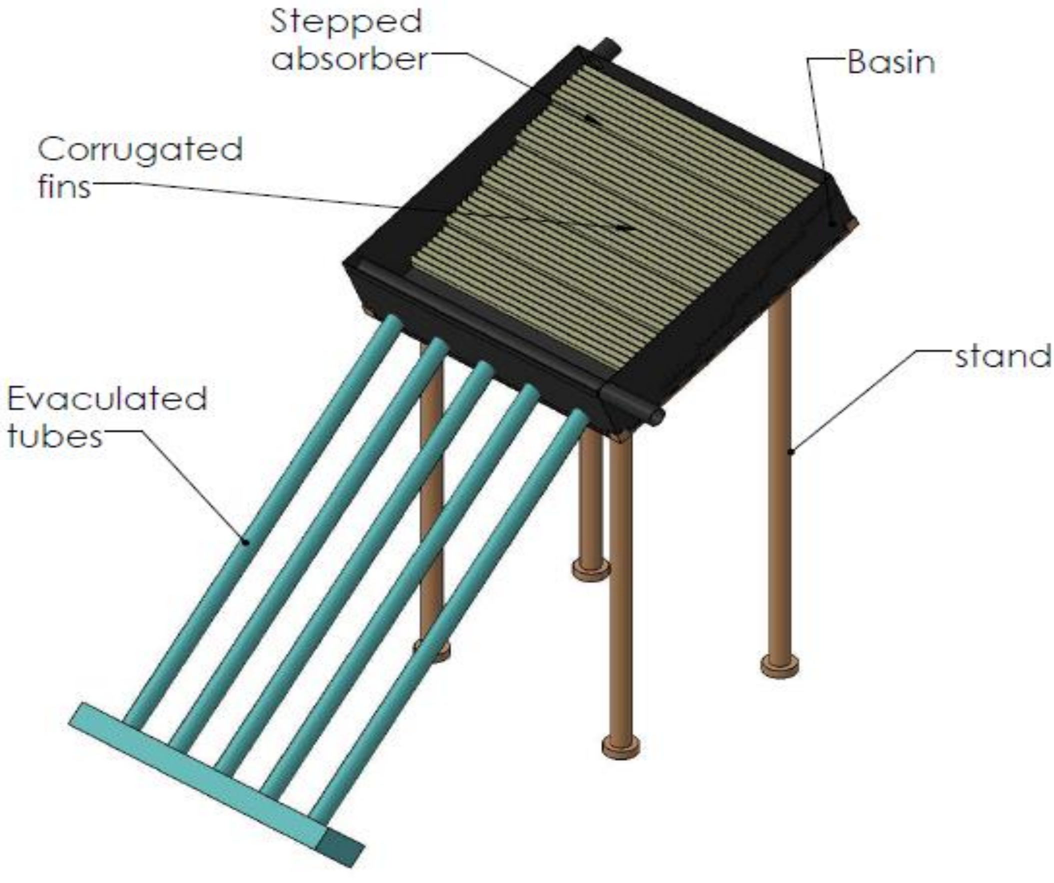


Figure 3.4. Schematic diagram of experimental setup with evacuated tube

3.3.2 Construction Details

In the solar desalination process for purifying the saline water, different parts are used to construct the solar still. In the construction of solar still, the following key parts and accessories are used.

1. Solar still single basin
2. Single slope glass cover
3. Evacuated tube
4. Stepped absorber plate
5. Corrugated fins
6. Inlet way
7. Drain tube
8. Out let way
9. Flexible out let hose
10. Collecting jar
11. Drain plug
12. Sealing paste
13. Insulation tape
14. Rubber feeding
15. PuF insulation

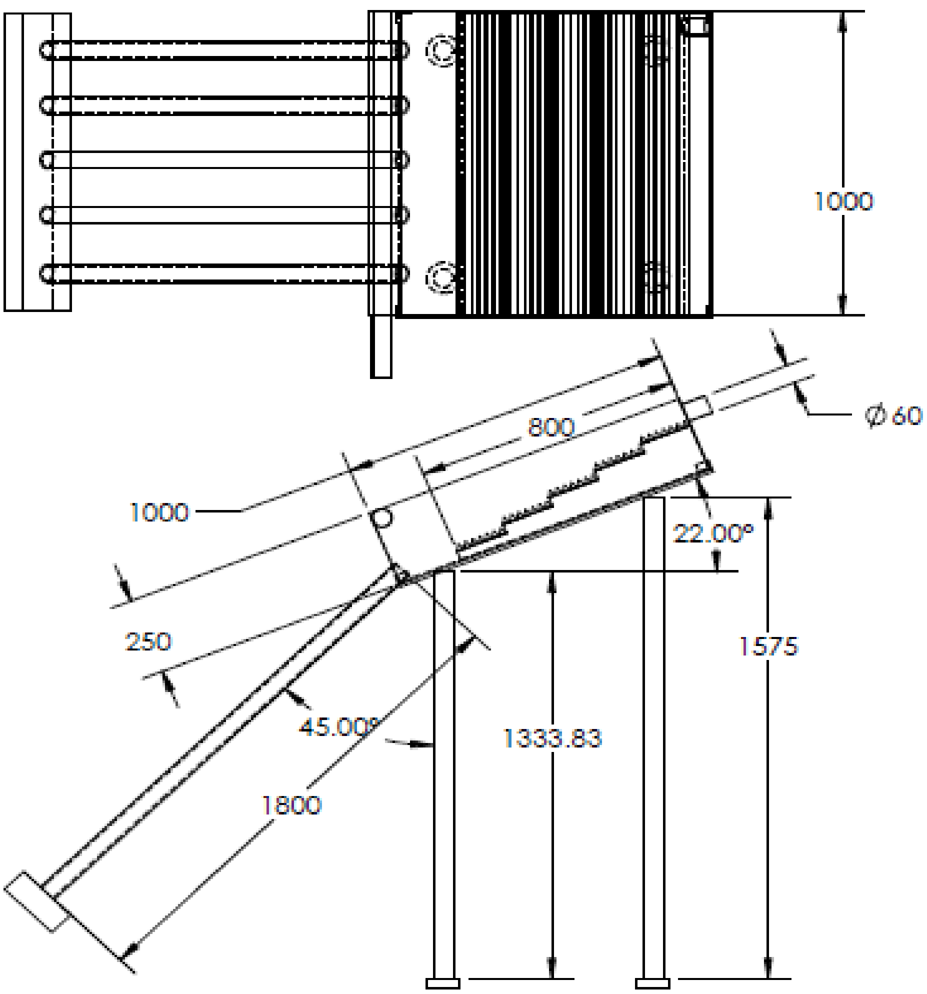


Figure 3.5. Design dimension of experimental Setup

3.3.2.1 Single basin based solar still

The basin is container in which saline water is stored. The inlet valve is attached on the upper side of a basin through which salty water is entered, while outlet valve is attached at a bottom side of a basin through which fresh water is obtained. A “U” shaped tube is placed below the glass cover and is connected to the outlet valve of the solar still. The fresh water obtained from the still is collected by the U tube connected by the flexible pipe in the collecting jar. A basin's interior has been painted black to better absorb solar radiation. A figure 3.6 b shows the photographic view of the solar still basin.

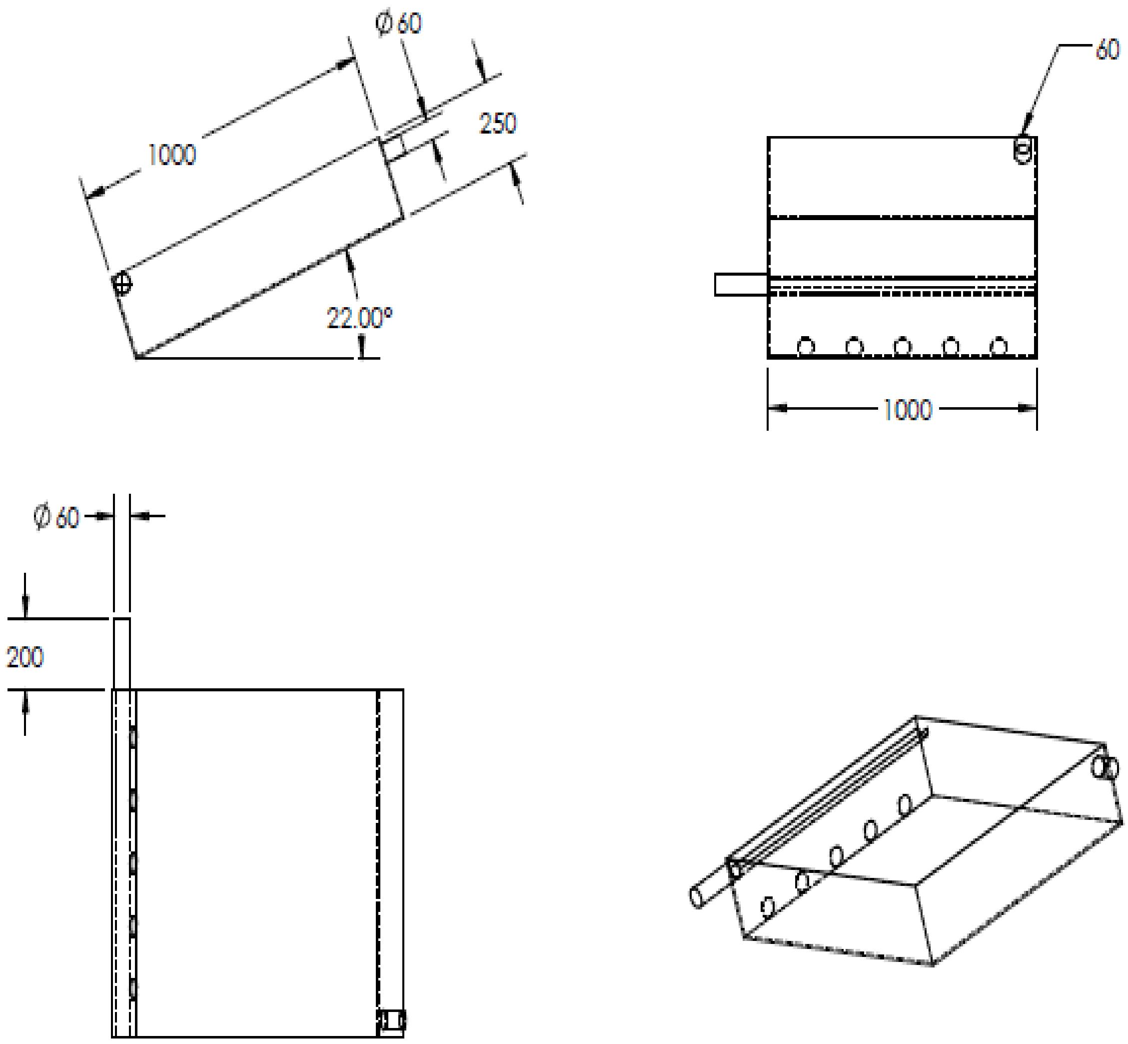


Figure 3.6 a. Dimension of solar still basin

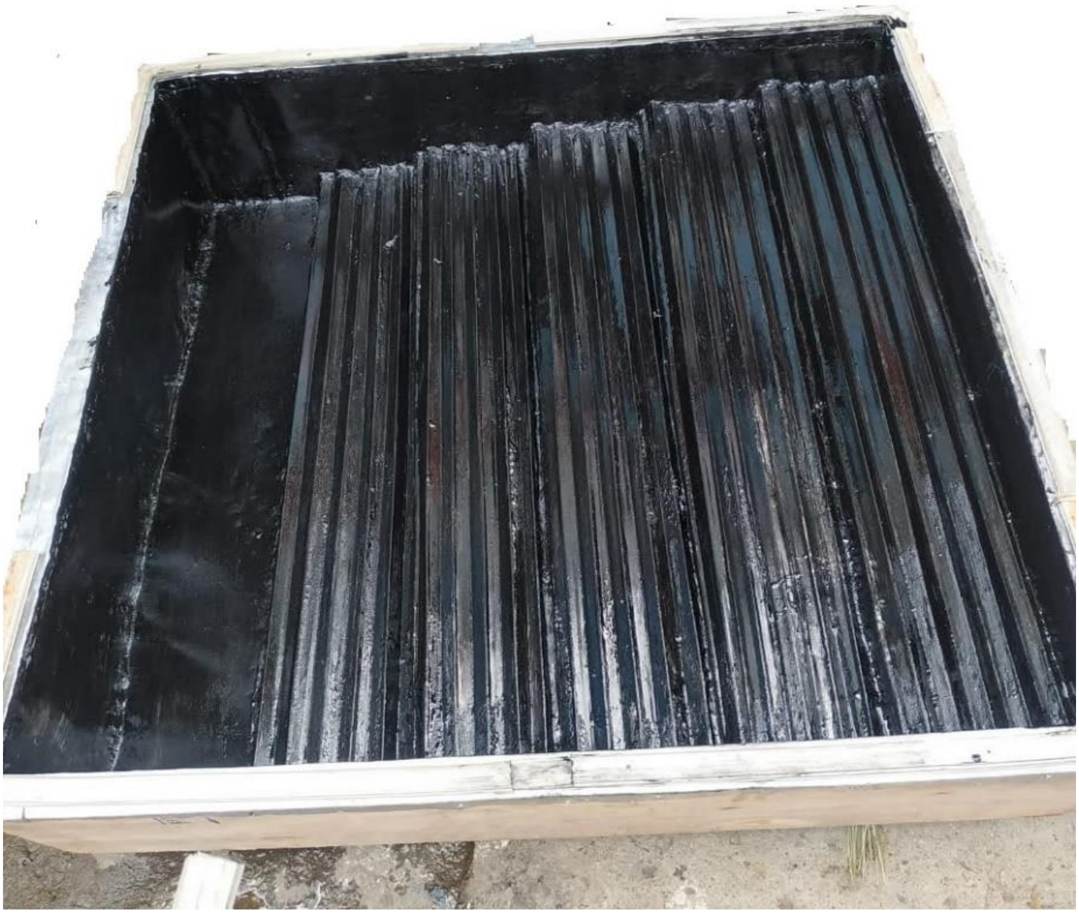


Figure 3.6 b. Solar Still Basin

Table 3.2: Design Parameters of Solar Still Basin

Material	Galvanized Iron Sheet (G.I)
Shape	Square
Type	Inclined basin
Basin Inner surface	Smooth surface
Basin Outer surface	Rough surface
Colour	Black
Basin Inner size	1000 mm x 1000 mm x 250 mm
Effective area of a basin	1 m^2

3.3.2.2 Single slope glass cover

A square-shaped, white glass cover with a white color protects the solar still basin. The following are the advantages of using a single slope glass cover.

1. The solar radiation is transmitted through the glass cover.

2. As it is transparent the inside portion of the still is clearly visible.
3. The vaporised water forms a layer on an inside of a glass cover for condensing purposes.
4. The inner side is where the water condenses.
5. It is very good corrosion resistant against the water.
6. It gives good stability for the solar still desalination process.

The 4 mm thick glass cover is selected for experimentation because it gives good stability for a longer time periods. According to a literature review, more solar radiation is absorbed when the glass is inclined at a level that is comparable to the experiment's location's latitude, therefore 22 degrees was chosen as the glass' inclination since it is about equivalent to Nagpur's latitude. To prevent the leaking of fresh water collected from the still as well as water vapour, a rubber gasket is installed on top of a basin's glass cover. A glass cover dimension and material are given in following table 3.3.

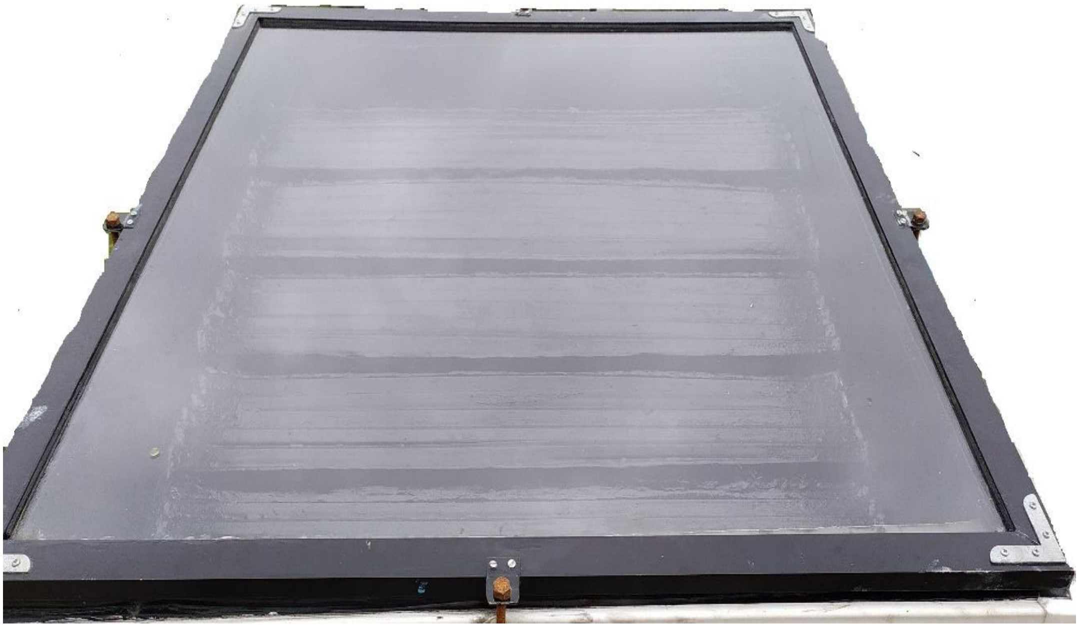


Figure 3.7. Single Slope Glass Cover

Table 3.3: Features of single slope glass cover

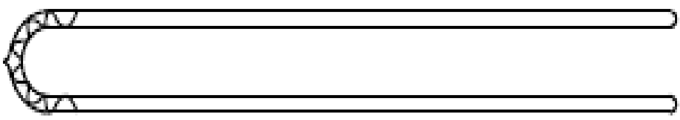
Material	Glass
Shape	Square
Size	1000 mm x 1000 mm
Thickness	4 mm

Colour	White
Inclined angle	22°

3.3.2.3 Evacuated Tube

The evacuated tube is made up of borosilicate glass having two concentric tubes. Due to the absence of air to conduct or move heat, convective and conductive heat losses are decreased. However, some radiant heat loss occurs as a result of heat moving through the tube from a warmer to a cooler area. When compared to the heat that is absorbed by the fluid that is moving inside of the tube, this loss is quite minimal. The solar radiation travels through the outer glass tube, is received by the coated surface, and is absorbed by the fluid that is contained within the tube. The evacuated tube has the following advantages:

1. It works in both direct and diffuse radiation
2. It doesn't need a tracking system to absorb solar radiation.
3. It has higher efficiency as compared to flat plate collectors.



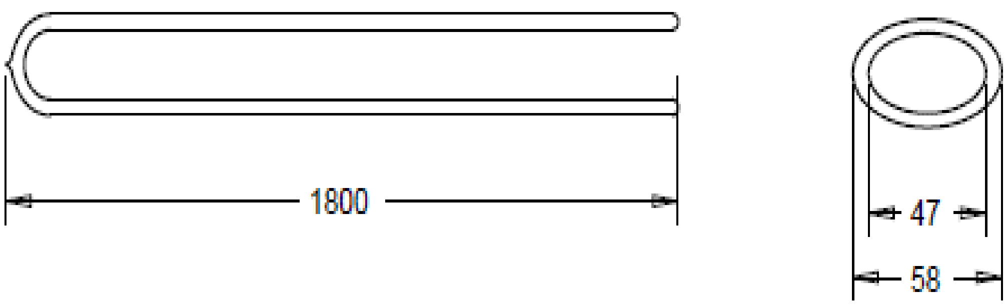


Figure 3.8 a. Dimension of Evacuated Tube

Figure 3.8 b. Photographic view of Evacuated Tube

The evacuated tube material and dimension is given in following table 3.4

Table 3.4: Features of evacuated tube

Material	Borosilicate Glass
Length	1800 mm
Outer Diameter	58 mm
Inner Diameter	47 mm
No. of Tubes	5 No’s
Inclination	45°

3.3.2.4 Stepped absorber plate

The stepped absorber has a cross section in the shape of a rectangle. As a result of solar energy being transferred from the top surface of the glass to the saline water in an absorber, some of the water in the absorber will evaporate and then condense on the inside of the glass cover. The following table 3.5 shows the dimension and material of the stepped absorber.

Figure 3.9 a. Photographic view of Stepped Absorber Plate

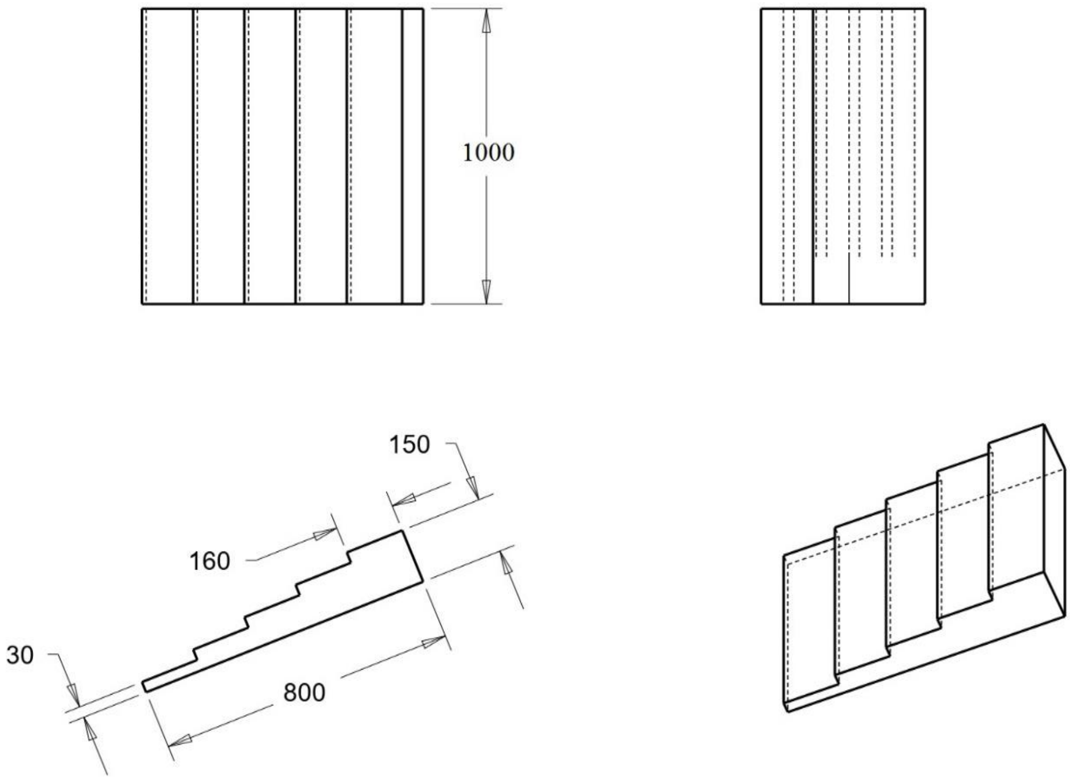


Figure 3.9 b. Dimension of Stepped Absorber

Table 3.5: Features of Stepped Absorber

Material	Galvanized Iron Sheet (G.I)
Shape	Rectangular
No. of Steps	5 No's
Dimension for 1 step	Length = 160 mm Width = 1000 mm Height = 30 mm
Dimension for 5 steps	Length = 800 mm Width = 1000 mm Height = 150 mm
Thickness	1mm

3.3.2.5 Corrugated fins

There are three triangles in the cross section of the corrugated fins. To expand the absorber plate's surface area, it is employed. Maximum sun energy is transported to the salt water as a result of the increased surface area, which also increases heat transmission. As a result, the salt water evaporates more quickly, increasing the output of fresh water. Table 3.6 shows the dimension and material of corrugated fins.

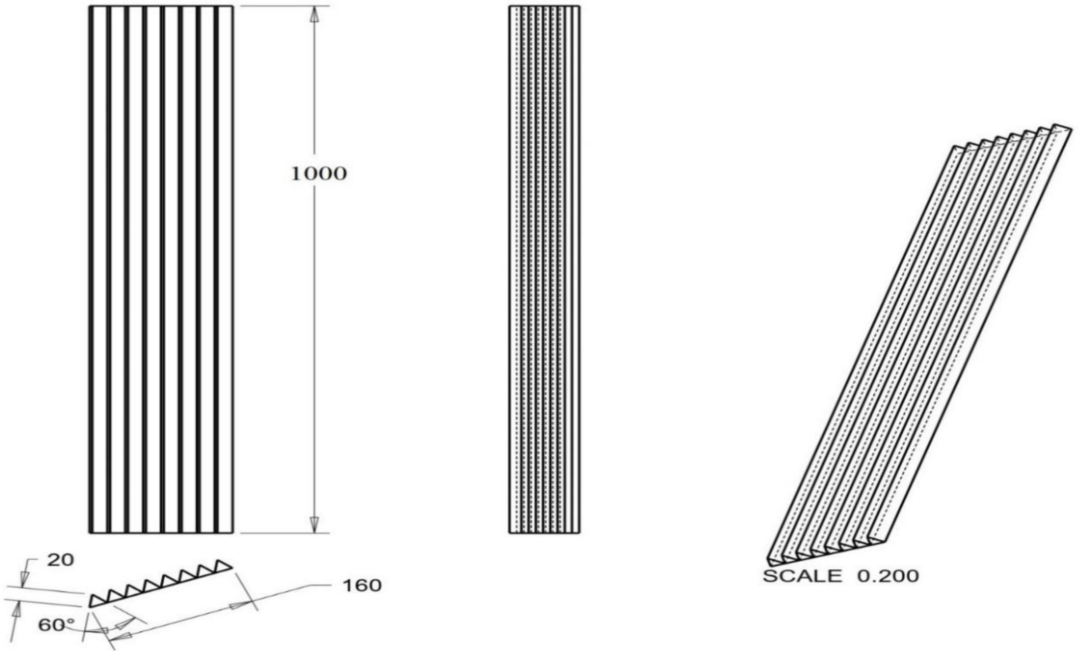


Figure 3.10. Dimension of Corrugated Fins

Table 3.6: Features of Corrugated fins

Material	Galvanized Iron Sheet (G.I)
Shape	Triangular
Base	20 mm
Height	20 mm
Thickness	1 mm

3.3.2.6 Inlet way

One hole, known as the inlet passage, is placed on a top edge of a still basin to allow salty water to enter a basin. By the gravitational force, only the saline water is feed into the basin and no external device is used for the inlet purpose, so this method of desalination is known as the Passive desalination method. To avoid leakage insulating tape and sealing paste are used for sealing and fixing the inlet pipe with a solar still basin. The PVC pipe is used for inlet pipe material.

3.3.2.7 Drain tube

The PVC pipe is cut into a semi-circular cross section and placed under the lower edge of the solar still glass cover. The outlet way of the solar still is connected to the drain tube outlet. It is fixed at some inclination on the support of the basin. It is used to collect, and condenses water obtained from the glass cover, and also the fresh water yield is collected in the collecting jar through a flexible outlet hose.

3.3.2.8 Out let way

On the lower side of a solar still basin, one passage is provided to collect a fresh distillate yield obtained from the still that hole is known as the outlet way. It is connected to the collecting jar through a flexible hose. The fresh water yield is collected in a measuring jar by gravitational force only without any external device. To avoid leakage from the outlet way an insulation tape is used.

3.3.2.9 Flexible out let hose

It is used to connect the outlet of the solar still basin with the collecting jar. The hose's other end is placed into the measuring jar while the other end is attached to the basin's outflow. To avoid the leakage of fresh water, an insulating tape is used to connect the outlet pipe with the flexible hose. Nylon is used as the flexible hose material.

3.3.2.10 Drain plug

It is a small passage is made at a bottom of a still basin. For cleaning purposes, it is possible to discharge the salt water from the solar still basin. The excess storage of saline water is also drained through the drain tube. It is made up of plastic material. It's one end is inserted inside the basin while the other end is outside the basin and fixed with proper insulating material to avoid leakage of fresh water.

3.3.2.11 Sealing paste

To fix the joints of the solar still sealing paste is used. The various joints of solar still such as basin edges joints, top cover glass joints, inlet way, outlet way and drain plug joints is sealed by the sealing paste. It is also used to join the solar still accessories for avoiding any leakage from the solar still basin. The material used to make the sealing paste is silicon sealant.

3.3.2.12 Rubber feeding (Gasket)

It is the sealant material that gives the cushioning effect between the two mating parts. For avoiding leakage between the two mating parts the rubber gasket is provided. Rubber gaskets are provided on both the upper and lower surfaces of a solar still basin, as well as on a lower side of a glass cover, which creates a cushioning effect when the two mating pieces are in contact with one another. Additionally, it stops water from vaporizing when solar still and a glass cover are in contact. A gasket is made up of rubber material.

3.3.2.13 PuF and Plywood insulation

The PuF and commercial plywood is used as an insulator material in experimentation. A solar still has a PuF and plywood coating applied to all four sides, as well as the bottom, to prevent heat from escaping into the atmosphere. It has low thermal conductivity due to which it does not allow the heat to flow outside from the still.

3.3.2.14 Nano Material

The colour of the nanoparticle is white. The purity of the nanoparticle is nearly 99 + %. The mean particle size of the nanoparticle is > 60 nm, Morphology of the nanoparticle is nearly spherical. A specific heat capacity of a nanoparticle is 900 J/Kg-K. Its size is uniform. It has a high degree of particle spherically as a result, high flow ability, and high packing density. It has high thermal conductivity, hardness, etc. Nano metal oxides have a greater surface area. Alumina nanoparticles are thermodynamically stable particles over a wide temperature range. The Nano material (Aluminium Oxide) is not dissolved in water and is not destroyed under sun light. Hence it is re- usable, and lost longer. The nano material could retain more heat energy and is also easily available Nano- material (Al_2o_3) is a sensible heat storage material and it is placed inside of the solar still basin.

3.4 MEASURING INSTRUMENT

An experimental work, the various readings are measured by using some measuring instruments. Every hour, thermocouples record the temperatures of the atmosphere, basin water, glasses, condensate yield, and diffused radiation. Using a Solar Meter, the strength of sun radiation is measured. A jar is used to calculate the rate of the hourly collected desalinated water.

3.4.1 PT 100 Thermocouple and Temperature Indicator:

To measure the temperature of the solar still, a thermocouple (PT-100) (copper constantan thermocouple sensors) is used in the experiment as shown in figure.3.11. To measure the various temperature of still at a different location, twelve different thermocouples are used. The following temperatures are measured by the thermocouple, they are:

a) Atmospheric temperature
b) Inlet water temperature
c) Outlet water temperature
d) Basin water temperature
e) Glass temperature
f) Absorber Plate temperature.

To measure the atmospheric temperature the first thermocouple is used. To monitor the temperature of the absorber plate, the second through sixth thermocouples are affixed to the plate. The temperature of the salty water in the solar still's basin is measured by a seven to nine thermocouple that is installed on the basin's bottom side. On the upper edge of the solar still's basin, a thermocouple is attached to measure a temperature of a glass. All temperature readings are measured in every one hour. The measuring temperature readings are in ^{o} C. The value of the temperature reading is displaced on the digital temperature indicator shown in figure 3.12.

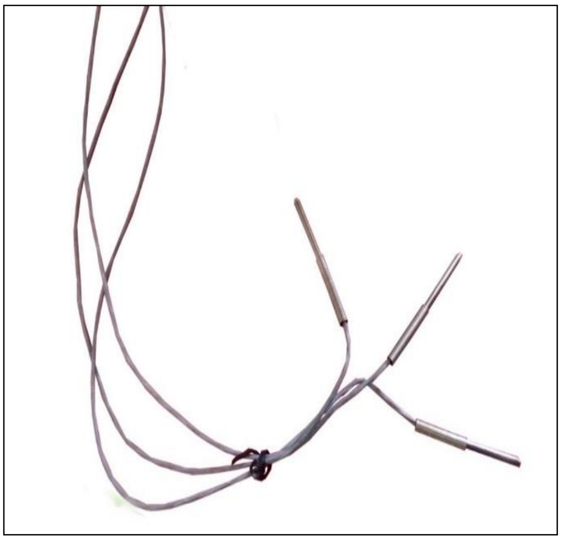


Figure 3.11. PT100 Thermocouple

Figure 3.12. Digital Temperature Indicator

3.4.2 Solar Meter:

The instrument that is used to evaluate the sun's intensity is called a solar meter. Calculating the hourly solar intensity in terms of W/m^2 requires its utilisation.

Figure 3.13. Solar Meter

3.4.3 pH and TDS Meter:

The pH Meter is the device that is used to gauge the purity of water. It measures the amount of hydrogen atom present in the water. The value of the pH meter indicates whether the water is suitable for drinking purpose or not. Normally the pH rate is 6-10. For good drinking water, the pH value is 7. As the amount of salt present in water is increased, the pH value of the water likewise rises, which makes the water unfit for human consumption and renders it useless for other purposes. The sea water is having 10 as pH value.

The device which is used to measure the solid contents dissolved in the water that device is known as TDS meter. A quality of fresh water is also indicated by the TDS value. The total dissolved solids (TDS) metre is used to determine whether or not the water contains any contaminants. The 500 mg/L to 2000 mg/L is the normal TDS rate. For drinking water, the TDS value is 100 mg/L. The sea water is having 1000 to 30, 000 mg/L of TDS value.

Figure 3.14. pH and TDS Meter

3.4.4 Collecting Jar:

It is a piece of machinery used to gather fresh water discharge that is made of glass or plastic. The collecting jar measures the distillate water that was produced by the solar still. On the outer surface of the jar, the marking is marked to measure the quantity of fresh water. The collecting jar used in experimentation for measuring distillate output is having a capacity of 1 liter.

Figure 3.15. Collecting Jar

3.5 PREPARATION OF NANOFLUID

In order to use nanoparticles to improve the thermal conductivity of fluids, it is essential to first prepare nanofluids. Aluminium oxide nanoparticles were acquired from Nanoshell Lab in Dera Bassi, Punjab (India) for the experiment, and using a two-step procedure with ground water as the base fluid, nanofluid was produced without the use of a surfactant. A nanofluid was then swirled by a magnetic stirrer for 45 minutes before being ultrasonicated for 1 hour with a Probe Sonicator. Nanofluids with 0.1% concentrations were created and used in the solar still in this study. Table 3.7 shows the nanoparticle's specifications.

$$\text{Amount of nanoparticles added in grams} = \frac{\text{Concentration in \%}}{100} \text{ x Volume of water in ml x Density of nanoparticles in grams/ml} \quad (3.9)$$

Table 3.7: Aluminium oxide nanoparticles specifications

Material	Chemical Symbol	True Density (Kg/m^3)	Average particle size (nm)	Thermal Conductivity (W/mK)
Aluminium Oxide	Al_2O_3	3900	10 – 14	46

Table 3.8: The thermal conductivity and cost of various nanoparticles [126].

Sr. No.	Nanopowders	Quantity	Thermal conductivity ($W\ m^{-1}\ °K^{-1}$)	Cost/Rs
1	Tin oxide (SnO_2)	25g	36	1500
2	Aluminium oxide (Al_2O_3)	25g	46	2000
3	Iron oxide (Fe_2O_3)	25g	7	1750
4	Zinc oxide (ZnO)	100 g	29	1500
5	Titanium dioxide (TiO_2)	100 g	8.5	12,859
6	Gold nanopowder (Au)	1 g	315	35,029
7	Carbon nanotubes	0.25 g	3000 – 6000	19,521
8	Copper oxide (CuO)	5 g	76	3111
9	Boron nitride (BN)	50 g	30 – 33	4911
9	Zirconium (IV) oxide (ZrO_2)	100 g	2	10,611
10	Diamond nanopowder (C)	l g	900	8755
11	Silicon nitride (Si_3N_4)	25g	29 30	11,434
12	Aluminium nitride (A1N)	50 g	140 – 180	5193
14	Silver nanopowder (Ag)	5 g	424	12,917

3.6 OPERATING PROCEDURE

It is important to ensure there are no leaks before beginning the experiment. The joints of the inlet and outlet portions, as well as the pipe fittings, were all thoroughly checked for leaks and professionally sealed to reduce the likelihood of leaks. To prevent vapour leakage, a glass cover is correctly positioned over a basin.

- A thermocouple is affixed to an absorber plate, inner glass cover, and submerged under a basin water to monitor a temperature.
- A flexible hose line is securely attached to the output path and collecting jar.

- The TDS and pH value of water is tested which is used for desalination.
- The input valve supplies water to a basin.
- An upper portion of a glass cover is properly cleaned with the tissue paper or cloth to avoid the reflection of solar still.
- The absorber plate, atmosphere, glass, and basin water temperatures are recorded hourly using the digital temperature indicator.
- When sunlight strikes a glass cover, it is absorbed by an absorber plate that is painted black and then transmitted to the water.
- The water absorbs the radiation due to which its temperature rises and is converted into vapour.
- On the inside of the glass cover, the vapour rises and condenses, discharging heat into the surrounding area.
- The condensate water is collected in the drain tube which is fixed at a bottom portion of a glass cover.
- Fresh yield is collected in the measurement jar and measured on at hourly basis.
- The TDS and pH value of fresh yield is calculated.
- The solar metre takes readings on an hourly basis to determine the amount of radiation received from the sun.
- An air temperature, a temperature of an absorber plate, a temperature of a glass, and a temperature of a water in a basin are all measured every hour.

3.7 DATA REDUCTION

The experimental data was compiled to determine the average absorber plate temperature, average glass temperature, average water temperature, sun intensity, and fresh yield. This data is then used to determine the efficiency of the still.

1. Average Temperature of Absorber Plate:

The temperature of the absorber plate is recorded at various locations and the average absorber plate temperature (T_p) is calculated:

$$T_p = \frac{T_2+T_3+T_4+T_5+T_6}{5} \tag{3.10}$$

Where:

T_2, T_3, T_4, T_5, and T_6 are the temperature of the absorber plate (^oC).

2. Average Water Temperature:

The temperature of the water is measured at a number of different locations, and from those readings, the average temperature of the water (Tw) is determined.:

$$T_w = \frac{T_7+T_8+T_9}{3} \qquad (3.11)$$

Where:

T_7, T_8, and T_9 are the temperature of water (^{o} C).

3. Average Glass Temperature:

The temperature of the glass is measured in a number of different spots, and from those readings, the "average glass temperature" (Tg) is determined:

$$T_g = \frac{T_{10}+T_{11}+T_{12}}{3} \qquad (3.12)$$

Where:

T_{10}, T_{11}, and T_{12} are the temperature of the glass (^{o} C).

4. Mean Temperature of Water and Glass:

The mean temperature of water and glass (T_i) is calculated:

$$T_i = \frac{T_g+T_w}{2} \qquad (3.13)$$

Where:

T_g = Average temperature of glass (^{o} C).

T_w = Average temperature of water (^{o} C).

5. Latent heat of vaporization of water [4], [90].**:**

The latent heat of the Vaporization of water (h_{fg}) is calculated:

$$h_{fg} = 3.1615(10^6 - 761.6\ T_i), \text{When } T_i > 70^o\text{C} \qquad (3.14)$$

$$h_{fg} = 2.4935\left(10^6 - 947.79\ T_i + 0.13132\ T_i^{\,2} - 0.0047974\ T_i^{\,3}\right), \text{When } T_i < 70^o\text{C}$$

(3.15**)**

Where:

T_i = Mean temperature of glass and water (^{o} C).

6. Efficiency of still [4], [90], [124], [125]**:**

$$\eta_{th} = \frac{\Sigma\, m_{ew}\, h_{fg}}{3600\ A_p \Sigma\, I\,(t)} \qquad (3.16)$$

Where:

h_{fg} = latent heat of vaporization of water (J/Kg).

A_p = Area of absorber plate (m^2).

I (t) = solar radiation (W/m^2).

m_{ew} = Fresh Yield (L).

3.8 VALIDATION FOR EXPERIMENTAL RESULT WITH PREVIOUS STUDIES

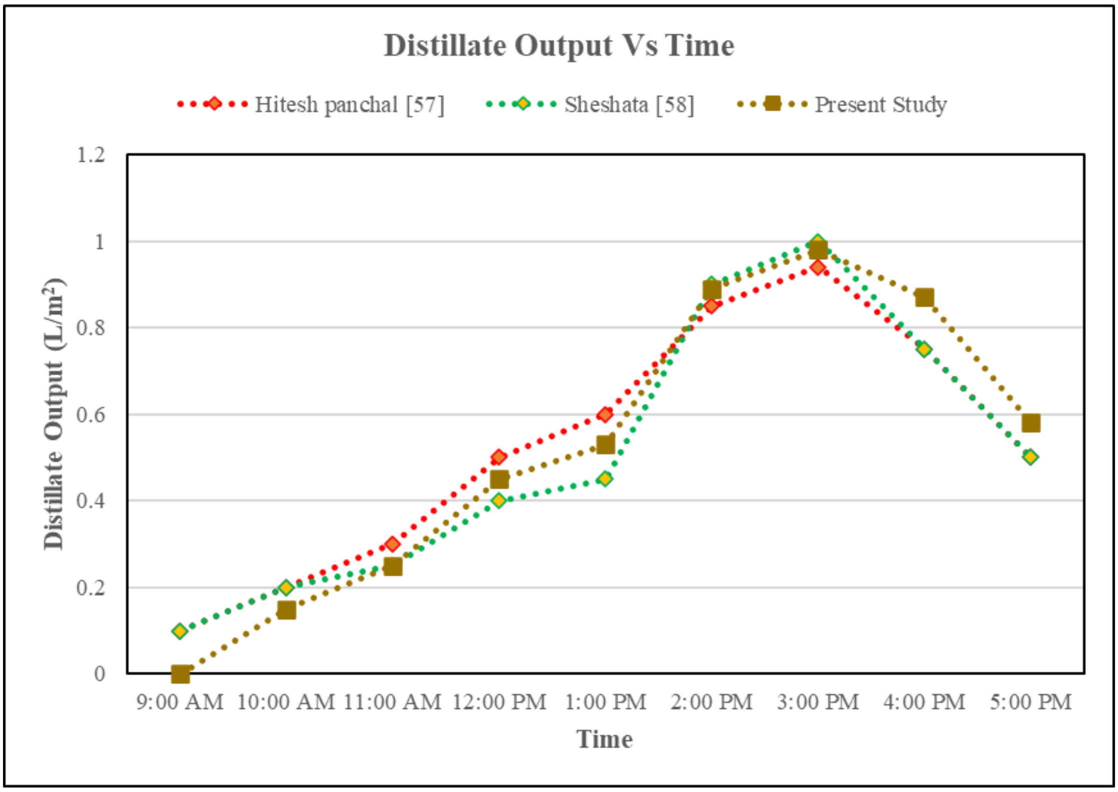


Figure 3.16. Validation of experimental results

The present experimental results have been validated by comparing them to the work of other researchers, as shown in Figure 3.16. According to the graph, the readings that were acquired for the current study effort are quite similar to the results that were gained from a prior research work that was carried out by a variety of researchers. The conclusion that can be drawn from this is that the experimental setting has been verified, and the result that was achieved may be trusted.

The results obtained during experimentation is discussed in the next chapter.

CHAPTER 4

RESULTS & DISCUSSION

This chapter provides a detailed evaluation of the performance studies based on experimental data gathered, yield output, and different component temperatures.

The data generated on the experimental setup and the results obtained for different cases of solar still for different basin conditions from which an effect obtained on the fresh yield productivity and efficiency of still are presented. We go into great detail on cost analysis and water quality.

The following cases have been discussed:

Case-1: Inclined solar still having stepped absorber with corrugated fin (Winter).

Case-2: Inclined solar still having stepped absorber with corrugated fin integrated with vacuum tubes (Winter).

Case-3: Inclined solar still having stepped absorber with corrugated fin (Summer).

Case-4: Inclined solar still having stepped absorber with corrugated fin integrated with vacuum tubes (Summer).

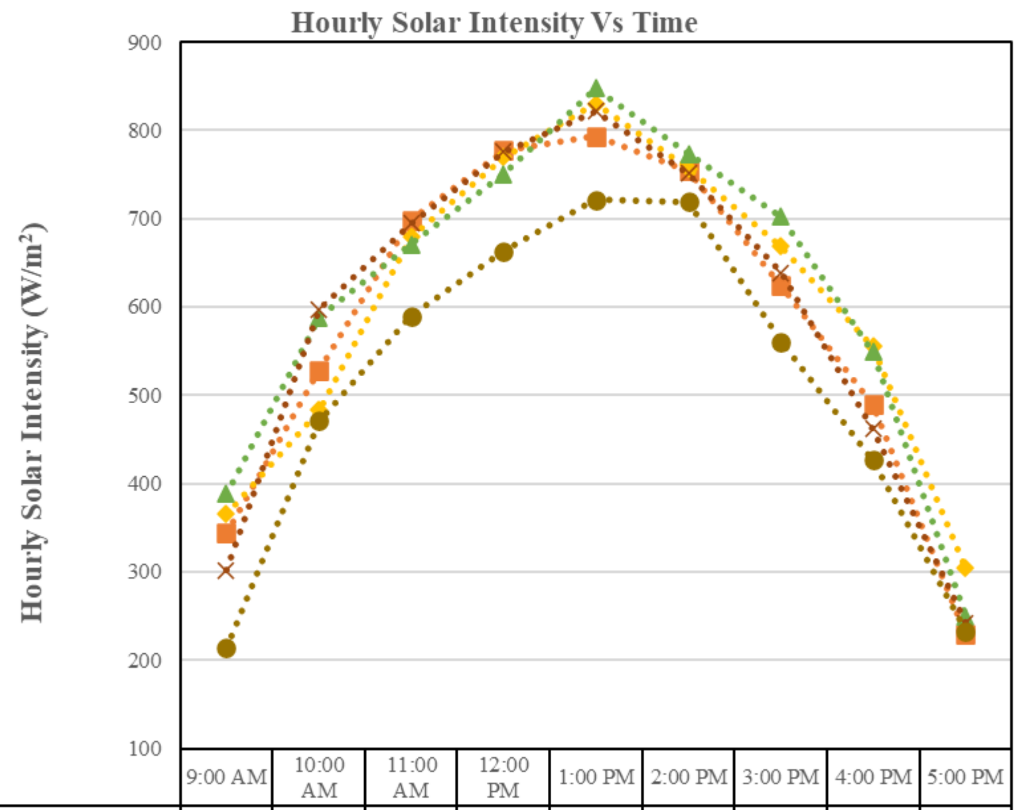
Case-5: Inclined solar still having stepped absorber with corrugated fin integrated with vacuum tubes by using Nanoparticles.

4.1 CASE-1: INCLINED SOLAR STILL HAVING STEPPED ABSORBER WITH CORRUGATED FIN (WINTER SEASON).

Based on the values that were measured for the different components, such as the solar incidence, the temperature of the absorber plate, the temperature of the glass, and the temperature of the basin water. A number of the subsequent observations have been plotted and discussed for an inclined solar still having stepped absorber with corrugated fin (Winter season).

4.1.1 Hourly Solar Intensity

The quantity of energy that is collected from the sun in the form of electromagnetic waves is what is referred to as solar intensity. Increasing the temperature of the various components that are employed in a solar still requires solar intensity. Both the quantity of fresh produce that may be collected from a still and its overall effectiveness are dependent on the amount of available solar energy.



	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM
03-02-2022	344	529	698	777	793	754	624	490	229
04-02-2022	366	483	679	769	830	757	668	555	304
06-02-2022	389	589	671	751	848	773	702	549	250
08-02-2022	302	597	694	776	822	751	639	462	243
14-02-2022	214	471	590	664	721	719	561	427	233

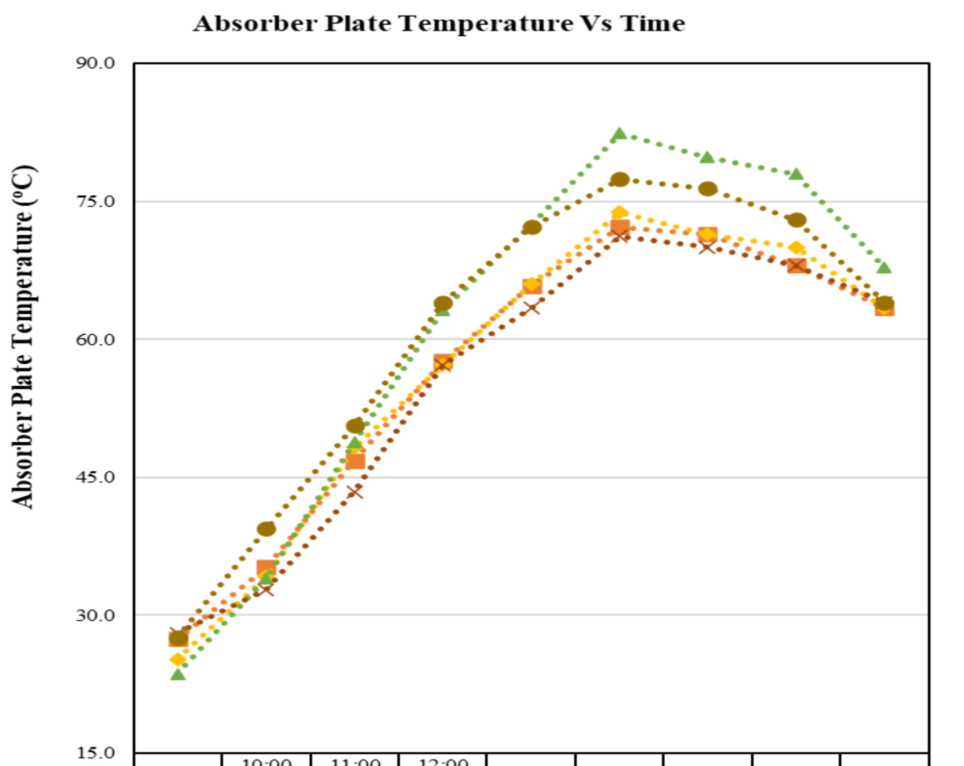
Time (Hrs.)

Figure 4.1. Time-dependent Changes in Solar Intensity (Case-1)

The change in hourly sun intensity for inclined solar stills with stepped absorbers and corrugated fins in the winter season for various testing days is depicted in Figure 4.1. It is evident from the graph that on all of the trial days, the hourly sun intensity rises from 9:00 am until 1:00 pm, after which it begins to steadily decline. For all days, the highest and minimum values of the hourly sun intensity are respectively measured at 1:00 pm and 5:00 pm. On February 3, 2022, at 1:00 pm and 5:00 pm, respectively, the maximum value of 793 W/m^2 and the minimum value of 229 W/m^2 are measured. In the same vein, the highest value of hourly sun intensity on the 04th, 06th, 08th, and 14th of February 2022 is 830 W/m^2, 848 W/m^2, 822 W/m^2, and 721 W/m^2 respectively, while the lowest value of hourly solar intensity is 304 W/m^2, 250 W/m^2, 243 W/m^2, and 233 W/m^2 respectively.

4.1.2 Absorber Plate Temperature

Solar stills have essential absorber plate temperatures. Because absorber plate temperature determines still output. The following graph shows the absorber plate temperature during several experimental days.



	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM
03-02-2022	27.4	35.2	46.8	57.6	65.8	72.2	71.4	68.0	63.4
04-02-2022	25.2	34.2	48.2	57.2	66.0	73.8	71.4	70.0	63.4
06-02-2022	23.6	34.0	48.8	63.2	72.4	82.4	79.8	78.0	67.8
08-02-2022	28.0	32.8	43.4	57.2	63.4	71.2	70.0	68.0	64.0
14-02-2022	27.6	39.4	50.6	64.0	72.2	77.4	76.4	73.0	64.0

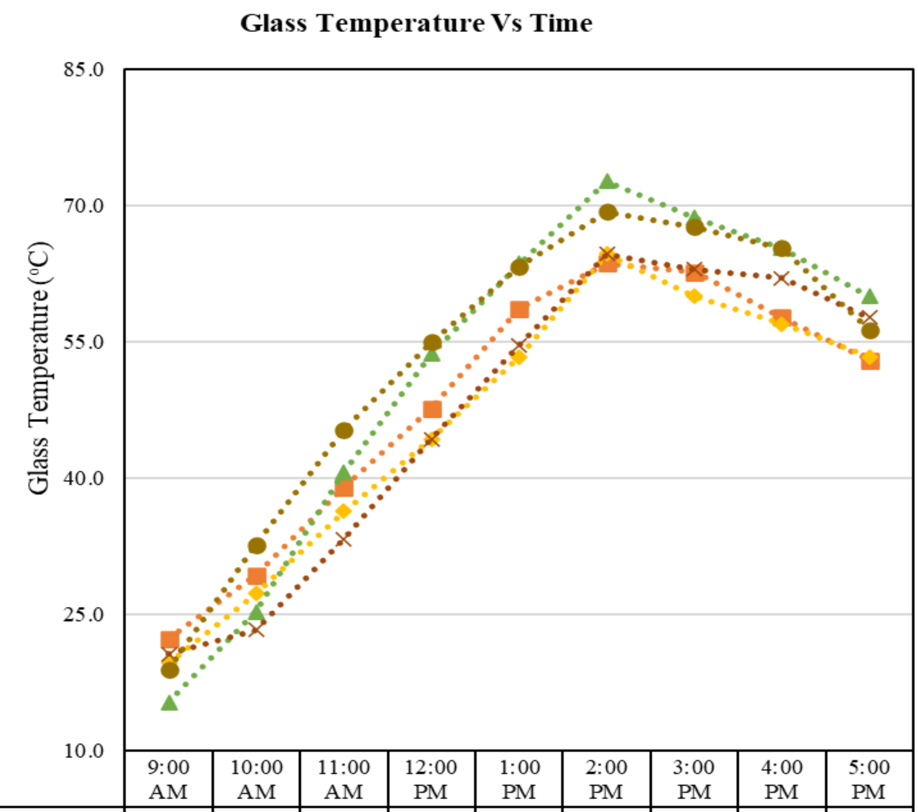
Figure 4.2. Time-dependent Temperature Variation of the Absorber Plate (Case-1).

For several trial days, Figure 4.2 shows the temperature of the absorber plate for inclined solar stills with stepped absorbers and corrugated fins changes over the winter.

From the graph, it is evident that for each of the experiment days, the absorber plate temperature increases from 9:00 am to 2:00 pm before beginning steadily fall, just as solar radiation rises from 9:00 am to 1:00 pm before falling. A highest temperature recorded for the absorber plate was 82.4°C on February 6, 2022, at 2:00 pm.

4.1.3 Glass Temperature

Solar still glass cover temperature matters. It controls condensation and solar still yield. The graph below illustrates glass temperature over a day. Solar intensity affects its temperature.



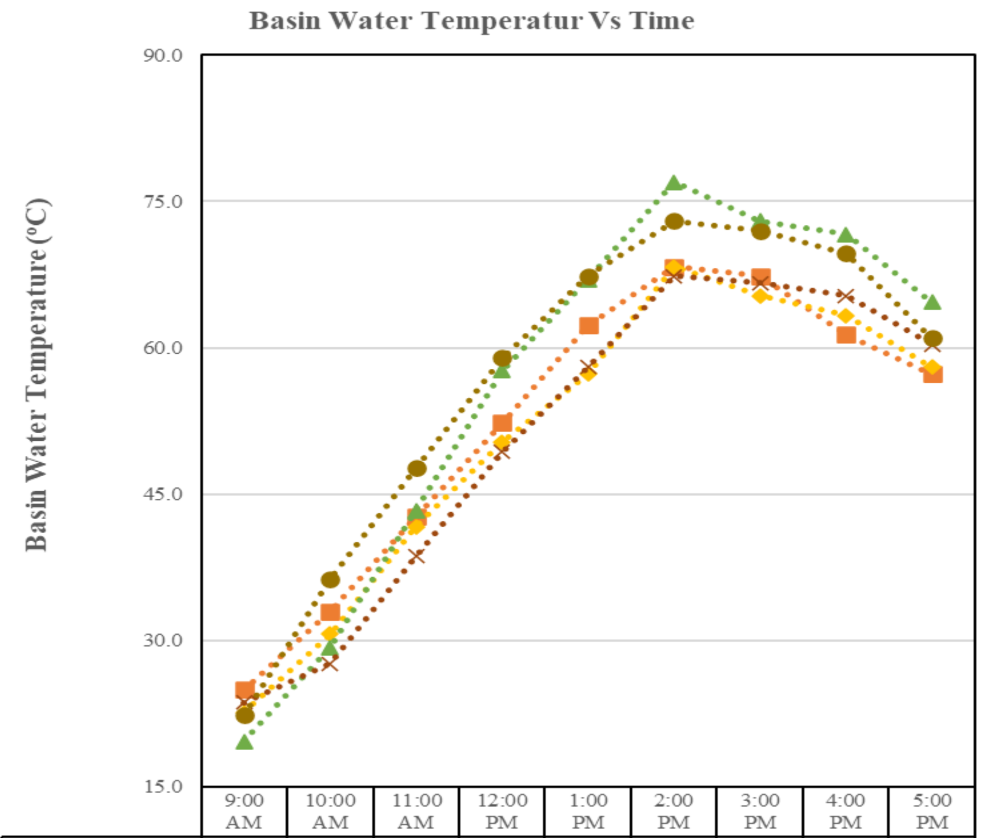
	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM
03-02-2022	22.3	29.3	39.0	47.7	58.7	63.7	62.7	57.7	53.0
04-02-2022	19.7	27.3	36.3	44.3	53.3	64.7	60.0	57.0	53.3
06-02-2022	15.3	25.3	40.7	53.7	63.7	72.7	68.7	65.3	60.0
08-02-2022	20.7	23.3	33.3	44.3	54.7	64.7	63.0	62.0	57.7
14-02-2022	19.0	32.7	45.3	55.0	63.3	69.3	67.7	65.3	56.3

Figure 4.3. Temperature Change in Glass with Time (Case-1)

Figure 4.3 depicts the fluctuation in glass temperature for various testing days for an inclined solar still with a stepped absorber and corrugated fins in winter season. From the graph, it is obvious that for each of the experiment days, the glass temperature increases from 9:00 am to 2:00 pm, after which it initiates to steadily fall, just as the solar radiation rises from 9:00 am to 1:00 pm, before falling again. A highest glass temperature measured was 72.7 ^{o}C on February 6, 2022, at 2:00 pm.

4.1.4 Basin Water Temperature

Basin water is solar still water that evaporates to provide new output. Fresh production depends on water temperature. Evaporation and production increase with basin water temperature.



	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM
03-02-2022	25.0	33.0	42.7	52.3	62.3	68.3	67.3	61.3	57.3
04-02-2022	22.7	30.7	41.7	50.3	57.3	68.3	65.3	63.3	58.0
06-02-2022	19.7	29.3	43.3	57.7	67.0	77.0	73.0	71.7	64.7
08-02-2022	23.7	27.7	38.7	49.3	58.0	67.3	66.7	65.3	60.3
14-02-2022	22.3	36.3	47.7	59.0	67.3	73.0	72.0	69.7	61.0

Figure 4.4. The temperature of the water in the basin changes throughout time (Case-1).

For various testing days, Figure 4.4 illustrates the variation in basin water temperature over the winter for an inclined solar still with a stepped absorber and corrugated fins. From the graph, it is obvious that for each of the experiment days, the basin's water temperature rises from 9:00 O'clock to 2:00 O'clock before gradually falling, just as the sun's rays rise from 9:00 am to 1:00 pm before falling. On February 6, 2022, at 2:00 pm, the greatest basin water temperature recorded was 77.0°C.

4.1.5 Absorber Plate, Glass and Basin Water Temperature for Different Experimental Days

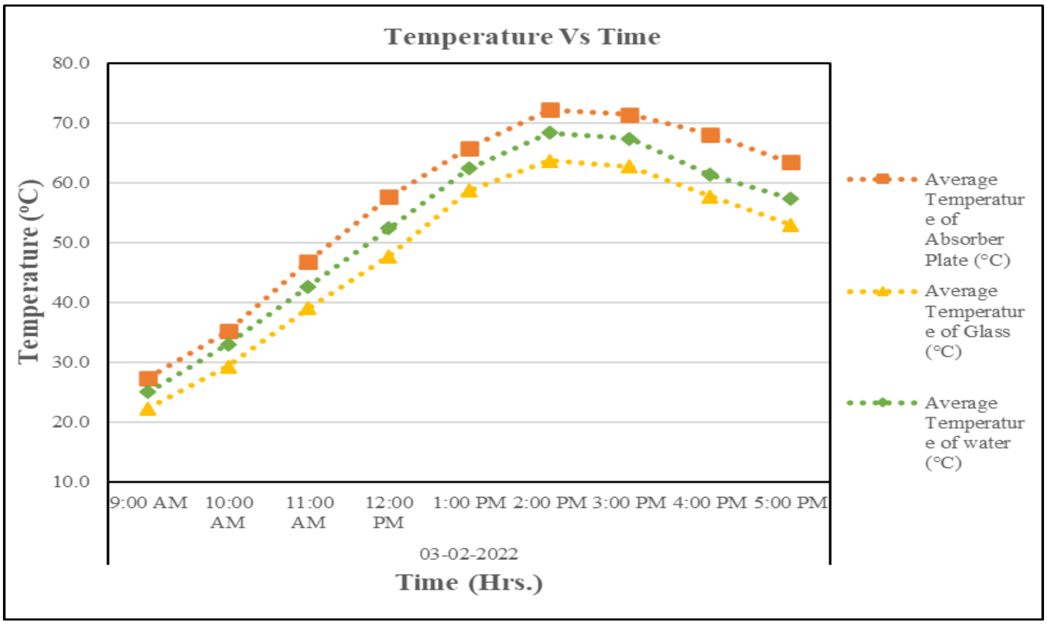


Figure 4.5. Shows the evolution of the water's temperature in the basin, glass, and absorber plate on February 3, 2022.

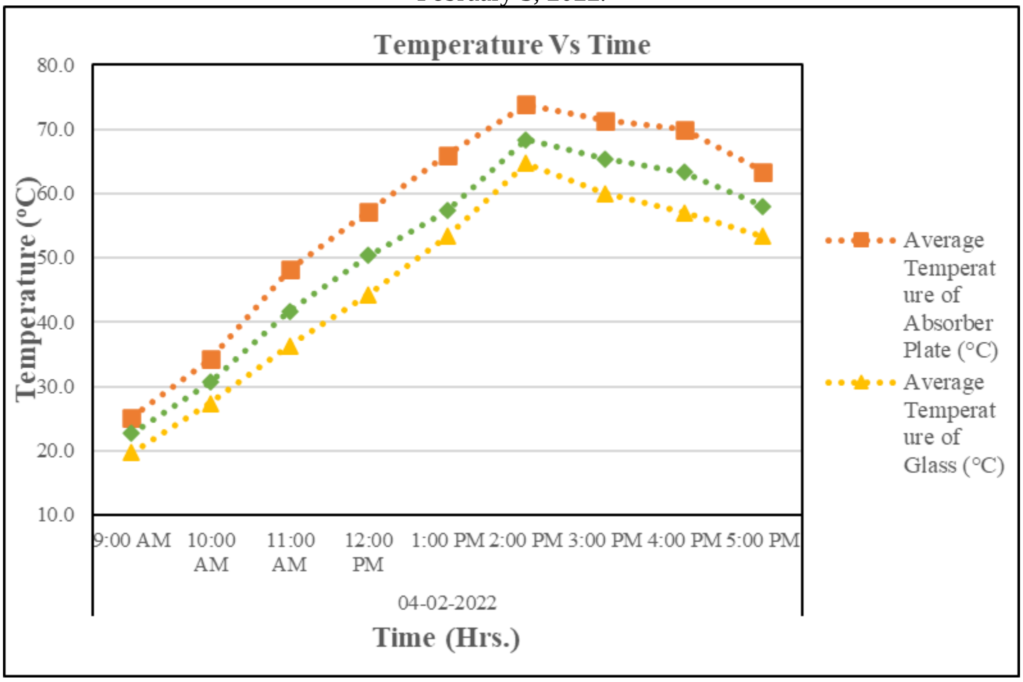


Figure 4.6. Shows the evolution of the water's temperature in the basin, glass, and absorber plate on February 4, 2022.

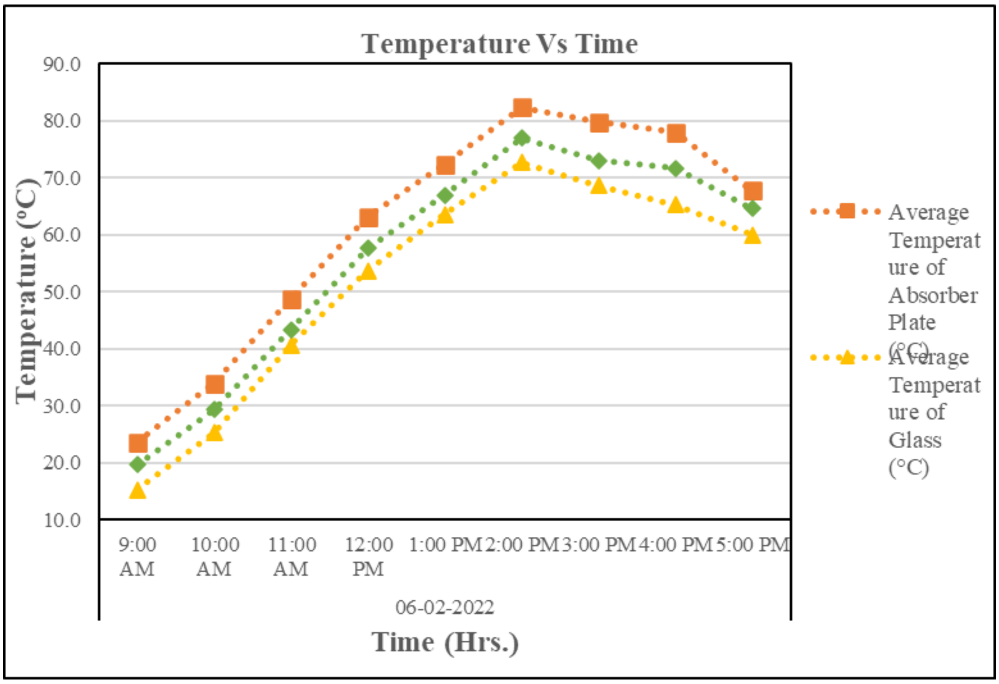


Figure 4.7. Shows the evolution of the water's temperature in the basin, glass, and absorber plate on February 6, 2022.

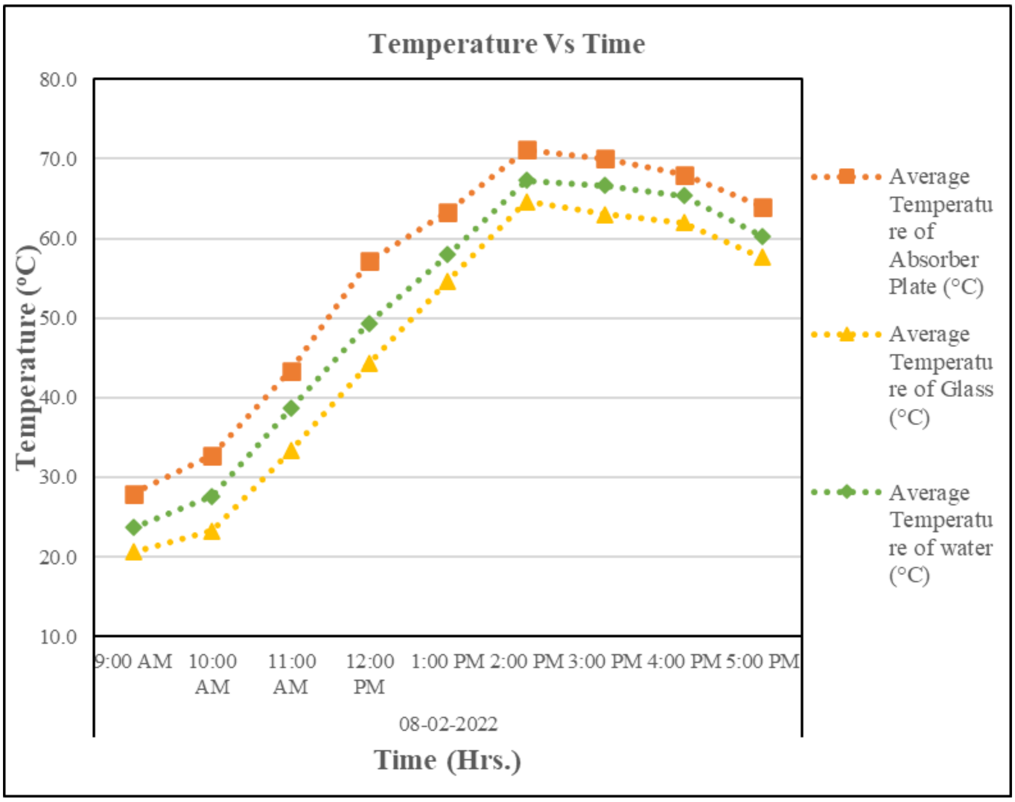


Figure 4.8. Shows the evolution of the water's temperature in the basin, glass, and absorber plate on February 8, 2022.

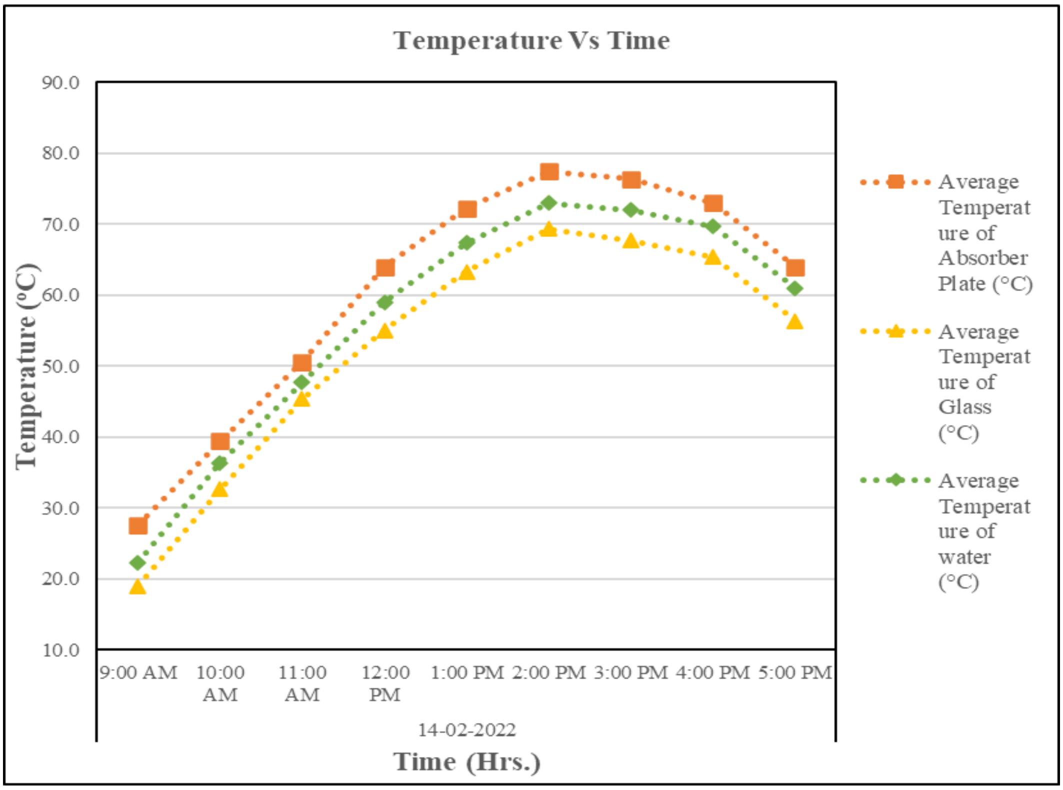
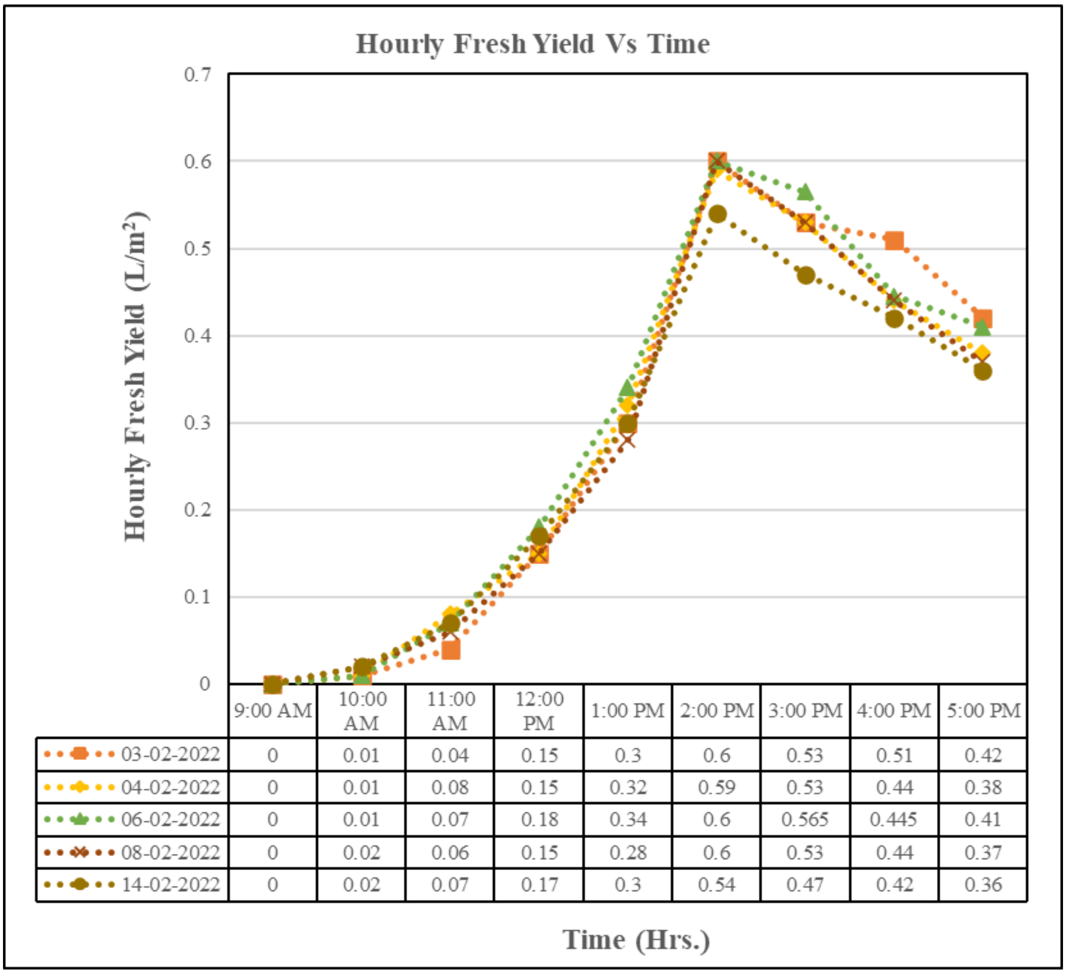


Figure 4.9. Shows the evolution of the water's temperature in the basin, glass, and absorber plate on February 14, 2022.

The temperature of the water that was collected in the basin, the glass, and the absorber in an inclined solar still with a stepped absorber and corrugated fins is depicted in figures 4.5 to 4.9. These figures show the fluctuation in temperature that occurred over the course of many test days. The graph makes it abundantly clear that throughout the course of each day of the experiment, the temperature of the absorber plate, the glass, and the water in the basin all increase from nine in the morning until two in the afternoon, at which point they all begin to gradually decrease. This coincides with the rise in solar radiation from nine in the morning until one in the afternoon, after which it begins to gradually decrease. The absorber plate, the glass, and the water in the basin all achieved their highest recorded temperatures on February 3, 2022 at 2:00 p.m., which were respectively 72.7 °C, 63.7 °C, and 68.3 °C. In a manner comparable to this, the maximum temperatures for the absorber plates on February 4, February 8, and February 14 in the year 2022 at 2:00 p.m. are 73.8°C, 82.4°C, 71.2°C, and 77.4°C, respectively; the highest temperatures for the glass are 64.7°C, 72.7°C, and 64.7°C, respectively; and the highest temperatures for the water in the basin are 68.3°C, 77.0°C, and 67.3°C

4.1.6 Hourly Fresh Yield

The fresh water obtained from still is measured on hourly basis, that measured quantity is known as hourly fresh yield. It is determined on an hourly basis how much energy was received by the water on an hourly basis and how much water will get transformed into new output in order to establish the hourly efficiency of the still. This is done by measuring it.



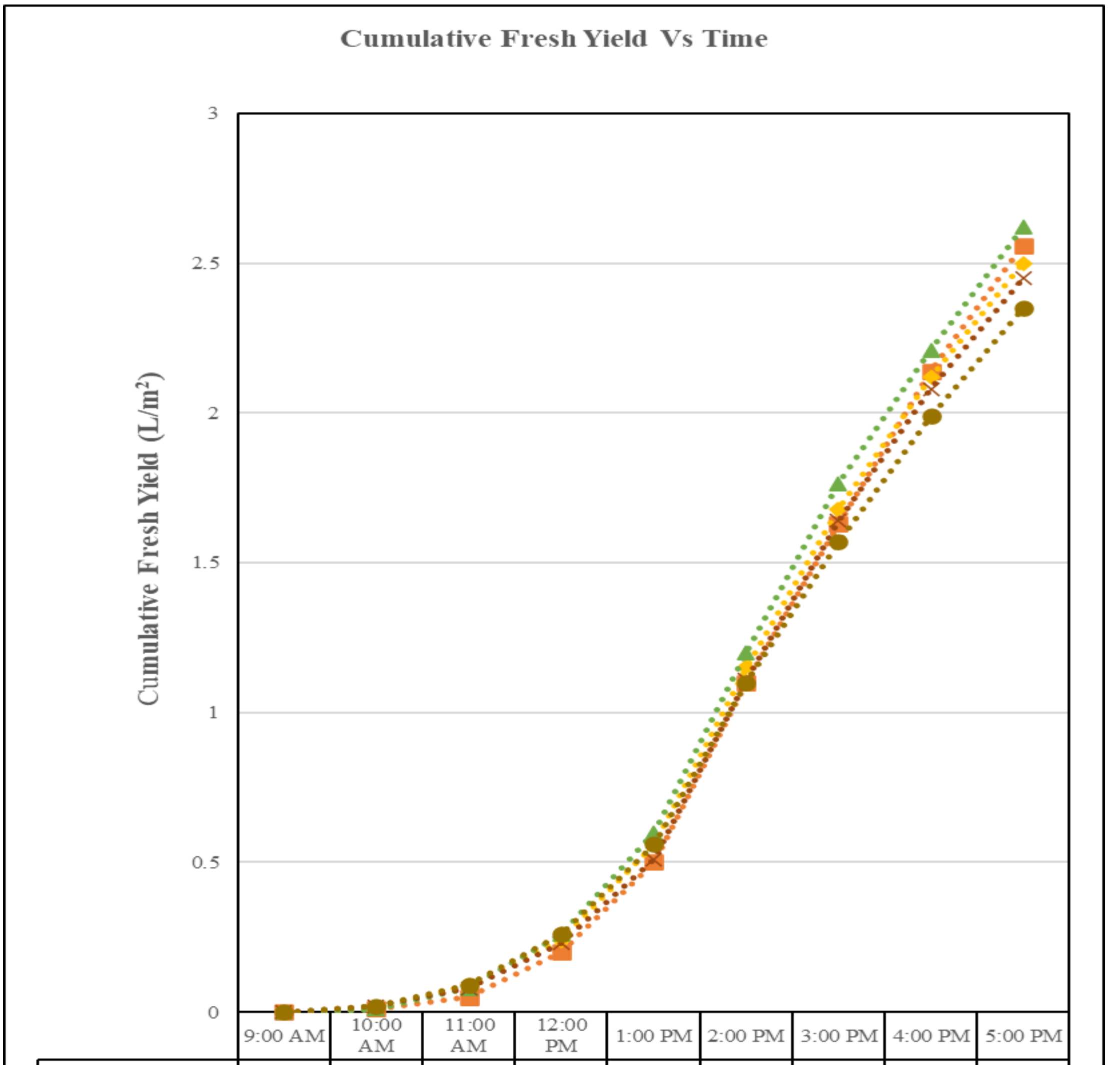
	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM
03-02-2022	0	0.01	0.04	0.15	0.3	0.6	0.53	0.51	0.42
04-02-2022	0	0.01	0.08	0.15	0.32	0.59	0.53	0.44	0.38
06-02-2022	0	0.01	0.07	0.18	0.34	0.6	0.565	0.445	0.41
08-02-2022	0	0.02	0.06	0.15	0.28	0.6	0.53	0.44	0.37
14-02-2022	0	0.02	0.07	0.17	0.3	0.54	0.47	0.42	0.36

Figure 4.10. Time-dependent Change in Hourly Fresh Yield (Case-1).

For various testing days, Figure 4.10 displays the variance in hourly fresh yield for an inclined solar still with a stepped absorber and corrugated fins in winter season. The graph shows that for all of the testing days, the hourly fresh yield increases between 9:00 am and 2:00 pm, after which it begins to steadily decrease. Since the amount of fresh yield produced depends on sun intensity, which rises from 9:00 am to 1:00 pm and then falls, the peak amount is produced at 2:00 pm. The highest hourly fresh yield measurement was 0.6 L/m^2 on February 3, 2022, at 2:00 pm. In a similar vein, the highest hourly fresh yield for the 04th, 06th, 08th, and 14th of February 2022 will be 0.59 L per m^2, 0.60 L per m^2, 0.60 L per m^2, and 0.54 L per m^2 at 2.00 pm, respectively.

4.1.7 Cumulative Fresh Yield

The total fresh water obtained from still for a particular experimental day is measured, that measured quantity is known as cumulative fresh yield. It is measured to determine the efficiency of the still for that particular day.



	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM
03-02-2022	0	0.01	0.05	0.2	0.5	1.1	1.63	2.14	2.56
04-02-2022	0	0.01	0.09	0.24	0.56	1.15	1.68	2.12	2.5
06-02-2022	0	0.01	0.08	0.26	0.6	1.2	1.765	2.21	2.62
08-02-2022	0	0.02	0.08	0.23	0.51	1.11	1.64	2.08	2.45
14-02-2022	0	0.02	0.09	0.26	0.56	1.1	1.57	1.99	2.35

Figure 4.11. Time-dependent Change in Cumulative Fresh Yield (Case-1).

The fluctuation of the cumulative fresh production for an inclined solar still with a stepped absorber and corrugated fins over the winter for several testing days is shown in Figure 4.11. The graph shows that the fresh yield reaches its peak around 2:00 pm on all experimental days. Because the amount of fresh produce produced depends on sunlight intensity, which rises from 9:00 am to 1:00 pm and then drops, the largest amount is produced at 2:00 pm. The highest cumulative fresh yield measurement was 2.62 L per m^2 per day on February 6th, 2022. Similarly, the cumulative fresh yield values for February 3, 4, 8, and 14 in 2022 are 2.56 L per m^2 per day, 2.5 L per m^2 per day, 2.45 L per m^2 per day, and 2.35 L per m^2 per day respectively.

4.1.8 Solar Intensity and Absorber Plate Temperature

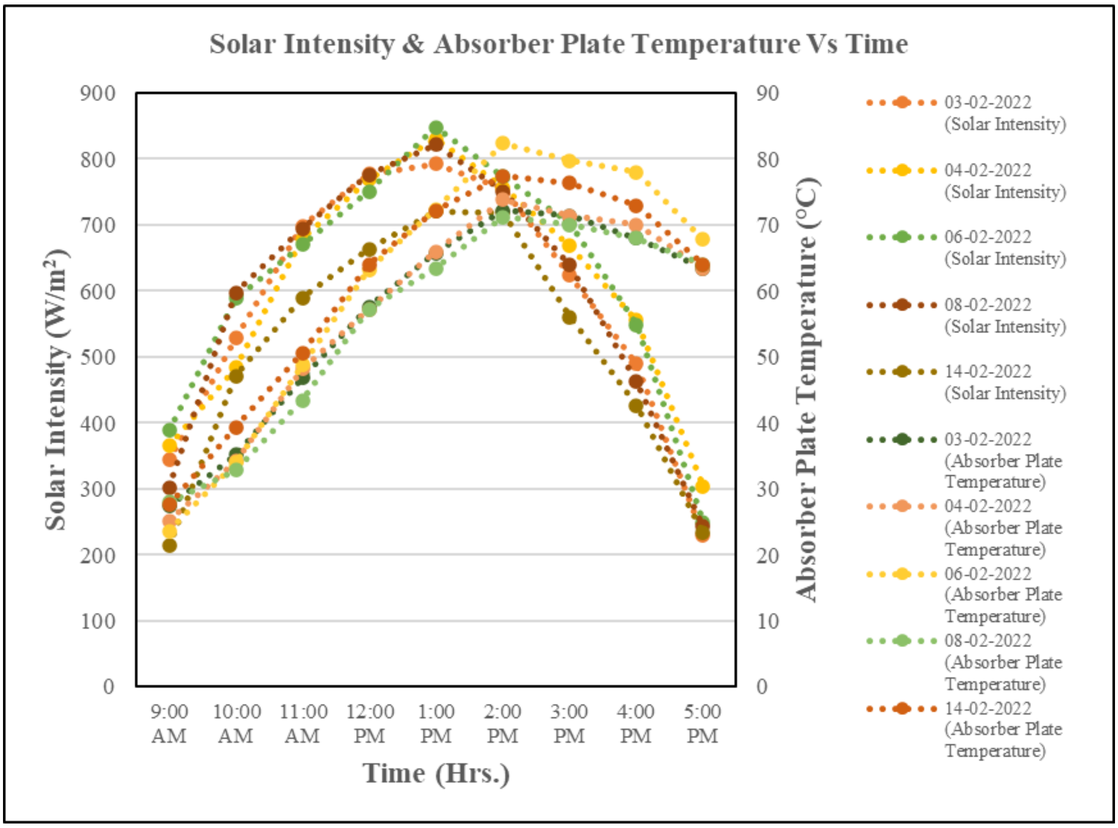


Figure 4.12. Solar Intensity and Absorber Plate Temperature with Time (Case-1)

Figure 4.12 illustrates how the sun intensity and absorber plate temperature changed over the course of many testing days during the winter season for inclined solar stills with stepped absorbers and corrugated fins. These stills were subjected to the tests on a variety of days. It has been found that the temperature of the absorber plate increases from 9:00 am to 2:00 pm on each of the testing days. After that, the temperature begins to gradually decrease. It has also been found that the solar intensity increases between the hours of 9:00 am and 1:00 pm on each of the testing days. As the absorber plate temperature totally depends upon the solar intensity, we get the maximum solar intensity at 1:00 pm for all the testing days therefore the highest temperature of the absorber plate is found at 2:00 pm. Because an absorber plate temperature remains greater after absorption of heat from the sun.

4.1.9 Daily Efficiency of Still

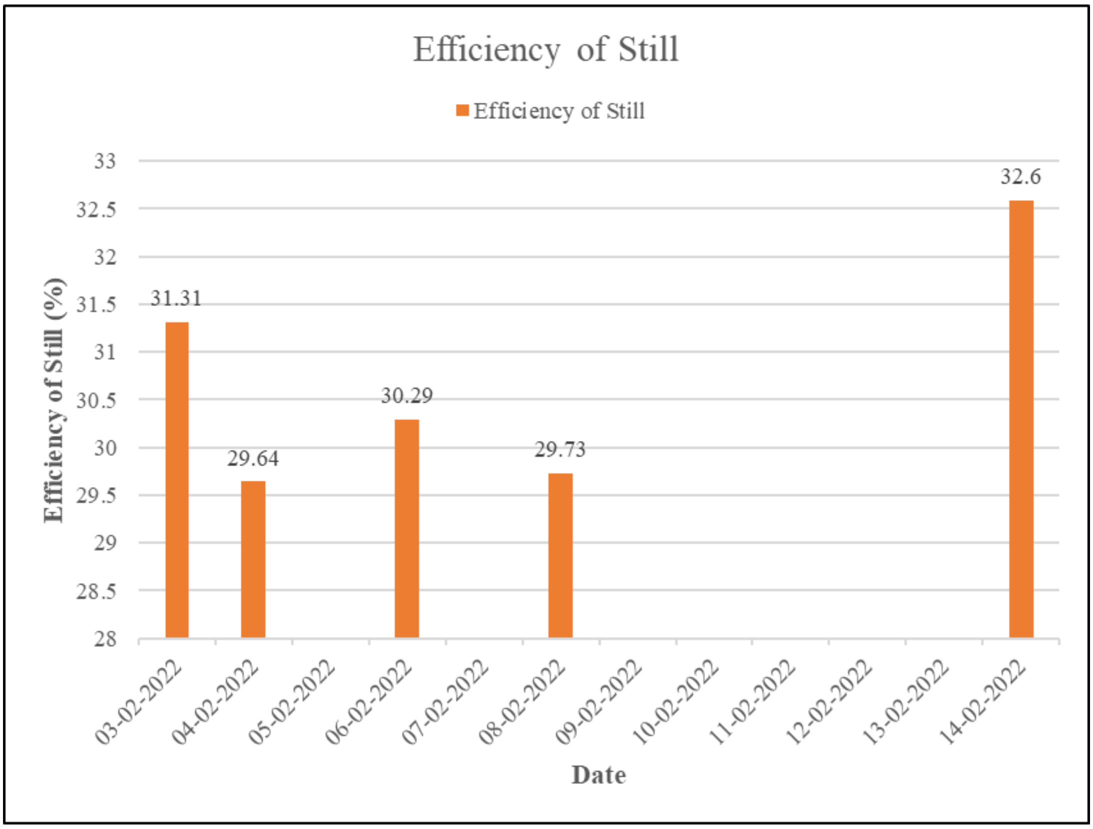


Figure 4.13. Daily Efficiency of Still (Case-1)

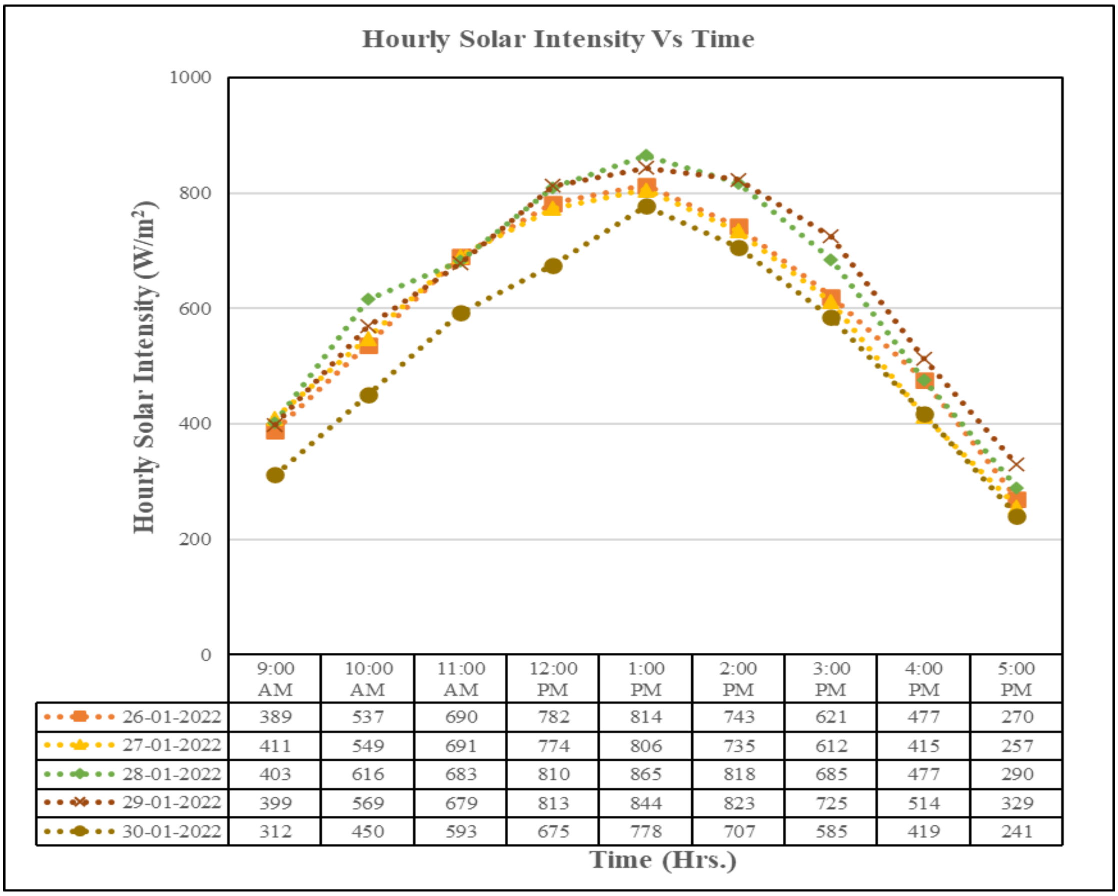
For various test days, Figure 4.13 displays a everyday efficiency for an inclined solar still with a stepped absorber and corrugated fins in winter season. According to the graph, the still will operate at its highest daily efficiency on February 14th, 2022, and its lowest daily efficiency on February 4th, 2022, at 29.64%. As the efficiency is depends upon the fresh output of still and solar intensity, that's why the variation in efficiency for different experimental days is recorded.

4.2 CASE-2: INCLINED SOLAR STILL HAVING STEPPED ABSORBER WITH CORRUGATED FIN INTEGRATED WITH VACUUM TUBES (WINTER SEASON).

Based on the measured value of various components like solar incident, temperature of absorber plate, glass temperature and basin water temperature. Various following observations has been plotted and discussed for inclined solar still having stepped absorber with corrugated fin integrated with vacuum tubes (Winter season).

4.2.1 Hourly Solar Intensity

The quantity of energy that is collected from the sun in the form of electromagnetic waves is what is referred to as solar intensity. Increasing the temperature of the various components that are employed in a solar still requires solar intensity. The production of fresh produce received from still as well as the efficiency of still is largely dependent on the amount of sun intensity that is present.



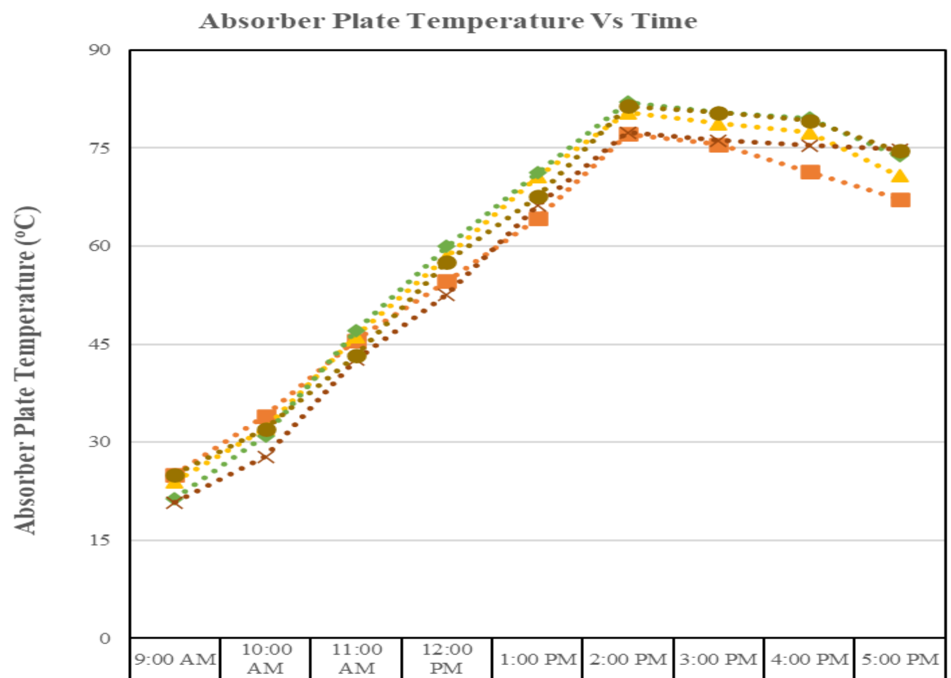
	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM
26-01-2022	389	537	690	782	814	743	621	477	270
27-01-2022	411	549	691	774	806	735	612	415	257
28-01-2022	403	616	683	810	865	818	685	477	290
29-01-2022	399	569	679	813	844	823	725	514	329
30-01-2022	312	450	593	675	778	707	585	419	241

Figure 4.14. Time-dependent Changes in Solar Intensity (Case-2).

Figure 4.14 depicts the hourly sun intensity fluctuation for an inclined solar still with a stepped absorber and corrugated fins combined with vacuum tubes in the winter season for various trial days. It is evident from the graph that on all of the trial days, the hourly sun intensity rises from 9:00 am until 1:00 pm, after which it begins to steadily decline. For all days, the highest and minimum values of the hourly sun intensity are respectively measured at 1:00 pm and 5:00 pm. On January 26, 2022, the highest value of 814 W/m^2 and the minimum value of 270 W/m^2 are attained at 5:00 pm and 1:00 pm respectively. In a similar fashion, the highest values of hourly solar intensity for the 27th, 28th, 29th, and 30th of January 2022 are 806 W/m^2, 865 W/m^2, and 844 W/m^2 respectively, while the lowest values are 257 W/m^2, 290 W/m^2, 329 W/m^2, and 241 W/m^2 appropriately.

4.2.2 Absorber Plate Temperature

The critical temperature of the solar still is determined by the temperature of the absorber plate. Seeing as since the temperature of the absorber plate is the sole factor that determines the output of the still. As a result, the temperature of the absorber plate was monitored during the experiment and recorded on the accompanying graph at various points in time.



	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM
26-01-2022	25	34	45.6	54.6	64.2	77.2	75.6	71.4	67.2
27-01-2022	24	32	46.2	58.4	70.6	80.4	78.8	77.4	70.8
28-01-2022	21.4	31	47	60	71.2	82	80.4	79.6	73.8
29-01-2022	20.8	27.8	42.6	52.6	66.2	77.4	76.2	75.4	74.8
30-01-2022	25	32	43.2	57.6	67.6	81.4	80.4	79.2	74.6

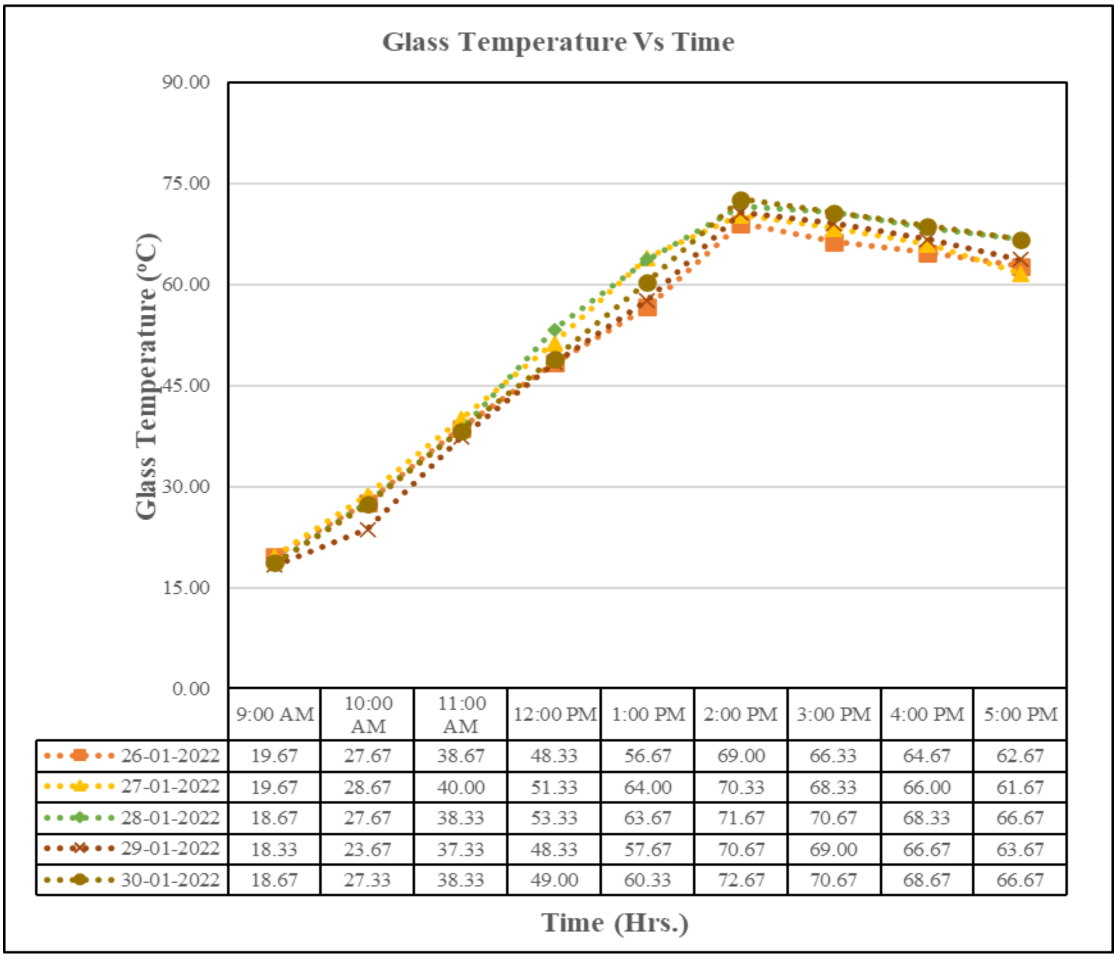
Time (Hrs.)

Figure 4.15. Time-dependent Temperature Variation of the Absorber Plate (Case-2).

Figure 4.15 depicts a temperature variation of an absorber plate for an inclined solar still having stepped absorber with corrugated fins and integrated with vacuum tubes in the winter season over various testing days. From the graph, it is evident that for each of the experiment days, the absorber plate temperature rises from 9:00 am to 2:00 pm before beginning to steadily fall, just as solar radiation rises from 9:00 am to 1:00 pm before falling. A highest temperature recorded for the absorber plate is 82°C on January 28, 2022, at 2:00 pm.

4.2.3 Glass Temperature

The temperature of the glass cover is a very crucial aspect in the solar still. because it determines the pace of condensation and, as a result, the amount of water that can be extracted from the solar still. The graph that follows illustrates how the temperature of the glass changed during the course of a single day. Its temperature is also dependent on the amount of sunlight that is received.



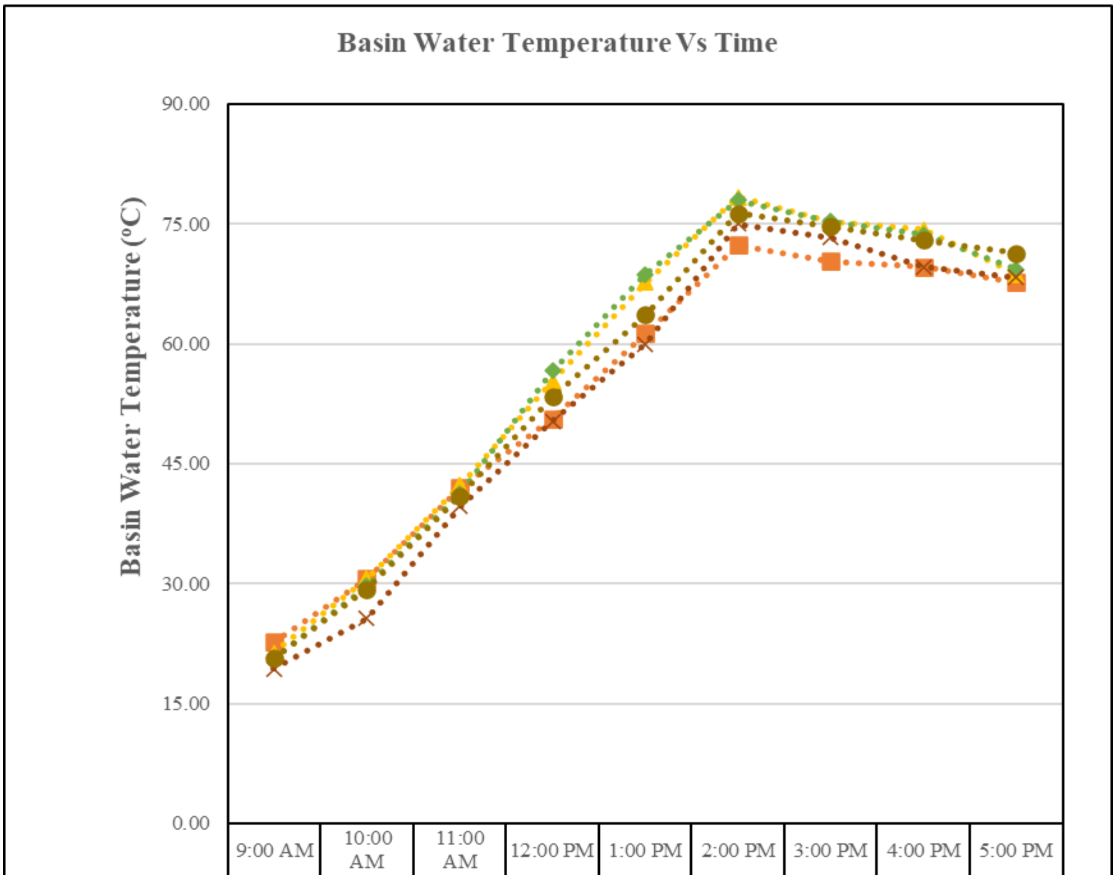
	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM
26-01-2022	19.67	27.67	38.67	48.33	56.67	69.00	66.33	64.67	62.67
27-01-2022	19.67	28.67	40.00	51.33	64.00	70.33	68.33	66.00	61.67
28-01-2022	18.67	27.67	38.33	53.33	63.67	71.67	70.67	68.33	66.67
29-01-2022	18.33	23.67	37.33	48.33	57.67	70.67	69.00	66.67	63.67
30-01-2022	18.67	27.33	38.33	49.00	60.33	72.67	70.67	68.67	66.67

Figure 4.16. Temperature Change in Glass with Time (Case-2).

Figure 4.16 depicts the fluctuation in glass temperature for various testing days for an inclined solar still having stepped absorber with corrugated fins integrated with vacuum tubes in winter season. It is evident from the graph that for each of the experiment days, the glass temperature rises from 9:00 am to 2:00 pm, after which it begins to steadily fall, just as the solar radiation rises from 9:00 am to 1:00 pm, after which it falls. The highest glass temperature measured was 72.67^{o} C on January 28, 2022, at 2:00 pm.

4.2.4 Basin Water Temperature

Basin water is solar still water that evaporates to provide new output. Fresh production depends on water temperature. Evaporation and production increase with basin water temperature..



	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM
26-01-2022	22.67	30.67	42.00	50.67	61.33	72.33	70.33	69.67	67.67
27-01-2022	21.33	30.67	42.33	55.33	67.67	78.33	75.33	74.33	68.67
28-01-2022	20.67	29.67	41.33	56.67	68.67	78.00	75.33	73.67	69.33
29-01-2022	19.33	25.67	39.67	50.33	60.00	75.00	73.33	69.67	68.33
30-01-2022	20.67	29.33	41.00	53.33	63.67	76.33	74.67	73.00	71.33

Figure 4.17. The temperature of the water in the basin changes throughout time (Case-2).

Figure 4.17 depicts the fluctuation in basin water temperature for various testing days for an inclined solar still having stepped absorber with corrugated fins and integrated with vacuum tubes in winter season. The graph shows that for all of the experiment days, the basin's water temperature rises from 9:00 am to 2:00 pm, after which it begins to fall steadily, just as the sun's rays rise from 9:00 am to 1:00 pm, after which they fall. The highest basin water temperature recorded for January 27, 2022, at 2:00 pm, is 78.33°C.

4.2.5 Absorber Plate, Glass and Basin Water Temperature for Different Experimental Days

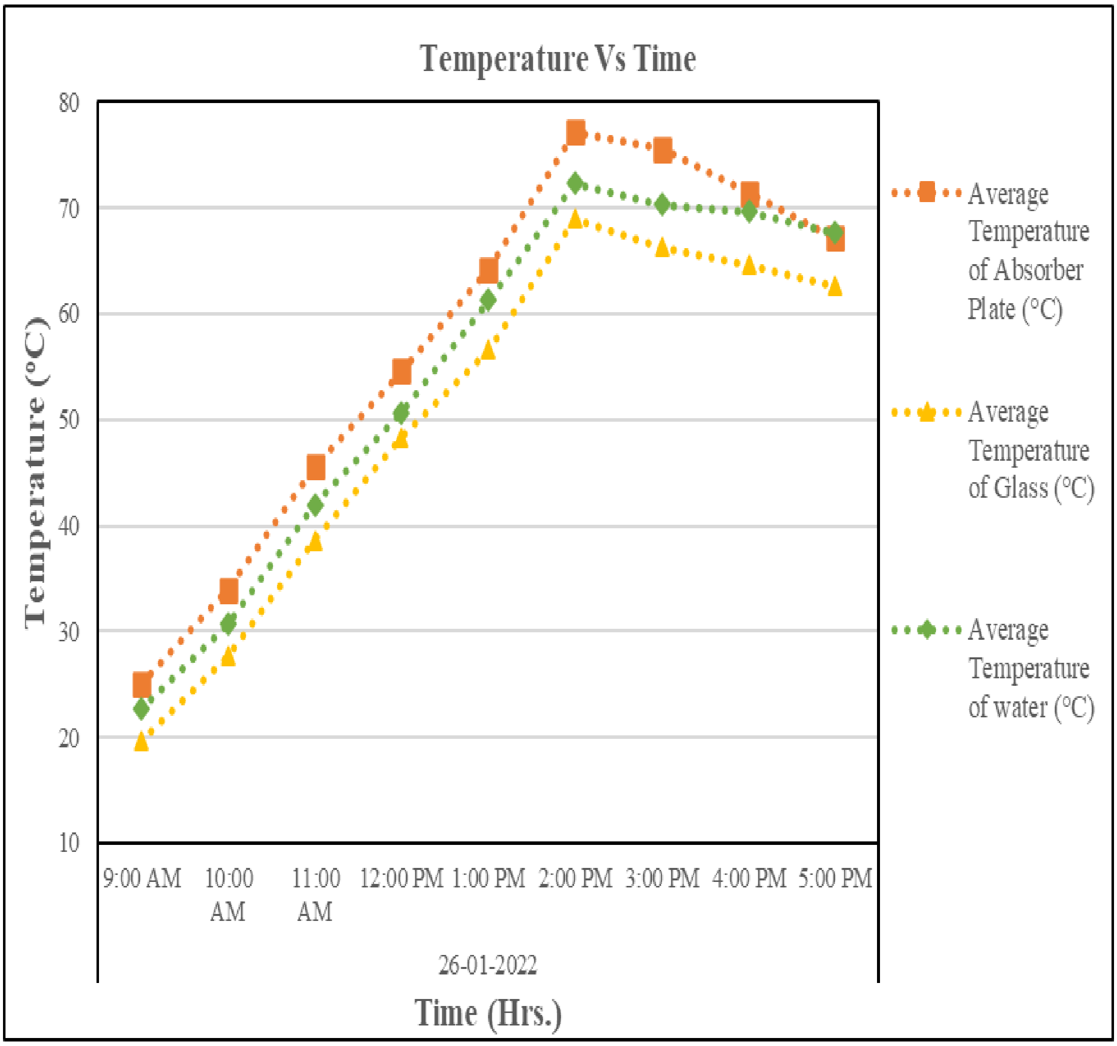


Figure 4.18. Shows the evolution of the water's temperature in the basin, glass, and absorber plate on January 26, 2022.

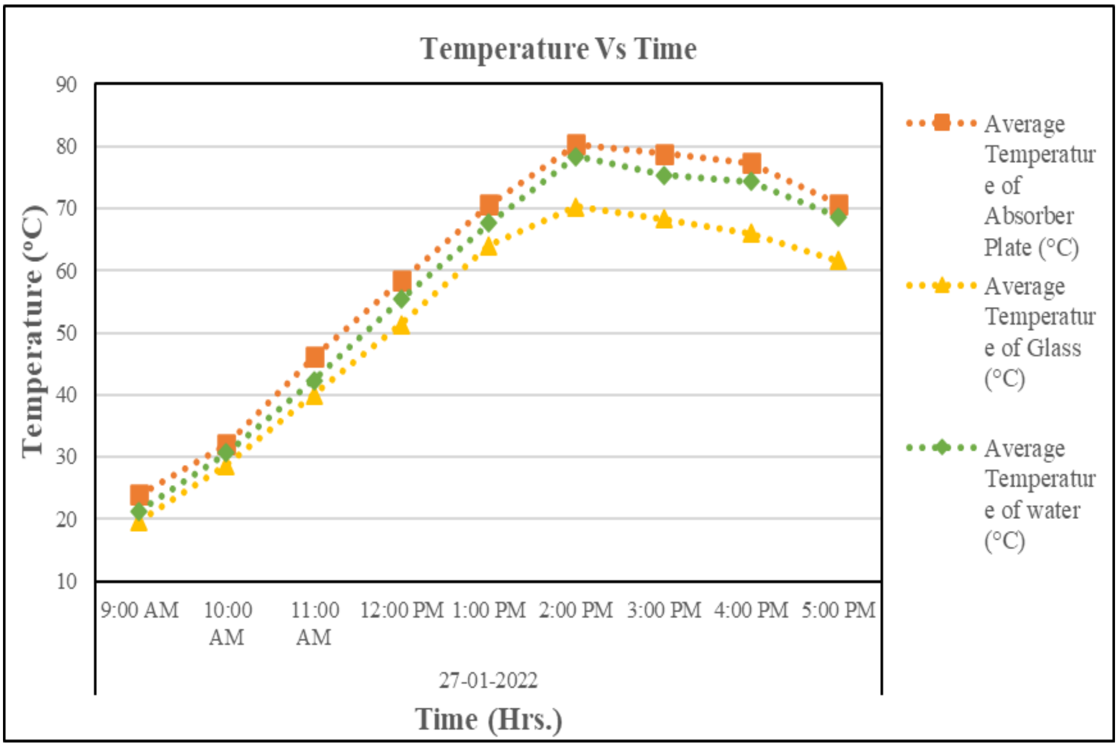


Figure 4.19. Shows the evolution of the water's temperature in the basin, glass, and absorber plate on January 27, 2022.

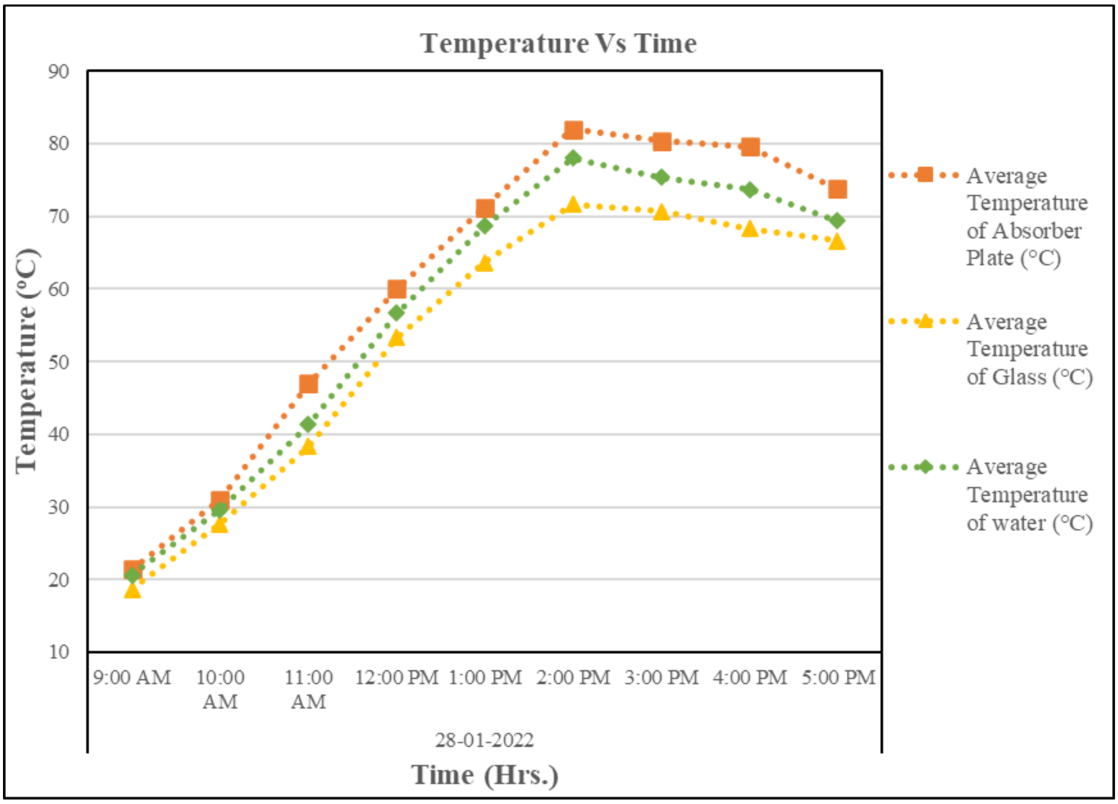


Figure 4.20. Shows the evolution of the water's temperature in the basin, glass, and absorber plate on January 28, 2022.

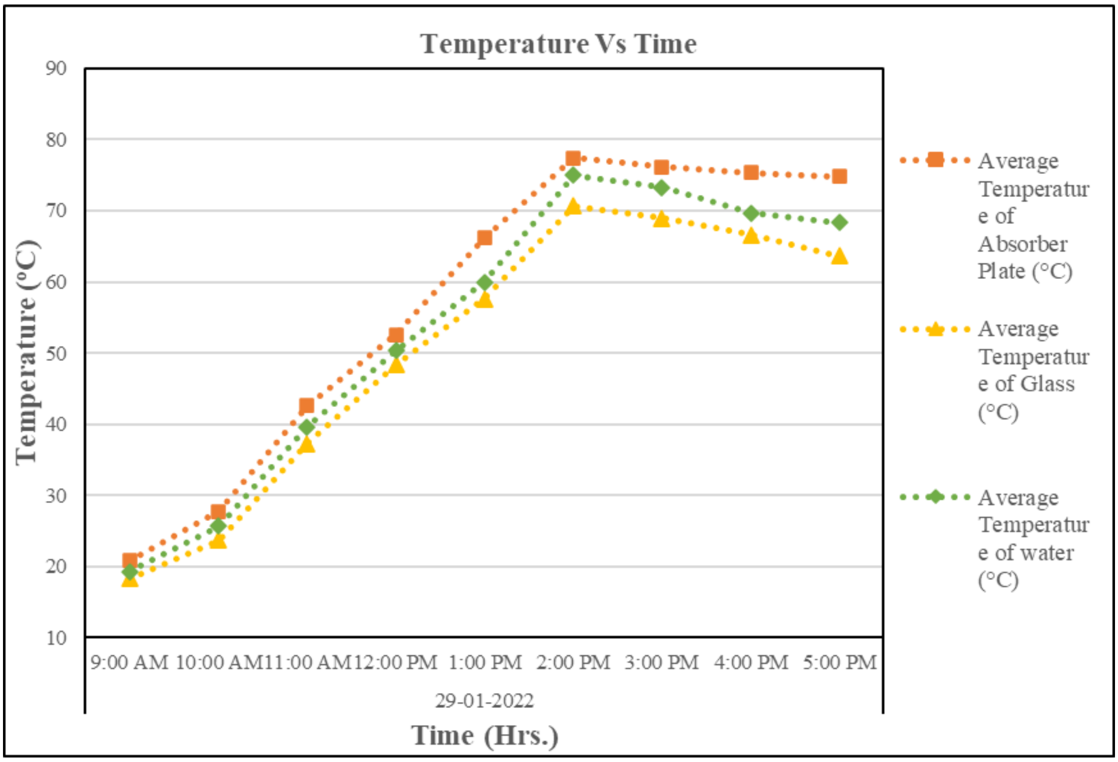


Figure 4.21. Shows the evolution of the water's temperature in the basin, glass, and absorber plate on January 29, 2022.

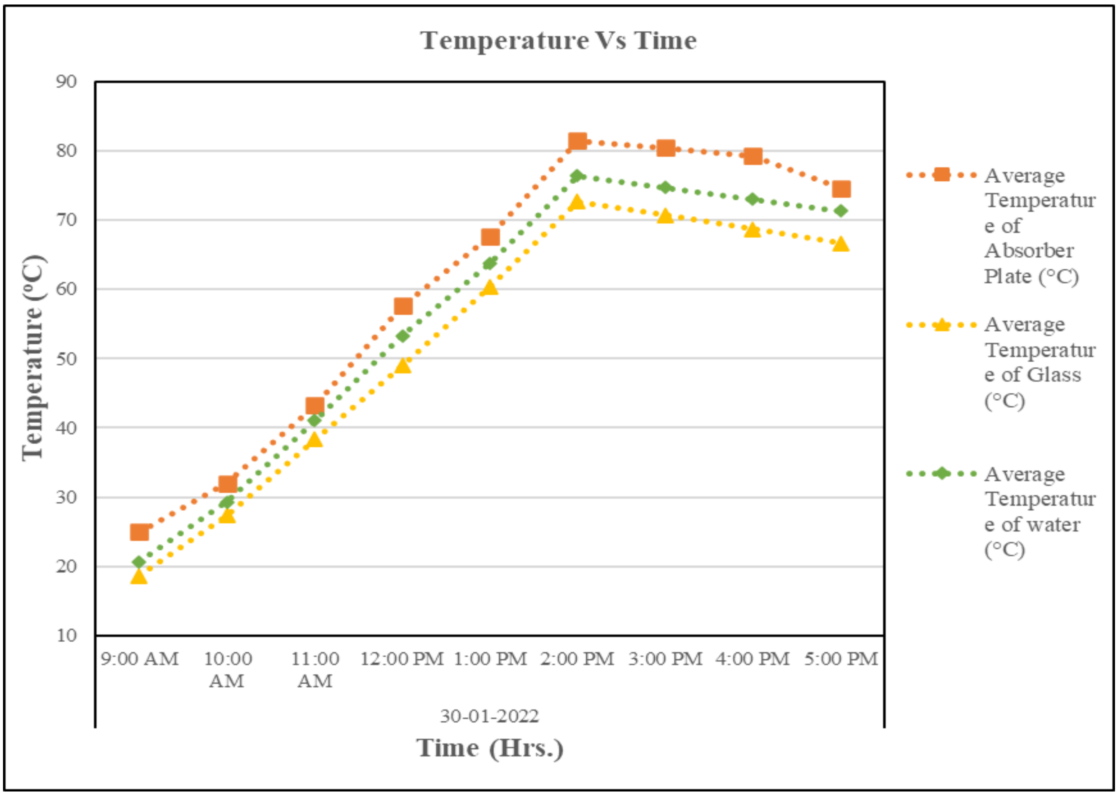
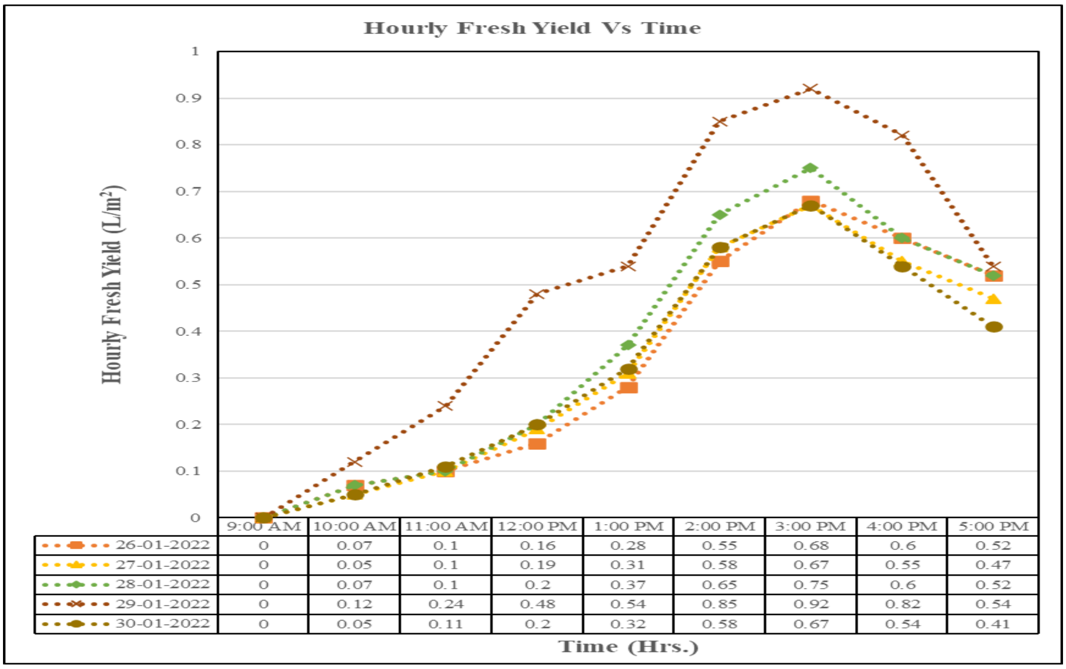


Figure 4.22. Shows the evolution of the water's temperature in the basin, glass, and absorber plate on January 30, 2022.

For inclined solar stills with stepped absorbers that have corrugated fins integrated with vacuum tubes in the winter season, Figures 4.18 to 4.22 illustrates the fluctuation in temperature of the water in the basin, glass, and absorber for several trial days. From the graph, it is evident that for each of the experiment days, the temperature of the water in the basin, glass, and absorber increases from 9:00 am to 2:00 pm, after which they begin to steadily decrease, just as the solar radiation does from 9:00 am to 1:00 pm, before decreasing. The highest values for the absorber plate temperature, glass temperature, and basin water temperature were recorded on January 26, 2022, at 2:00 pm 77.2°C, 69.0°C, and 73.67°C, respectively. Similar to this, the maximum temperatures for the absorber plates on the 27th, 28th, 29th, and 30th of January 2022 are 80.4°C, 82.0°C, 77.4°C, and 81.4°C, respectively, at 2.00 pm; a highest temperature for the glass are 70.33°C, 72.67°C, 71.67°C, and 70.67°C, respectively; and a maximum temperature of the basin water are 78.0°C, 78.33°C, 75.0°C, and 76.33°C respectively at 2.00 pm.

4.2.6 Hourly Fresh Yield

The fresh water obtained from still is measured on hourly basis, that measured quantity is known as hourly fresh yield. It is monitored hourly to assess the water's energy intake and how much water is turned into new output to establish the still's hourly efficiency.



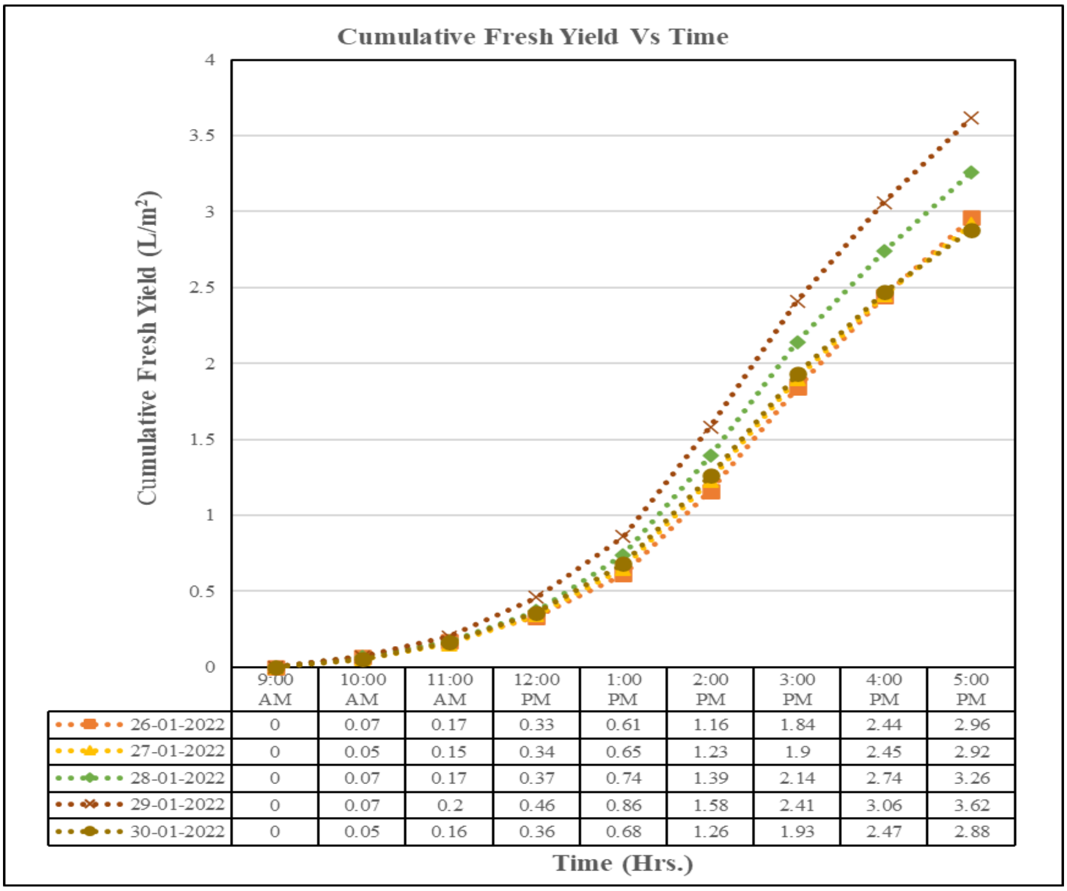
	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM
26-01-2022	0	0.07	0.1	0.16	0.28	0.55	0.68	0.6	0.52
27-01-2022	0	0.05	0.1	0.19	0.31	0.58	0.67	0.55	0.47
28-01-2022	0	0.07	0.1	0.2	0.37	0.65	0.75	0.6	0.52
29-01-2022	0	0.12	0.24	0.48	0.54	0.85	0.92	0.82	0.54
30-01-2022	0	0.05	0.11	0.2	0.32	0.58	0.67	0.54	0.41

Figure 4.23. Time-dependent Change in Hourly Fresh Yield (Case-2).

For various testing days, Figure 4.23 displays the variance in hourly fresh yield for an inclined solar still with a stepped absorber and corrugated fins combined with vacuum tubes in winter season. The graph shows that during the experiment, hourly fresh distillate output increases from 9:00 am until 3:00 pm, after which it begins to steadily decline. The maximum yield is achieved at 3:00 pm because the output of fresh yield is based on solar intensity, which rises from 9:00 am to 1:00 pm and then falls. Additionally, because evacuated tubes are utilized, water temperature climbs more and stays higher for longer periods of time. A maximum value of hourly fresh yield obtained is 0.68 L/m^2 for 26th January 2022 at 3.00 pm. Similarly, for 27th, 28th, 29th, and 30th January 2022 the maximum value of hourly fresh yield is 0.67 L per m^2, 0.75 L per m^2, 0.83 L per m^{2,} and 0.67 L per m^2 respectively at 3.00 pm.

4.2.7 Cumulative Fresh Yield

The total fresh water obtained from still for a particular experimental day is measured, that measured quantity is known as cumulative fresh yield. It is measured to determine the efficiency of the still for that particular day.



	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM
26-01-2022	0	0.07	0.17	0.33	0.61	1.16	1.84	2.44	2.96
27-01-2022	0	0.05	0.15	0.34	0.65	1.23	1.9	2.45	2.92
28-01-2022	0	0.07	0.17	0.37	0.74	1.39	2.14	2.74	3.26
29-01-2022	0	0.07	0.2	0.46	0.86	1.58	2.41	3.06	3.62
30-01-2022	0	0.05	0.16	0.36	0.68	1.26	1.93	2.47	2.88

Figure 4.24. Time-dependent Change in Cumulative Fresh Yield (Case-2).

For several testing days, the change of the cumulative fresh yield for an inclined solar still with a stepped absorber and corrugated fins combined with vacuum tubes in the winter season is shown in Figure 4.24. It is evident from the graph that on all of the experimental days, the fresh yield peaks at about 3:00 PM. Because the fresh yield production is influenced by solar intensity, which rises from 9:00 am to 1:00 pm, and because evacuated tubes are employed, which cause the water temperature to rise more and stay higher for longer, the highest yield is attained at 3:00 pm. For the 29th of January 2022, the highest cumulative fresh yield measurement was 3.62 L/m^2/day. Similarly, for 26th, 27th, 28th, and 30th January 2022 the value of cumulative fresh yield is 2.96 L per m^2 per day, 2.92 L per m^2 per day, 3.26 L per m^2 per day, and 2.88 L per m^2 per day respectively.

4.2.8 Solar Intensity and Absorber Plate Temperature

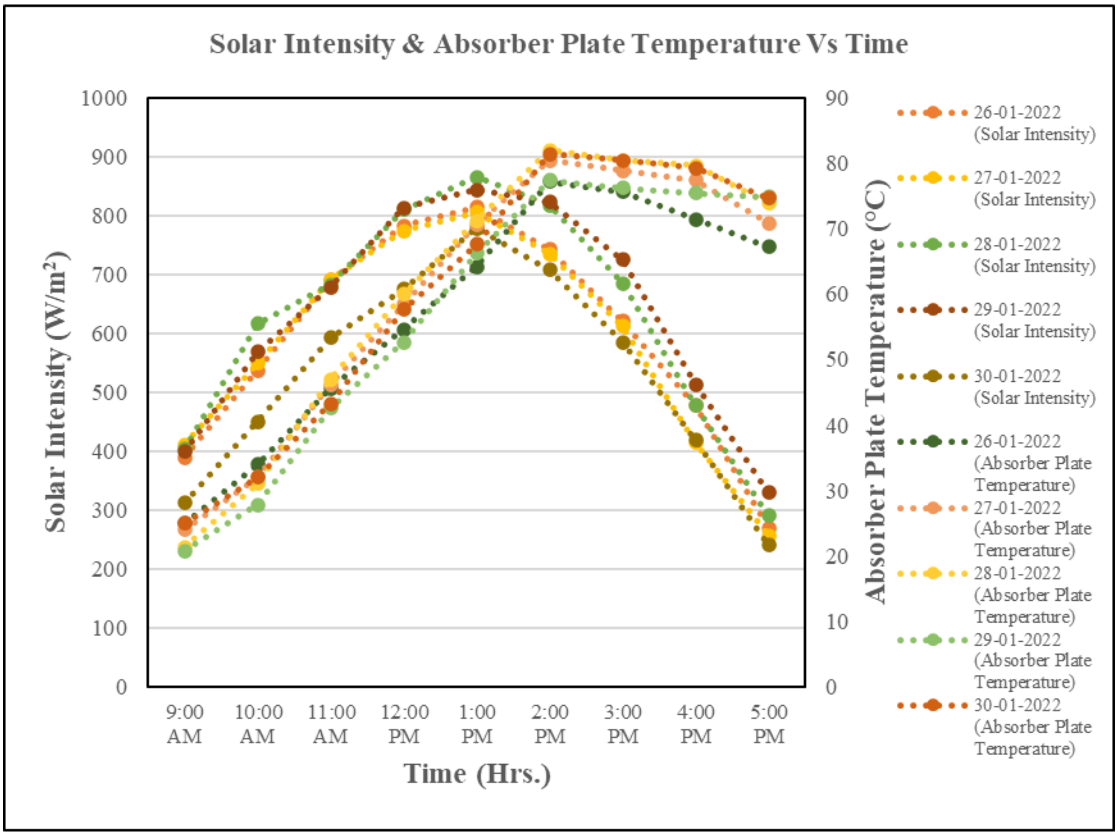


Figure 4.25. Solar Intensity and Absorber Plate Temperature with Time (Case-2).

During an inclined solar still with a stepped absorber and corrugated fins combined with vacuum tubes throughout the winter for several trial days, Figure 4.25. depicts the fluctuation of solar intensity and absorber plate temperature with regard to time. On all testing days, it is found that the sun intensity increases from 9:00 am to 1:00 pm before beginning to decline. Similarly, its observed that a temperature of an absorber plate increases from 9:00 am to 2:00 pm before beginning to gently decline after that. The maximum temperature of the absorber plate is found at 2:00 pm since a temperature of an absorber plate completely depends on solar intensity, which is at its highest for all testing days at 1:00 pm. The temperature of the absorber plate is increased by absorbing heat from the solar rays falling on an upper portion of a glass through which it is transmitted inside the solar still.

4.2.9 Daily Efficiency of Still

As the efficiency is depends upon the fresh output of still and solar intensity, that's why the variation in efficiency for different experimental days is recorded and shown in below graph.

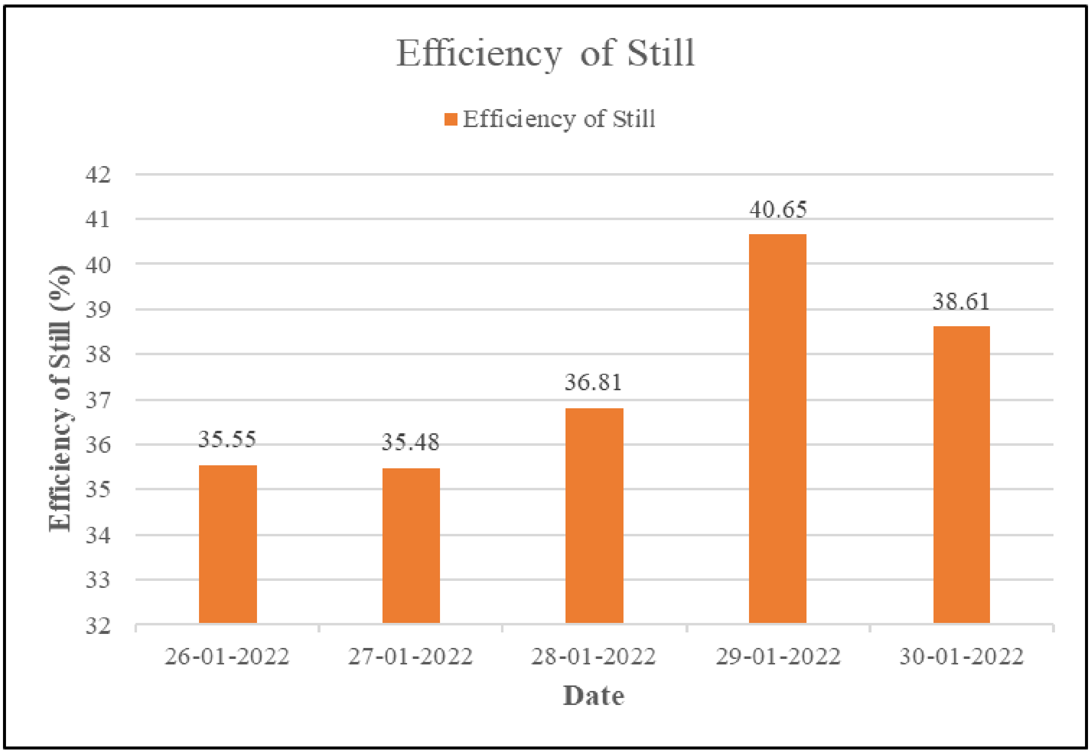


Figure 4.26. Daily Efficiency of Still (Case-2).

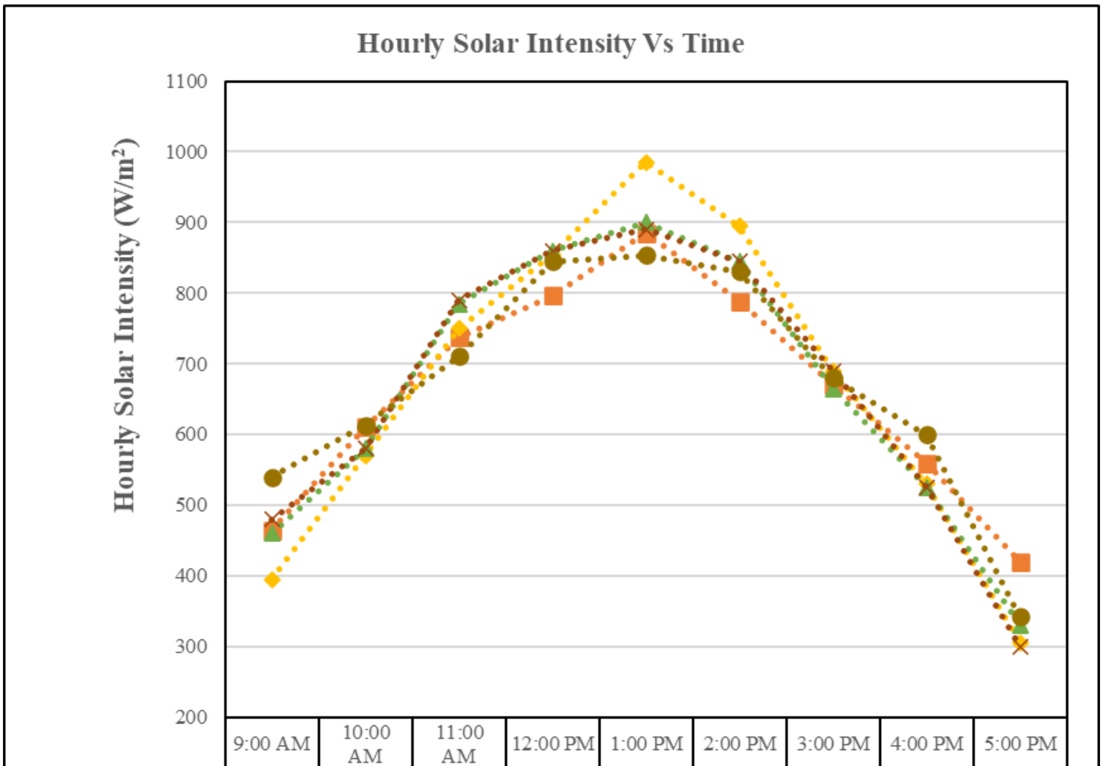
Figure 4.26 displays the daily efficiency for an inclined solar still with a stepped absorber and corrugated fins combined with vacuum tubes in the winter season for various test days. According to the graph, the still will operate at its highest daily efficiency 40.65 percent, on January 29, 2022, and its lowest daily efficiency on January 27, 2022, will be 35.48 percent.

4.3 CASE-3: INCLINED SOLAR STILL HAVING STEPPED ABSORBER WITH CORRUGATED FIN (SUMMER SEASON).

Based on the measured value of various components like solar incident, temperature of absorber plate, glass temperature and basin water temperature. Various following observations has been plotted and discussed for inclined solar still having stepped absorber with corrugated fin (Summer season).

4.3.1 Hourly Solar Intensity

The quantity of energy that is collected from the sun in the form of electromagnetic waves is what is referred to as solar intensity. Increasing the temperature of the various components that are employed in a solar still requires solar intensity. The production of fresh produce received from still as well as the efficiency of still is largely dependent on the amount of sun intensity that is present.



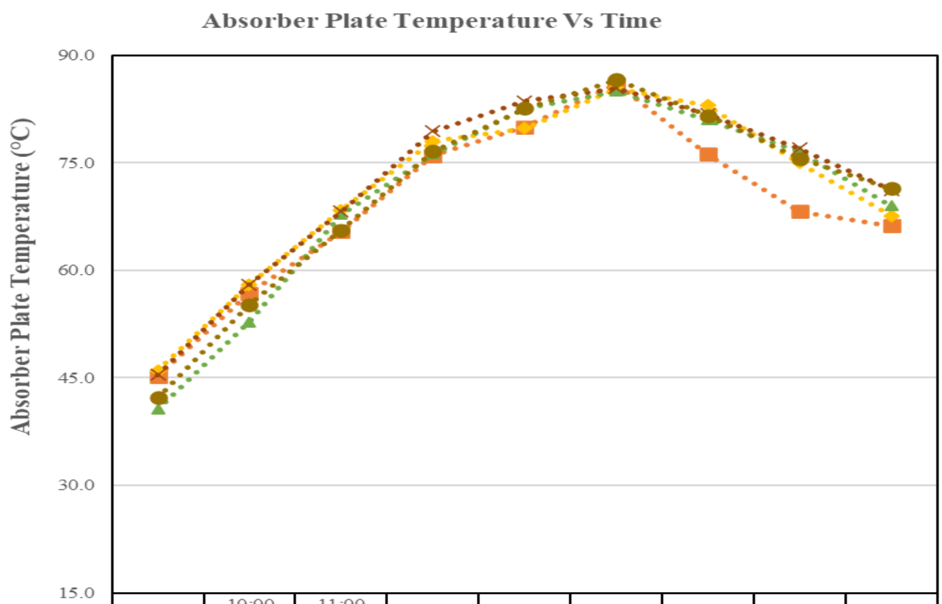
	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM
02-05-2022	465	610	737	796	885	788	670	559	420
03-05-2022	395	570	750	855	985	895	690	530	305
04-05-2022	460	580	785	860	900	845	665	525	330
05-05-2022	480	580	790	860	890	845	690	525	300
06-05-2022	540	613	711	845	854	830	680	600	342

Figure 4.27. Time-dependent Changes in Solar Intensity (Case-3).

For several test days during the summer, Figure 4.27 depicts the variance in hourly sun intensity for inclined solar stills with stepped absorbers and corrugated fins. It is evident from the graph that on all of the trial days, the hourly sun intensity rises from 9:00 am until 1:00 pm, after which it begins to steadily decline. For all days, the highest and minimum values of the hourly sun intensity are respectively recorded at 1:00 pm and 5:00 pm. On May 2, 2022, at 1:00 pm and 5:00 pm, respectively, the greater value of 885 W/m^2 and the lesser value of 420 W/m^2 are measured. Likewise, for May 3rd, 4th, 5th, and 6th, 2022, the highest and minimum values of hourly sun intensity are, 985 W/m^2, 900 W/m^2, 890 W/m^2, 854 W/m^2 and 305 W/m^2, 330 W/m^2, 300 W/m^2, 342 W/m^2 respectively.

4.3.2 Absorber Plate Temperature

The critical temperature of the solar still is determined by the temperature of the absorber plate. Seeing as since the temperature of the absorber plate is the sole factor that determines the output of the still. As a result, the temperature of the absorber plate is recorded over the several days of the experiment and represented on the accompanying graph.



	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM
02-05-2022	45.2	56.8	65.4	76.0	80.0	86.0	76.2	68.2	66.2
03-05-2022	46.0	58.0	68.4	78.0	79.8	85.4	83.0	75.0	67.6
04-05-2022	40.6	52.8	67.8	76.2	82.6	85.0	81.0	76.6	69.0
05-05-2022	45.4	58.0	68.2	79.4	83.6	85.4	81.8	77.0	71.2
06-05-2022	42.2	55.2	65.6	76.6	82.6	86.6	81.6	75.6	71.4

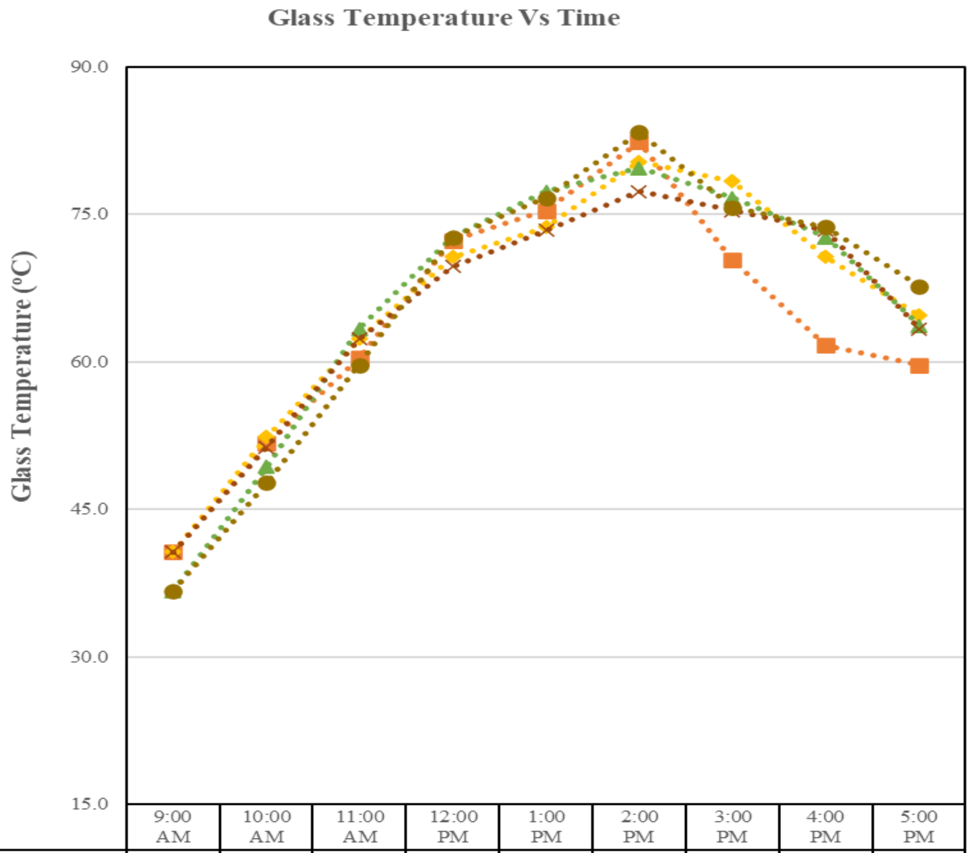
Time (Hrs.)

Figure 4.28. Time-dependent Temperature Variation of the Absorber Plate (Case-3)

Figure 4.28 depicts the change in absorber plate temperature for inclined solar stills with stepped absorbers and corrugated fins throughout various test days during the summer. The graph shows that for all of the experiment days, the absorber plate temperature rises from 9:00 am to 2:00 pm, after which it begins to fall steadily, just as the solar radiation rises from 9:00 am to 1:00 pm, after which it falls. The highest absorber plate temperature measured was 86.6 ^{o} C on May 6, 2022, at 2:00 pm.

4.3.3 Glass Temperature

The temperature of the glass cover is a very crucial aspect in the solar still. because it determines the pace of condensation and, as a result, the amount of water that can be extracted from the solar still. The graph that follows illustrates how the temperature of the glass changed during the course of a single day. Its temperature is also dependent on the amount of sunlight that is received.



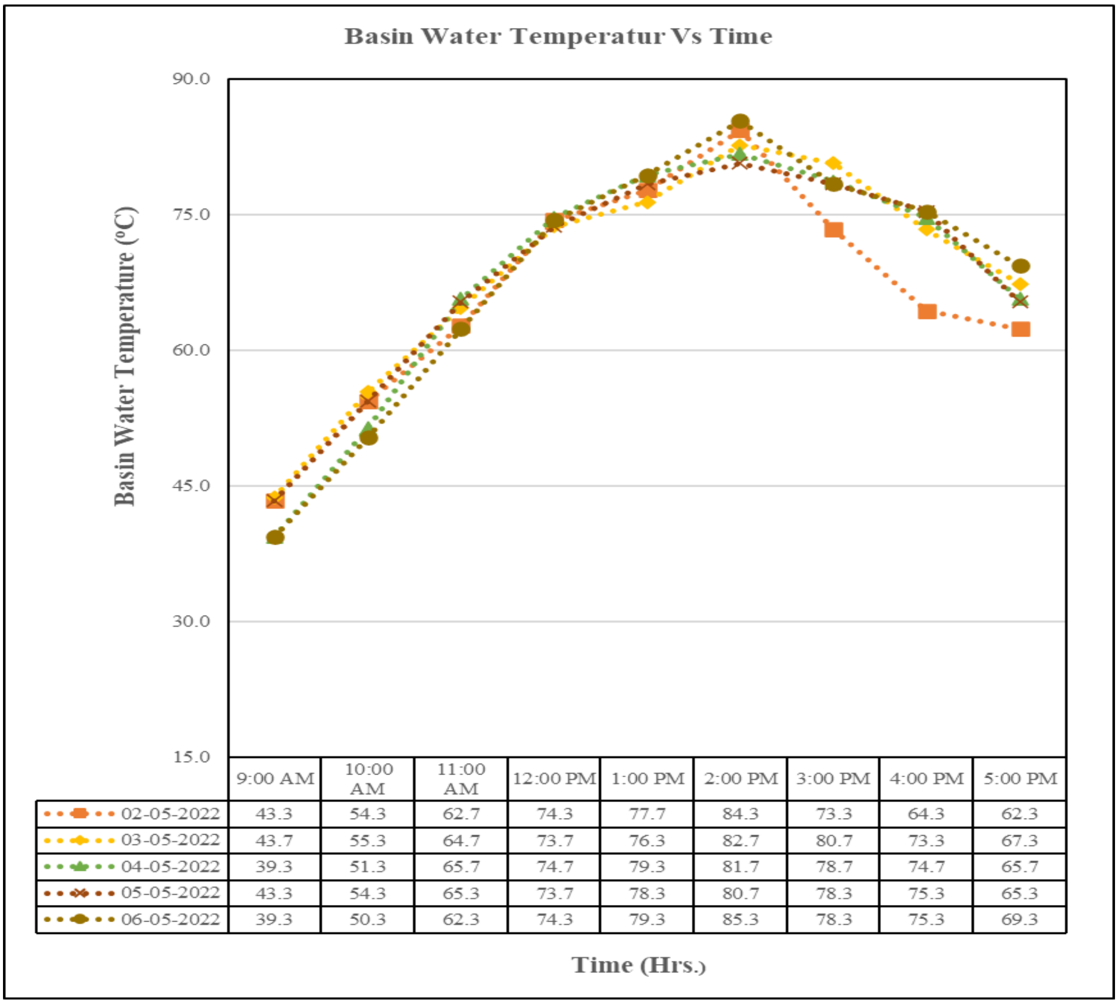
	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM
02-05-2022	40.7	51.7	60.3	72.3	75.3	82.3	70.3	61.7	59.7
03-05-2022	40.7	52.3	62.3	70.7	73.7	80.3	78.3	70.7	64.7
04-05-2022	36.7	49.3	63.3	72.7	77.3	79.7	76.7	72.7	63.7
05-05-2022	40.7	51.3	62.3	69.7	73.3	77.3	75.3	73.3	63.3
06-05-2022	36.7	47.7	59.7	72.7	76.7	83.3	75.7	73.7	67.7

Figure 4.29. Temperature Change in Glass with Time (Case-3).

In Figure 4.29, the fluctuation in glass temperature for an inclined solar still with a stepped absorber and corrugated fins is shown for various test days during the summer. It is evident from the graph that for each of the experiment days, the glass temperature rises from 9:00 am to 2:00 pm, after which it begins to steadily fall, just as the solar radiation rises from 9:00 am to 1:00 pm, after which it falls. The highest glass temperature measured was 83.3° C on May 6, 2022, at 2:00 pm.

4.3.4 Basin Water Temperature

The term "basin water" refers to the water that is held within the solar still for the purpose of evaporation so that it may be transformed into a new output. The temperature of this water is also very significant, as the amount of fresh produce that can be extracted is solely dependent on the temperature of this water. The higher the temperature of the water in the basin, the higher the evaporation rate will be, and the bigger the production will be..



	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM
02-05-2022	43.3	54.3	62.7	74.3	77.7	84.3	73.3	64.3	62.3
03-05-2022	43.7	55.3	64.7	73.7	76.3	82.7	80.7	73.3	67.3
04-05-2022	39.3	51.3	65.7	74.7	79.3	81.7	78.7	74.7	65.7
05-05-2022	43.3	54.3	65.3	73.7	78.3	80.7	78.3	75.3	65.3
06-05-2022	39.3	50.3	62.3	74.3	79.3	85.3	78.3	75.3	69.3

Figure 4.30. The temperature of the water in the basin changes throughout time (Case-3).

For several test days during the summer, Figure 4.30 depicts the variance in basin water temperature for an inclined solar still with a stepped absorber and corrugated fins. The graph shows that for all of the experiment days, a basin's water temperature rises from 9:00 am to 2:00 pm, after which it begins to fall steadily, just as the sun's rays rise from 9:00 am to 1:00 pm, after which they fall. The highest water temperature measured in the basin was 85.3º C on May 6, 2022, at 2:00 pm.

4.3.5 Absorber Plate, Glass and Basin Water Temperature for Different Experimental Days

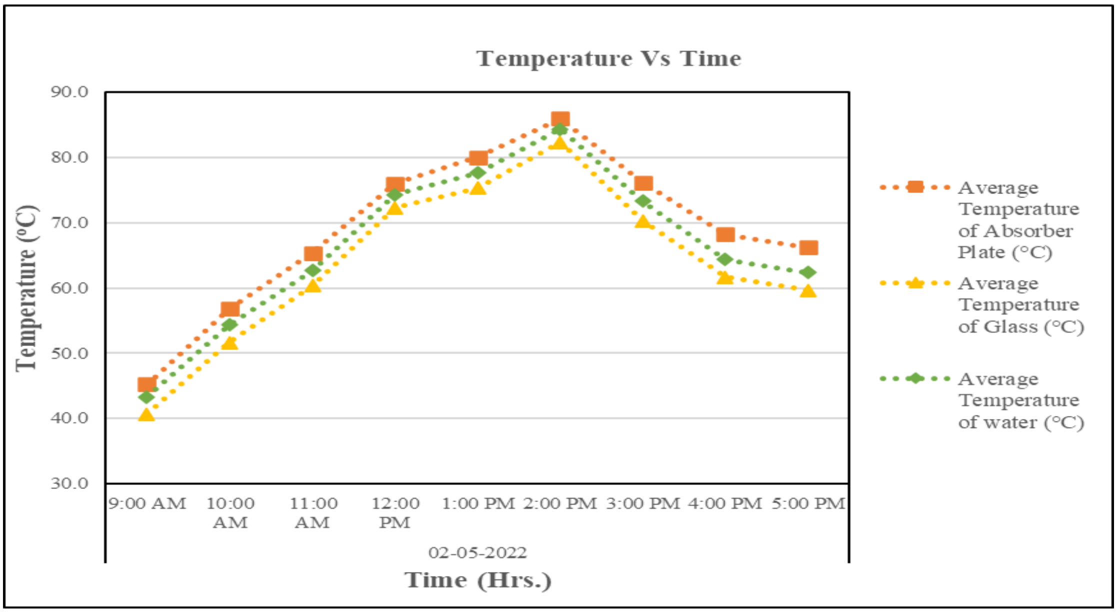


Figure 4.31. Shows the evolution of the water's temperature in the basin, glass, and absorber plate on May 02, 2022

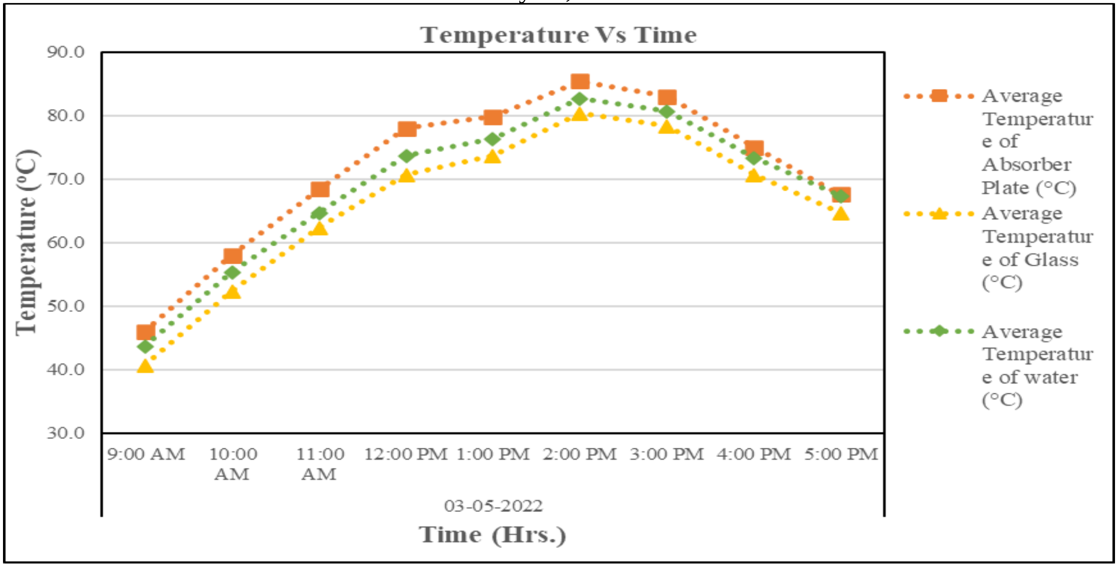


Figure 4.32. Shows the evolution of the water's temperature in the basin, glass, and absorber plate on May 03, 2022

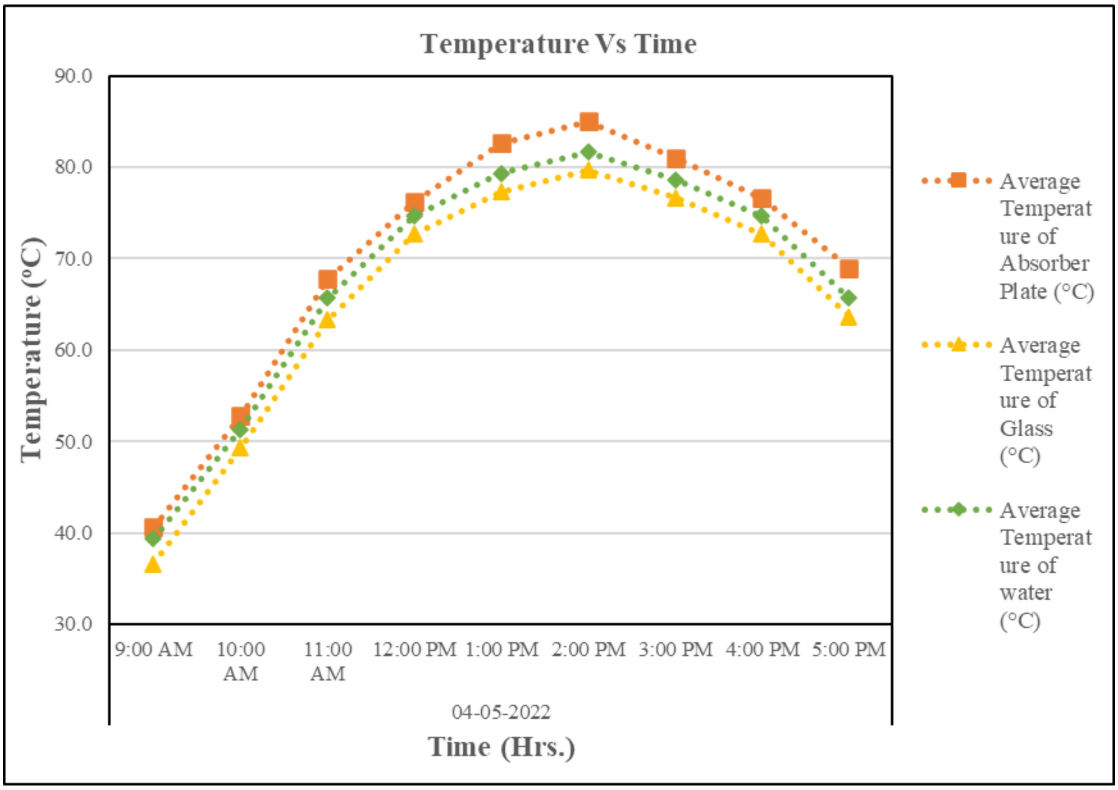


Figure 4.33. Shows the evolution of the water's temperature in the basin, glass, and absorber plate on May 04, 2022

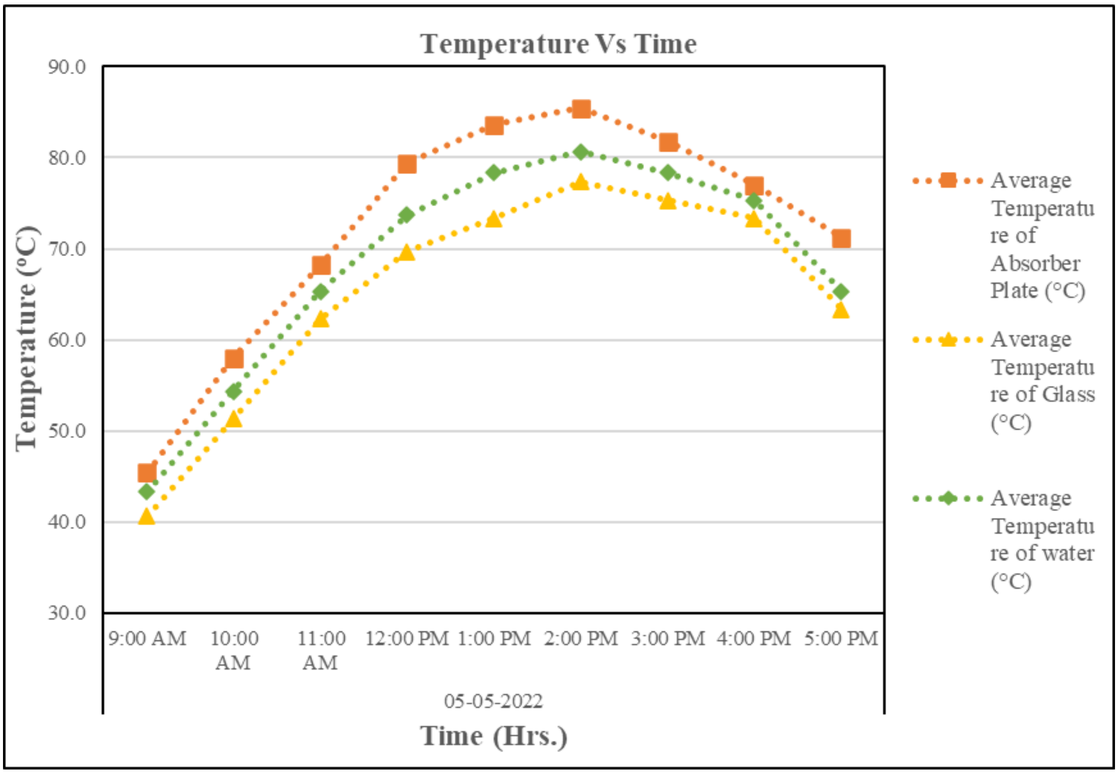


Figure 4.34. Shows the evolution of the water's temperature in the basin, glass, and absorber plate on May 05, 2022

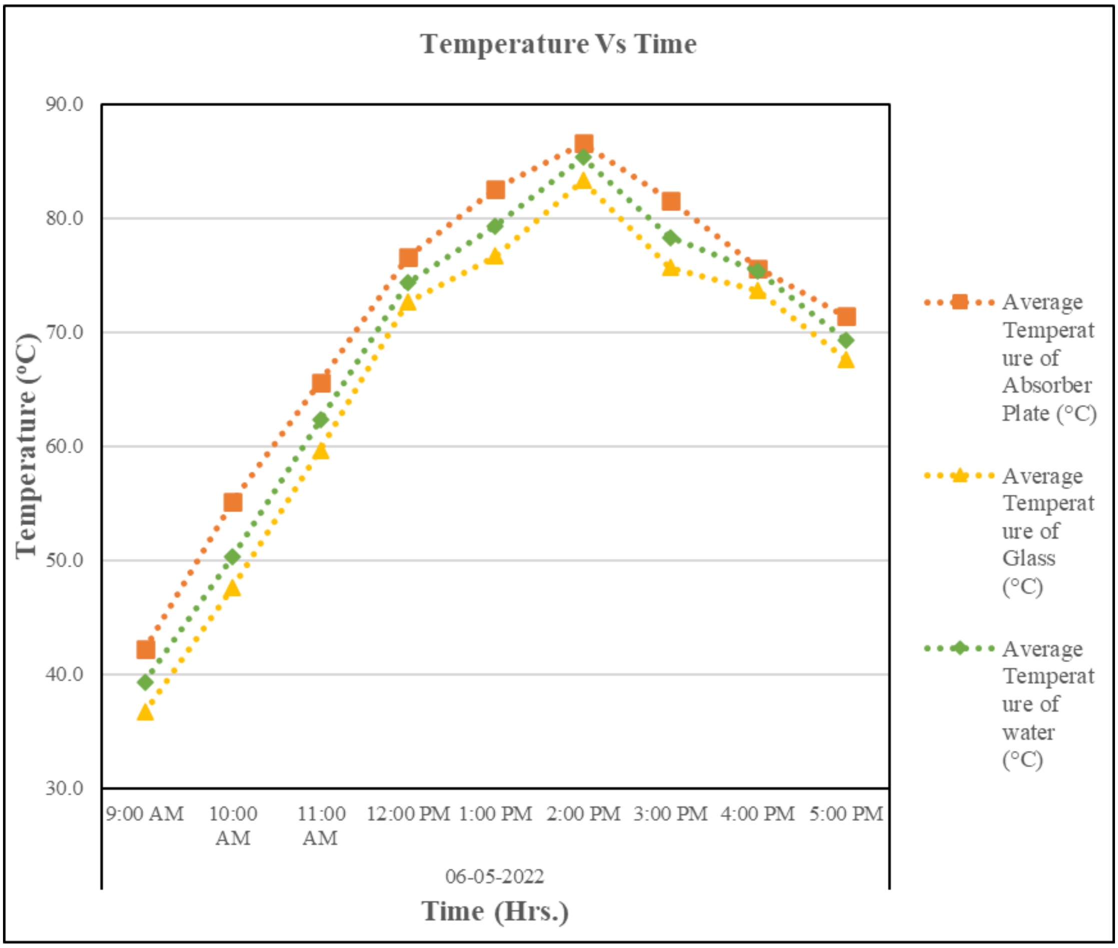
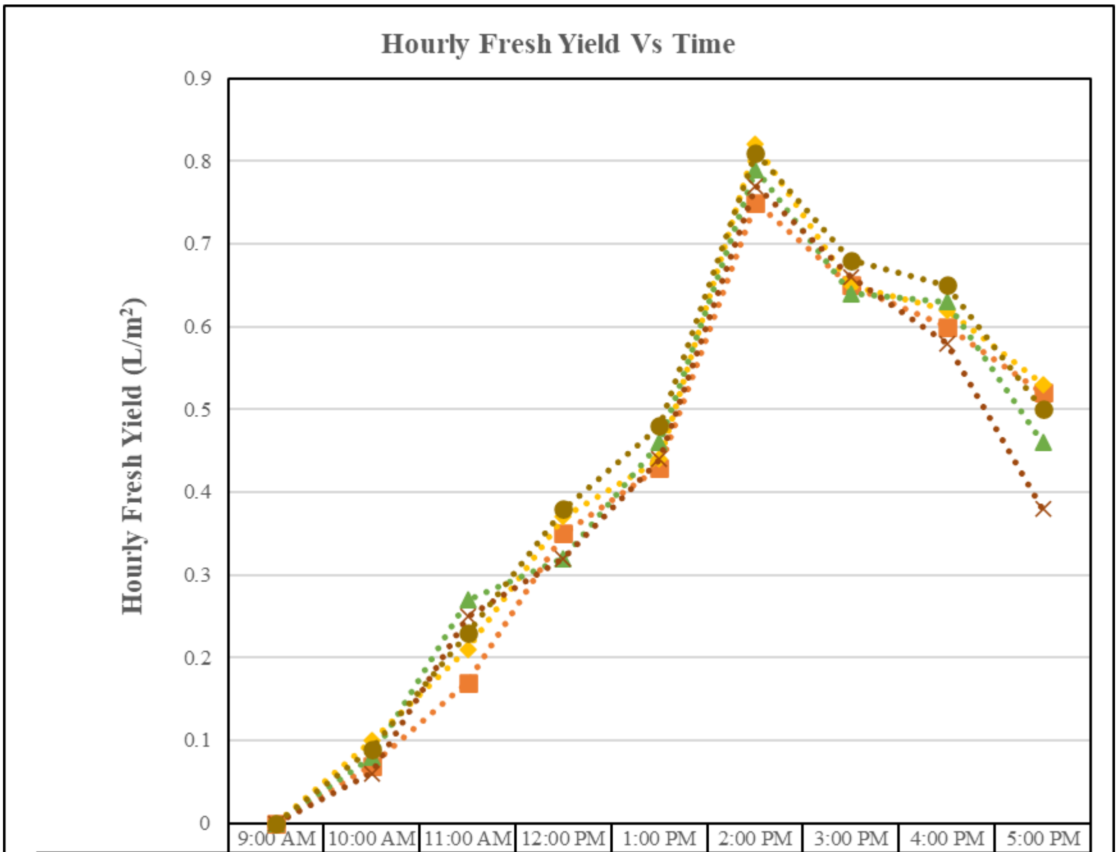


Figure 4.35. Shows the evolution of the water's temperature in the basin, glass, and absorber plate on May 06, 2022

Figures 4.31 to 4.35 show a temperature variation of the water in a basin, glass, and absorber plate for several trial days throughout the summer for inclined solar stills with stepped absorbers and corrugated fins. It is clear from the graph that for each of the experiment days, the temperature of an absorber plate, a glass, and a water in a basin rise from 9:00 am to 2:00 pm, after which they start to progressively decline, exactly like the solar radiation does from 9:00 am to 1:00 pm, before declining. The greatest temperatures for the absorber plate, glass, and water in the basin were recorded at 2:00 pm on May 2, 2022, and they are 86.0°C, 82.3°C, and 84.3°C, respectively. Like this, the highest possible absorber plate temperature for the third, fourth, fifth, and sixth days of May 2022 is 85.4°C, 85.0°C, 85.4°C, and 86.6°C, respectively, at 2:00 pm; the highest possible glass temperature is 80.3°C, 79.7°C, 77.3°C, and 83.3°C, respectively, at 2:00 pm; and the highest possible basin water temperature is 82.7°C, 81.7°C, 80.7°C.

4.3.6 Hourly Fresh Yield

The fresh water obtained from still is measured on hourly basis, that measured quantity is known as hourly fresh yield. It is determined on an hourly basis how much energy was received by the water on an hourly basis and how much water will get transformed into new output in order to establish the hourly efficiency of the still. This measurement is done every hour.



	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM
02-05-2022	0	0.07	0.17	0.35	0.43	0.75	0.65	0.6	0.52
03-05-2022	0	0.1	0.21	0.37	0.44	0.82	0.65	0.62	0.53
04-05-2022	0	0.08	0.27	0.32	0.46	0.79	0.64	0.63	0.46
05-05-2022	0	0.06	0.25	0.32	0.44	0.77	0.66	0.58	0.38
06-05-2022	0	0.09	0.23	0.38	0.48	0.81	0.68	0.65	0.5

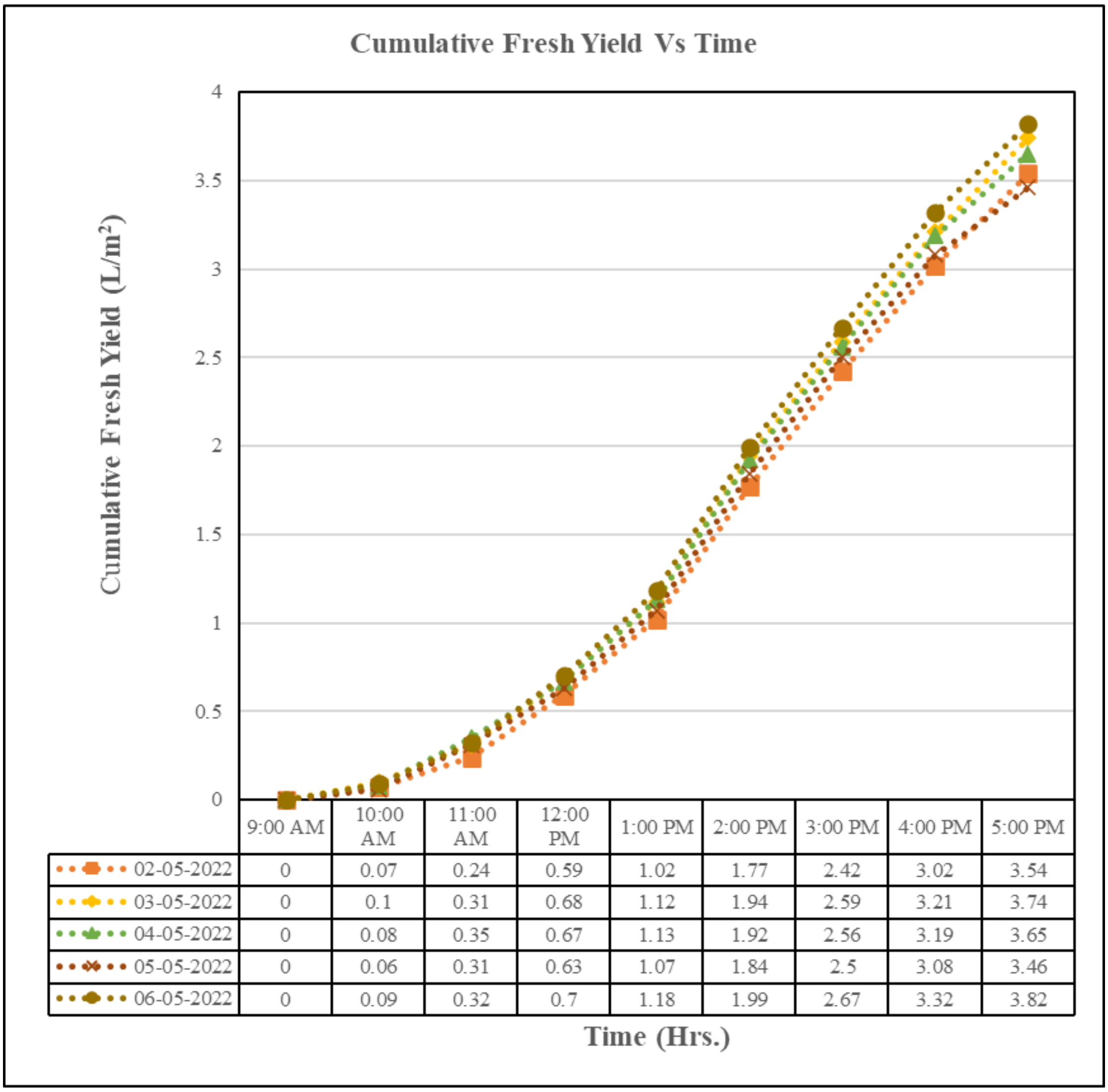
Time (Hrs.)

Figure 4.36. Hourly Fresh Yield Changes Over Time (Case-3).

Figure 4.36 depicts the change in hourly fresh yield for an inclined solar still with a stepped absorber and corrugated fins during various test days during the summer. The graph shows that for all of the testing days, the hourly fresh yield increases between 9:00 am and 2:00 pm, after which it begins to steadily decrease. Since the amount of fresh distillate produced depends on sun intensity, which rises from 9:00 am to 1:00 pm and then falls, the peak amount is produced at 2.00 pm. The highest hourly fresh yield measurement was 0.75 L/m^2 on May 2, 2022, at 2 o'clock. Similarly, for 03rd, 04th, 05th, and 06th February 2022 the maximum value of hourly fresh yield is 0.82 L per m^2, 0.79 L per m^2, 0.77 L per m^2 and 0.81 L per m^2 respectively at 2.00 pm.

4.3.7 Cumulative Fresh Yield

The total fresh water obtained from still for a particular experimental day is measured, that measured quantity is known as cumulative fresh yield. It is measured to determine the efficiency of the still for that particular day.



	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM
02-05-2022	0	0.07	0.24	0.59	1.02	1.77	2.42	3.02	3.54
03-05-2022	0	0.1	0.31	0.68	1.12	1.94	2.59	3.21	3.74
04-05-2022	0	0.08	0.35	0.67	1.13	1.92	2.56	3.19	3.65
05-05-2022	0	0.06	0.31	0.63	1.07	1.84	2.5	3.08	3.46
06-05-2022	0	0.09	0.32	0.7	1.18	1.99	2.67	3.32	3.82

Figure 4.37. Time-dependent Change in Cumulative Fresh Yield (Case-3).

Figure 4.37 shows the variation of cumulative fresh yield for inclined solar still having stepped absorber with corrugated fins for different experimental days in summer season. From the graph, it is observed that for all an experimental day a fresh distillate output is maximum at 2:00 pm. Since the amount of fresh yield produced depends on sun intensity, which rises from 9:00 am to 1:00 pm and then falls, the peak amount is produced at 2:00 pm. The maximum value of cumulative fresh yield obtained is 3.82 L/m^2/ day for 06th May 2022. Similarly, for the 02nd, 03th, 04^{th,} and 05th May 2022 the value of cumulative fresh yield is 3.54 L per m^2 per day, 3.74 L per m^2 per day, 3.65 L per m^2 per day and 3.46 L per m^2 per day respectively.

4.3.8 Solar Intensity and Absorber Plate Temperature

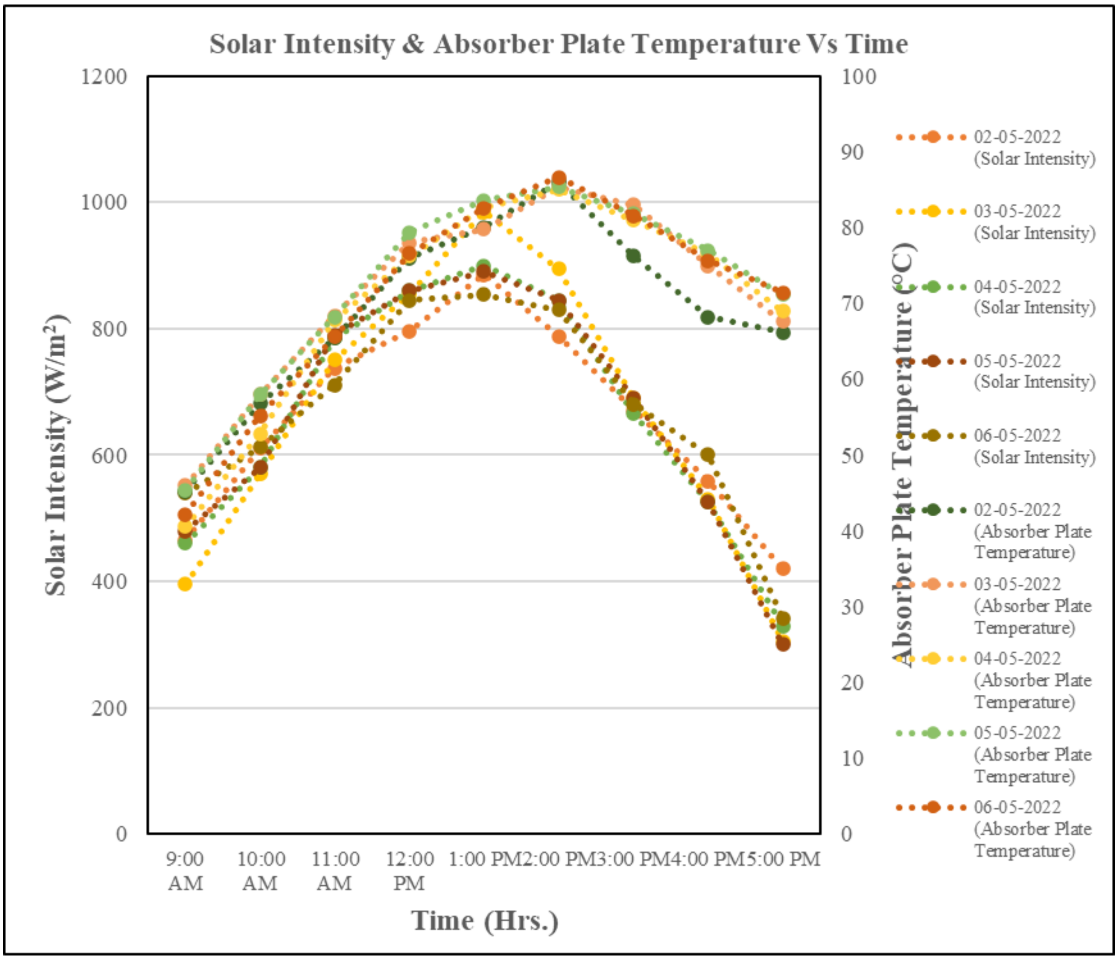


Figure 4.38. Solar Intensity and Absorber Plate Temperature with Time (Case-3).

Figure 4.38 depicts the time-dependent change of solar intensity and absorber plate temperature for an inclined solar still with stepped absorbers and corrugated fins across many testing days throughout the summer season. It is noticed that the sun intensity increases from 9:00 a.m. to 1:00 p.m. on all testing days and then gradually decreases. Similarly, the temperature of the absorber plate rises from 9:00 a.m. to 2:00 p.m. on all testing days and then gradually decreases. Because the temperature of the absorber plate is entirely dependent on solar intensity, we obtain the highest solar intensity at 1:00 pm on all testing days, and thus the maximum temperature of the absorber plate is determined at 2:00 pm. Because the absorber plate temperature remains higher for several time periods after the absorption of heat from the sun's rays.

4.3.9 Daily Efficiency of Still

As the efficiency is depends upon the fresh output of still and solar intensity, that's why the variation in efficiency for different experimental days is recorded and shown in below graph.

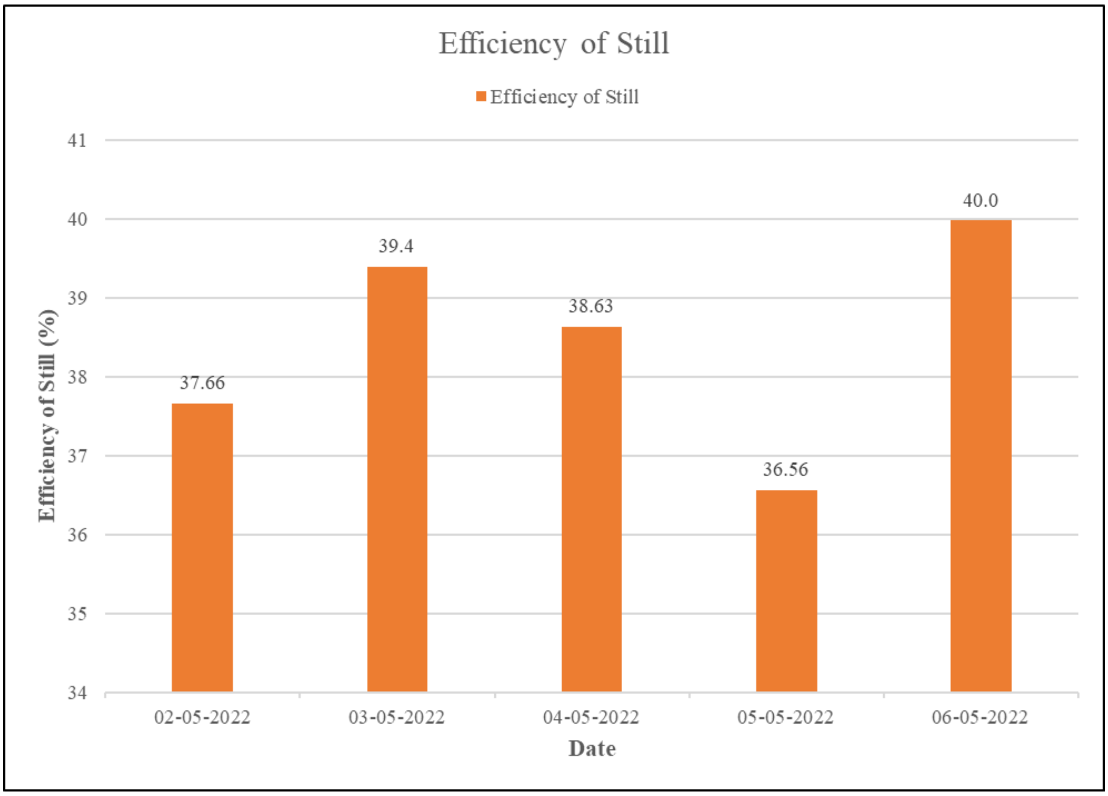


Figure 4.39. Daily Efficiency of Still (Case-3).

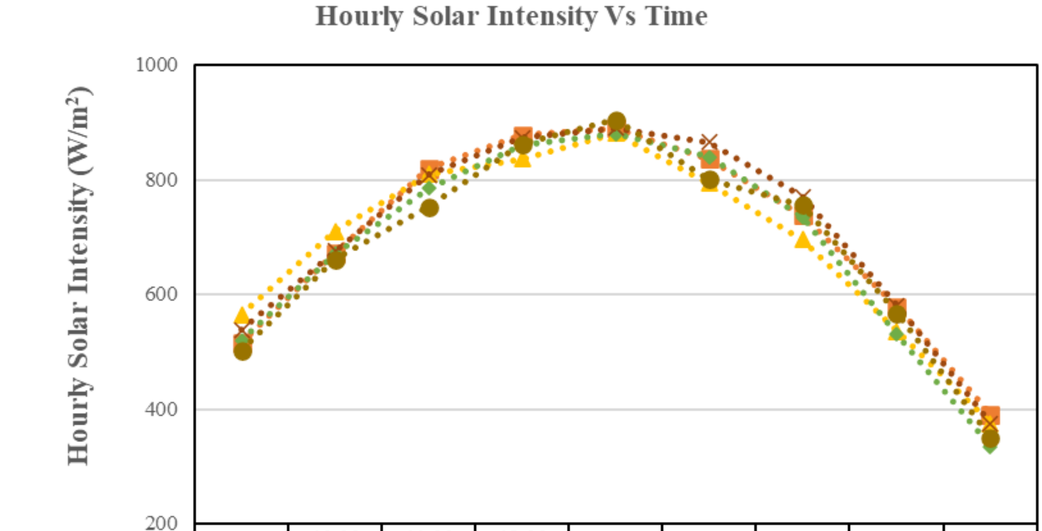
Figure 4.39 shows the daily efficiency for inclined solar still having stepped absorber with corrugated fins for different experimental days in summer season. From the graph, it is found that the still's daily efficiency at its highest is 40.0% on 06th May 2022 and the minimum efficiency of the still is 36.56% on 05th May 2022.

4.4 CASE-4: INCLINED SOLAR STILL HAVING STEPPED ABSORBER WITH CORRUGATED FIN INTEGRATED WITH VACUUM TUBES (SUMMER SEASON).

Based on the measured value of various components like solar incident, temperature of absorber plate, glass temperature and basin water temperature. Various following observations has been plotted and discussed for inclined solar still having stepped absorber with corrugated fin integrated with vacuum tubes (Summer season).

4.4.1 Hourly Solar Intensity

The quantity of energy that is collected from the sun in the form of electromagnetic waves is what is referred to as solar intensity. Increasing the temperature of the various components that are employed in a solar still requires solar intensity. The production of fresh produce received from still as well as the efficiency of still is largely dependent on the amount of sun intensity that is present.



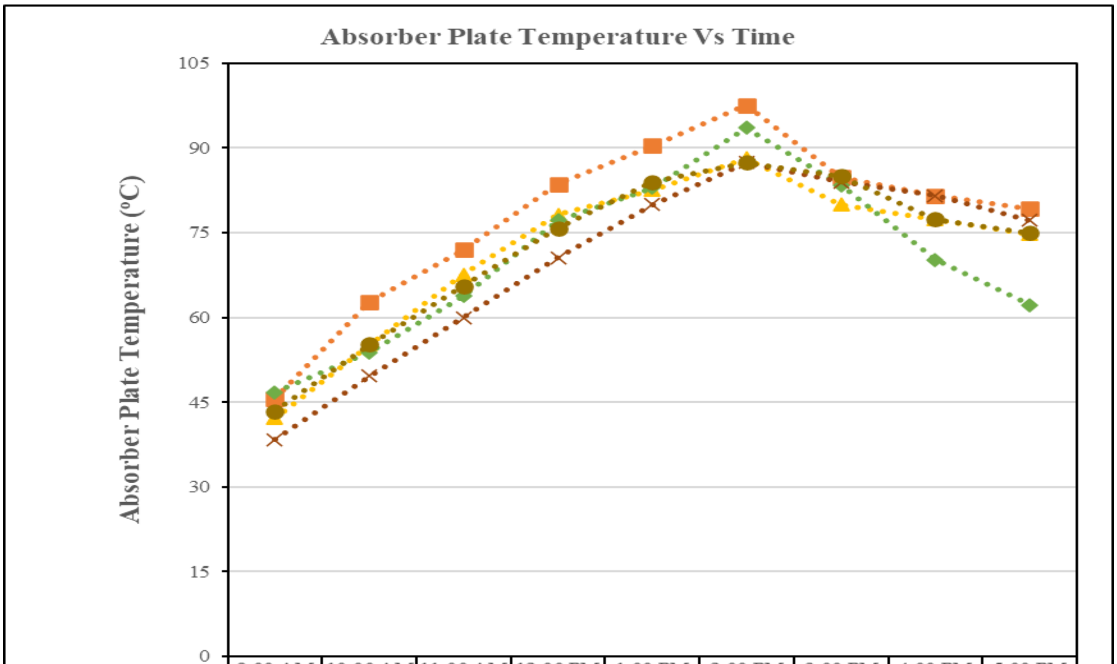
	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM
26-04-2022	516	672	820	878	890	836	738	578	390
27-04-2022	565	710	810	836	881	794	696	536	375
28-04-2022	520	671	785	860	880	840	735	530	335
29-04-2022	538	676	808	873	890	865	770	580	375
30-04-2022	502	661	753	862	905	801	756	567	350

Figure 4.40. Changes in Solar Intensity over Time (Case-4).

For several test days during the summer, Figure 4.40 depicts the variation in hourly solar intensity for an inclined solar still with a stepped absorber and corrugated fins combined with vacuum tubes. It is evident from the graph that on all of the trial days, the hourly sun intensity rises from 9:00 am until 1:00 pm, after which it begins to steadily decline. For all days, the highest and minimum values of the hourly sun intensity are respectively recorded at 1:00 pm and 5.00 pm. On April 26, 2022, the highest value of 890 W/m^2 and the minimum value of 390 W/m^2 are both attained at 1:00 pm. Similarly, for 27th, 28th, 29th, and 30th April 2022 a greatest value of hourly solar insolation is 881 W/m^2, 880 W/m^2, 890 W/m^2, and 905 W/m^2 correspondingly and a minimum value of hourly solar intensity is 375 W/m^2, 350 W/m^2, 375 W/m^2 and 410 W/m^2 respectively.

4.4.2 Absorber Plate Temperature

The critical temperature of the solar still is determined by the temperature of the absorber plate. Seeing as since the temperature of the absorber plate is the sole factor that determines the output of the still. As a result, the temperature of the absorber plate was monitored during the experiment and recorded on the accompanying graph at various points in time.



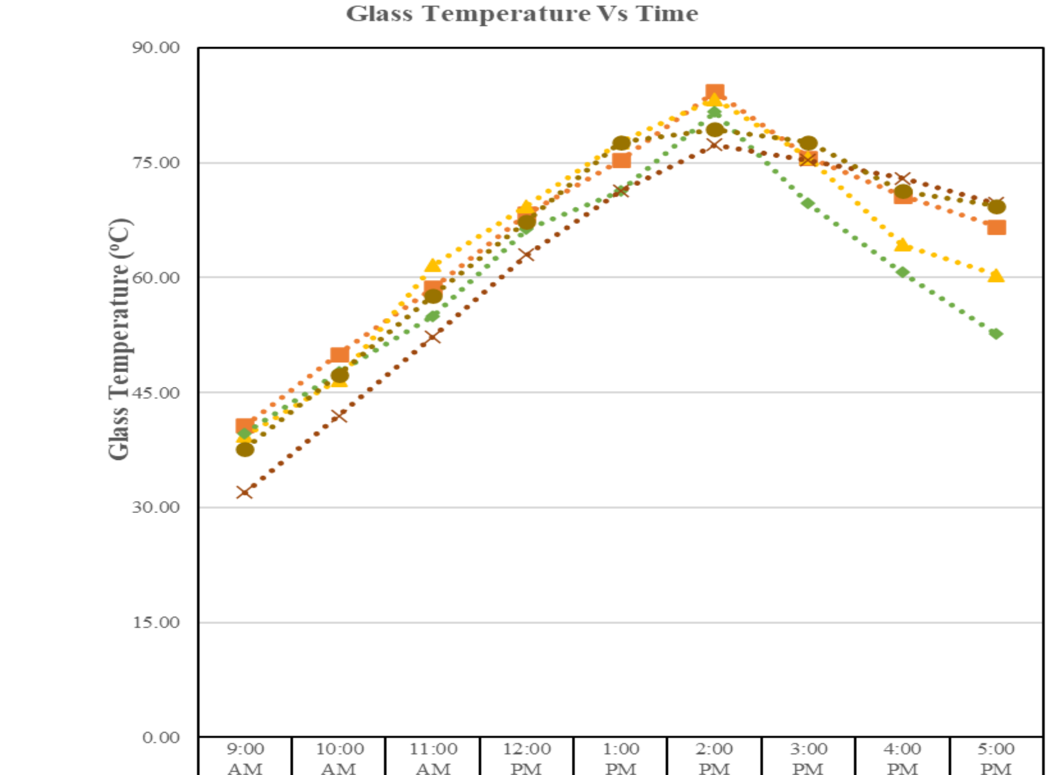
	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM
26-04-2022	45.6	62.8	72	83.6	90.4	97.6	84.8	81.6	79.2
27-04-2022	42.2	55.2	67.6	78.2	82.6	88.2	80	77.4	74.8
28-04-2022	46.8	53.8	63.8	77.2	83	93.6	83.4	70.2	62.2
29-04-2022	38.4	49.6	60	70.6	80	87.4	84	81.6	77.2
30-04-2022	43.4	55.2	65.6	75.8	84	87.4	85	77.4	75

Figure 4.41. Time-dependent Temperature Variation of the Absorber Plate (Case-4).

Figure 4.41 depicts the change in absorber plate temperature for inclined solar stills with stepped absorbers that have corrugated fins combined with vacuum tubes on several trial days throughout the summer. The graph shows that for all of the experiment days, an absorber plate temperature increases from 9:00 am to 2:00 pm, after which it starts to fall steadily, just as a solar insolation rises from 9:00 am to 1:00 pm, after which it falls. The highest absorber plate temperature recorded is 97.6°C on April 26, 2022, at 2:00 pm.

4.4.3 Glass Temperature

The temperature of the glass cover is a very crucial aspect in the solar still. because it determines the pace of condensation and, as a result, the amount of water that can be extracted from the solar still. The graph that follows illustrates how the temperature of the glass changed during the course of a single day. Its temperature is also dependent on the amount of sunlight that is received.



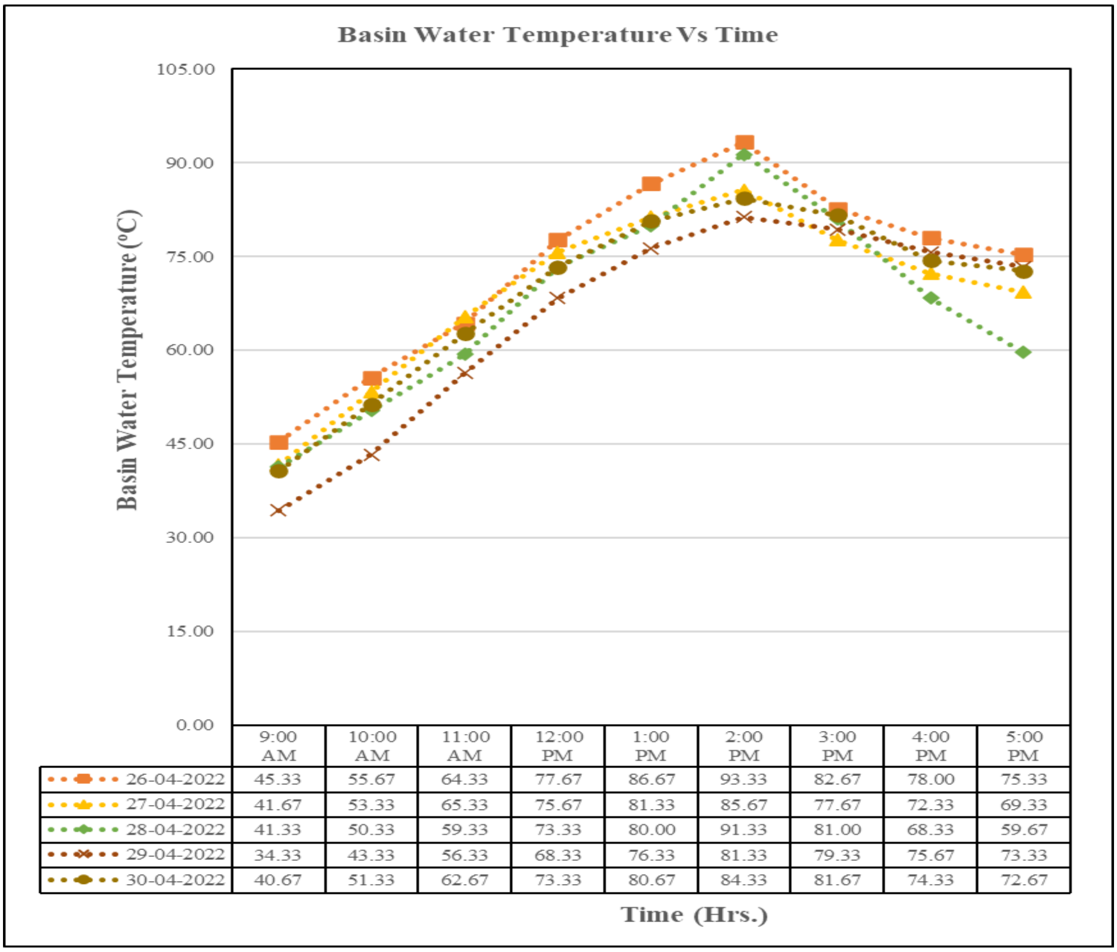
	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM
26-04-2022	40.67	50.00	58.67	68.33	75.33	84.33	75.67	70.67	66.67
27-04-2022	39.33	46.67	61.67	69.33	77.67	83.33	75.67	64.33	60.33
28-04-2022	39.67	47.67	55.00	66.33	71.33	81.67	69.67	60.67	52.67
29-04-2022	32.00	42.00	52.33	63.00	71.33	77.33	75.33	73.00	69.67
30-04-2022	37.67	47.33	57.67	67.33	77.67	79.33	77.67	71.33	69.33

Figure 4.42. Temperature Change in Glass with Time (Case-4).

For several test days during the summer, Figure 4.42 depicts the variation in glass temperature for an inclined solar still with stepped absorbers that have corrugated fins combined with vacuum tubes. It is evident from the graph that for each of the experiment days, the glass temperature increases from 9:00 am to 2:00 pm, after which it initiates to steadily fall, just as the solar insolation rises from 9:00 am to 1:00 pm, after which it falls. The highest glass temperature measured was 84.33° C on April 26, 2022, at 2:00 pm.

4.4.4 Basin Water Temperature

The term "basin water" refers to the water that is held within the solar still for the purpose of evaporation so that it may be transformed into a new output. The temperature of this water is also very significant, as the amount of fresh produce that can be extracted is solely dependent on the temperature of this water. The higher the temperature of the water in the basin, the higher the evaporation rate will be, and the bigger the production will be.



	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM
26-04-2022	45.33	55.67	64.33	77.67	86.67	93.33	82.67	78.00	75.33
27-04-2022	41.67	53.33	65.33	75.67	81.33	85.67	77.67	72.33	69.33
28-04-2022	41.33	50.33	59.33	73.33	80.00	91.33	81.00	68.33	59.67
29-04-2022	34.33	43.33	56.33	68.33	76.33	81.33	79.33	75.67	73.33
30-04-2022	40.67	51.33	62.67	73.33	80.67	84.33	81.67	74.33	72.67

Figure 4.43. Temperature Changes in the Basin Water Over Time (Case-4).

For various testing days during the summer, Figure 4.43 depicts the variation in basin water temperature for an inclined solar still with stepped absorbers that have corrugated fins combined with vacuum tubes. The graph shows that for all of the experiment days, the basin's water temperature increases from 9:00 am to 2:00 pm, after which it begins to fall steadily, just as a sun's rays rise from 9:00 am to 1:00 pm, after which they fall. The highest water temperature recorded for the basin is 93.33° C on April 26, 2022, at 2:00 pm.

4.4.5 Absorber Plate, Glass and Basin Water Temperature for Different Experimental Days

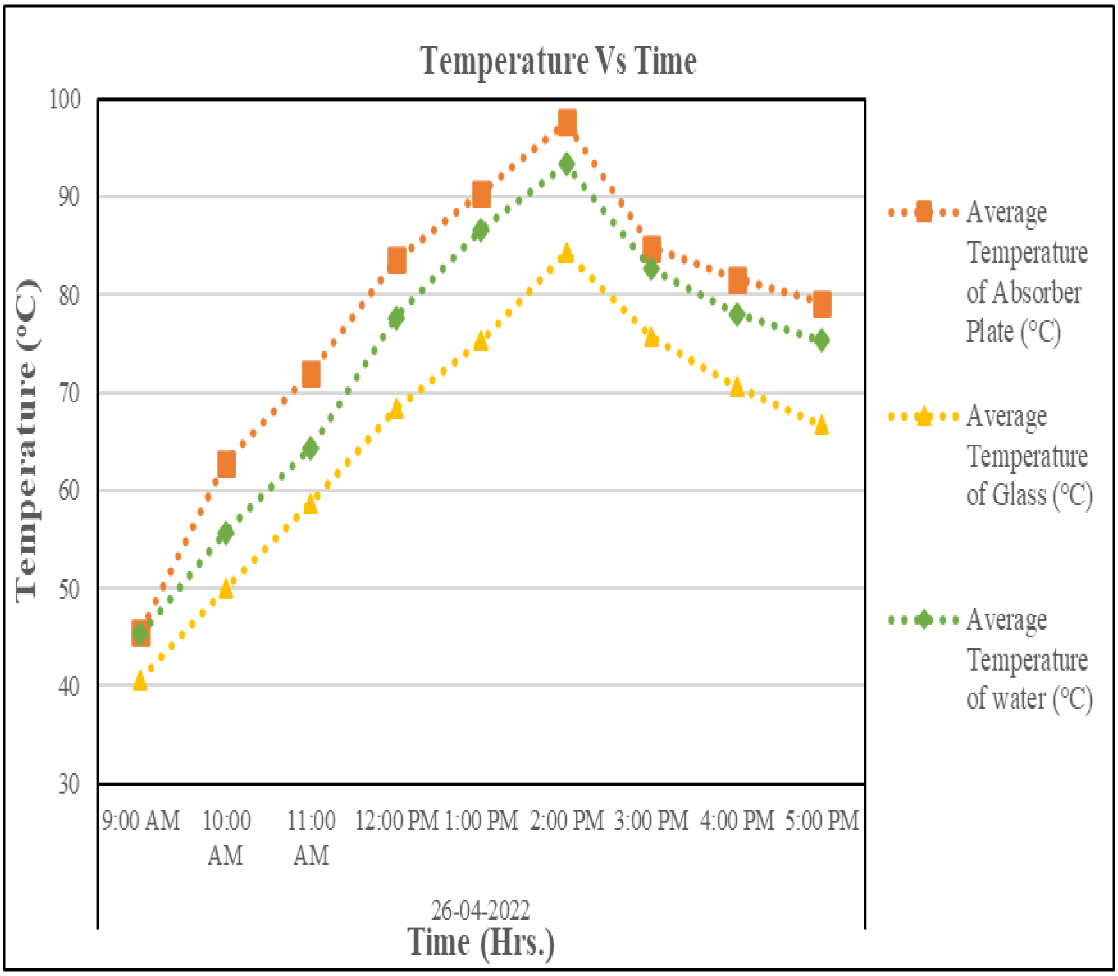


Figure 4.44 Shows the evolution of the water's temperature in the basin, glass, and absorber plate on April 26, 2022

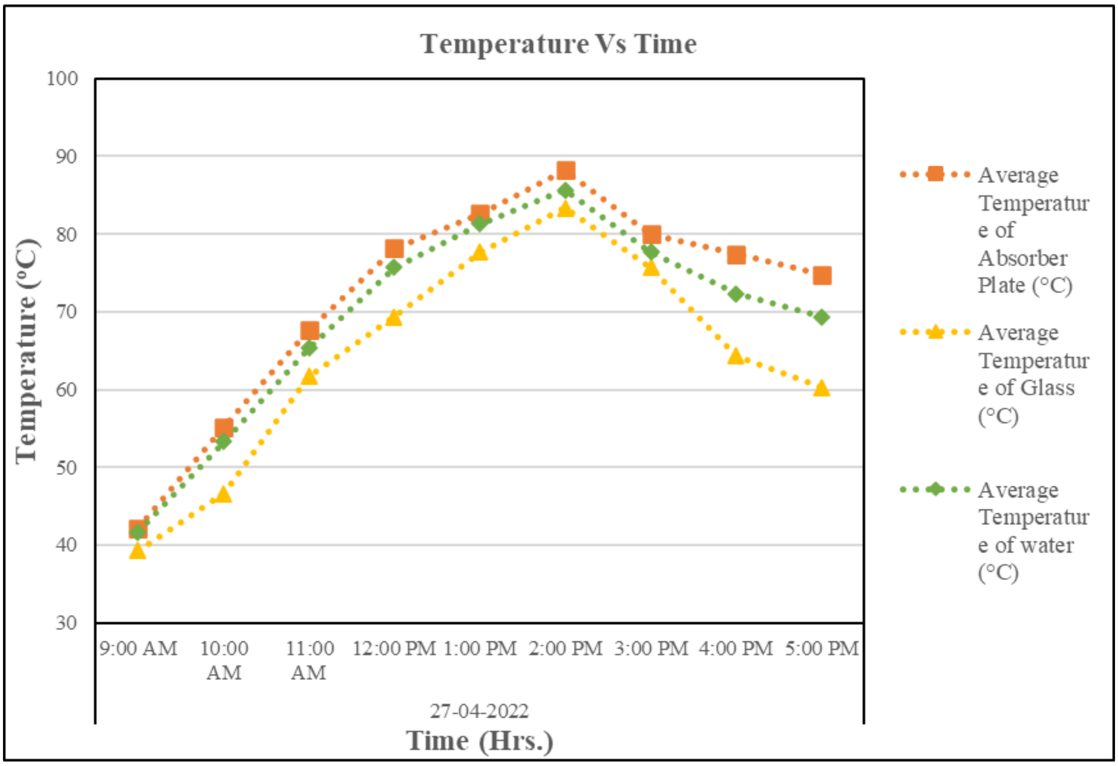


Figure 4.45 Shows the evolution of the water's temperature in the basin, glass, and absorber plate on April 27, 2022

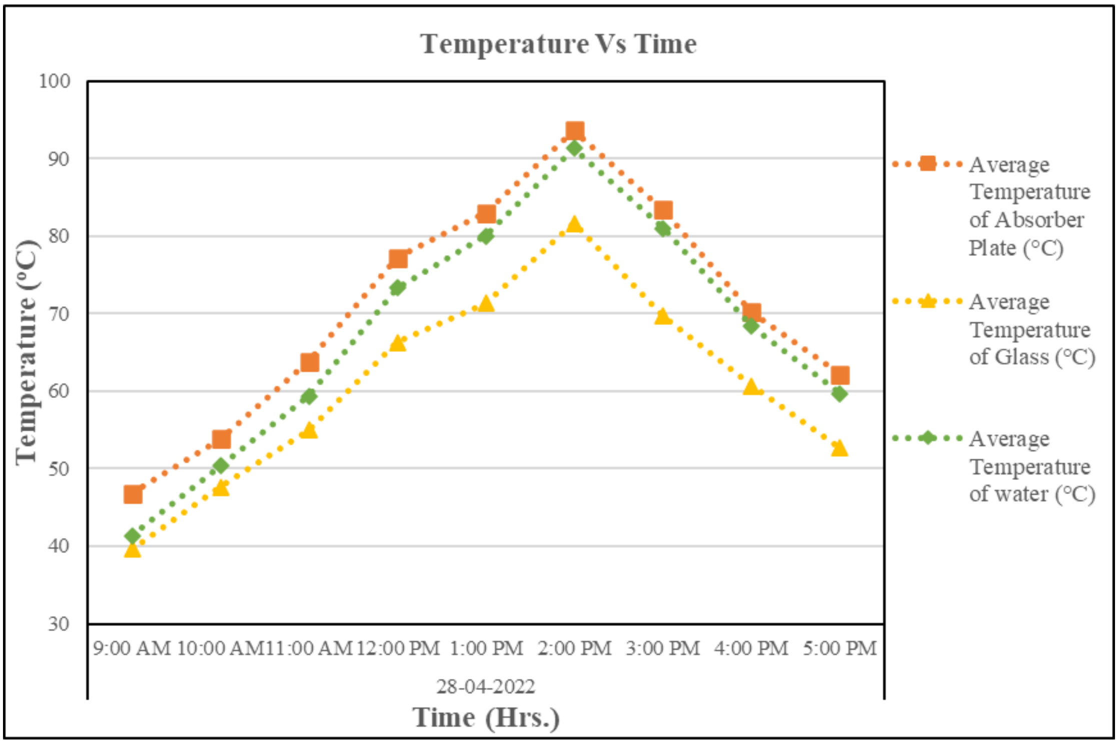


Figure 4.46. Shows the evolution of the water's temperature in the basin, glass, and absorber plate on April 28, 2022

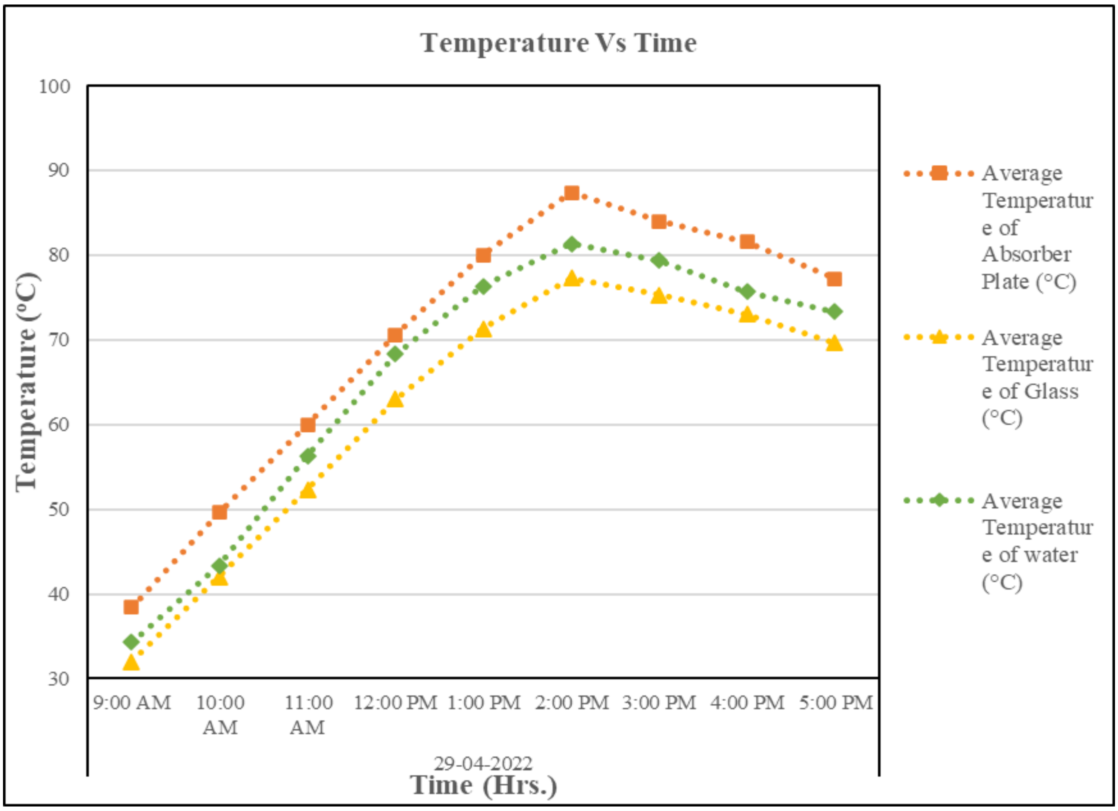


Figure 4.47. Shows the evolution of the water's temperature in the basin, glass, and absorber plate on April 29, 2022

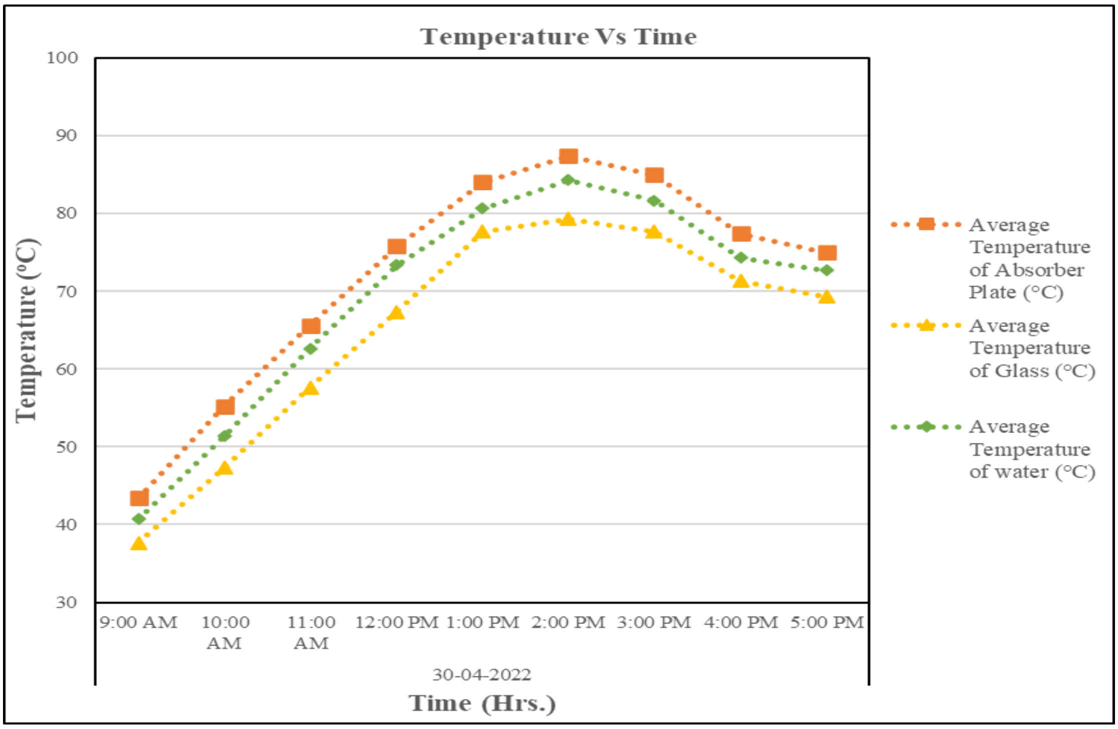
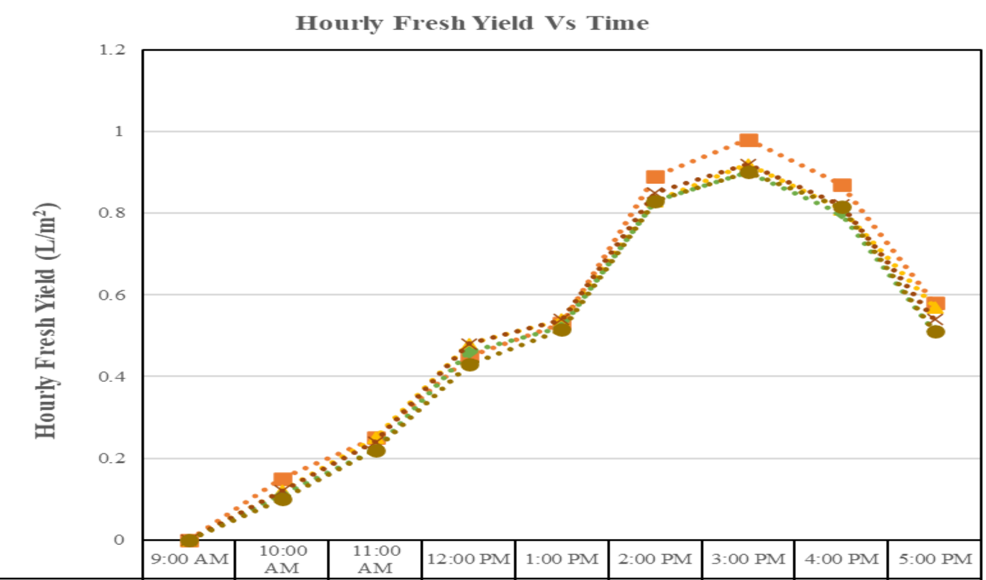


Figure 4.48. Shows the evolution of the water's temperature in the basin, glass, and absorber plate on April 30, 2022

For inclined solar stills with stepped absorbers that have corrugated fins integrated with vacuum tubes, Figures 4.44 – 4.48 illustrates a temperature variation of a glass, water in the basin, and absorber for various trial days over the summer. From the graph, it is evident that for each of an experiment day, glass temperature, absorber plate temperature, and basin water temperature increase from 9:00 am to 2:00 pm, after which they begin to steadily decrease, just as the solar insolation does from 9:00 am to 1:00 pm, before decreasing. A highest value of the absorber plate, glass, and basin water temperature were recorded for April 26, 2022, at 2:00 pm, and are 97.6^{o}C, 84.33^{o}C, and 93.33^{o}C, respectively. In a similar vein, the maximum absorber plate temperatures for the 27th, 28th, 29th, and 30th of April 2022 are 88.2°C, 93.6°C, 87.4°C, and 87.4°C, respectively, at 2:00 pm; a greatest glass temperatures are 83.33°C, 81.67°C, 77.33°C, and 79.33°C, respectively; and the maximum basin water temperatures are 85.67°C.

4.4.6 Hourly Fresh Yield

The fresh water obtained from still is measured on hourly basis, that measured quantity is known as hourly fresh yield. It is determined on an hourly basis how much energy was received by the water on an hourly basis and how much water will get transformed into new output in order to establish the hourly efficiency of the still. This measurement is done every hour.



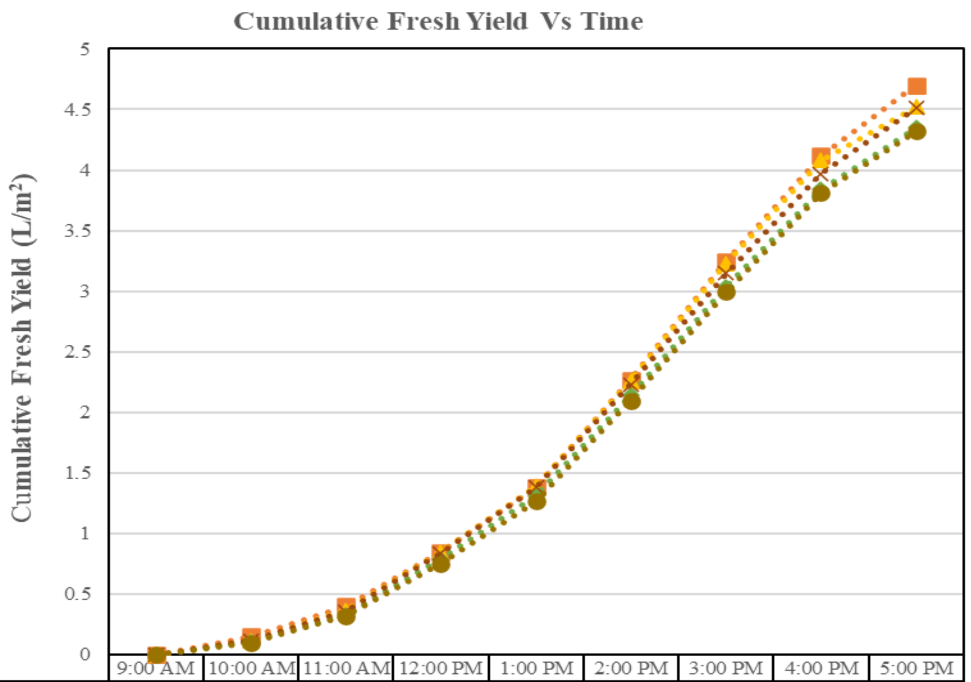
	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM
26-04-2022	0	0.15	0.25	0.45	0.53	0.89	0.98	0.87	0.58
27-04-2022	0	0.12	0.25	0.48	0.54	0.83	0.92	0.81	0.57
28-04-2022	0	0.11	0.22	0.46	0.52	0.83	0.9	0.8	0.51
29-04-2022	0	0.12	0.24	0.48	0.54	0.85	0.92	0.82	0.54
30-04-2022	0	0.1	0.22	0.43	0.515	0.83	0.9	0.815	0.51

Figure 4.49. Hourly Fresh Yield Changes Over Time (Case-4).

For several test days during the summer, Figure 4.49 displays the variance in hourly fresh yield for an inclined solar still with a stepped absorber and corrugated fins combined with vacuum tubes. The graph shows that during the experiment, a hourly fresh output increases from 9:00 am until 3:00 pm, after which it begins to steadily decline. The maximum yield is achieved at 3:00 pm because the output of fresh yield is based on solar intensity, which rises from 9:00 am to 1:00 pm and then falls. Additionally, because evacuated tubes are utilized, water temperature climbs more and stays greater for longer periods of time. A maximum value of hourly fresh yield obtained is 0.98 L/m^2 for 26th April 2022 at 3:00 pm. Similarly, for 27th, 28th, 29^{th,} and 30th April 2022 the maximum value of hourly fresh yield is 0.92 L per m^2, 0.9 L per m^2, 0.92 L per m^2, and 0.9 L per m^2 respectively at 3:00 pm.

4.4.7 Cumulative Fresh Yield

The total fresh water obtained from still for a particular experimental day is measured, that measured quantity is known as cumulative fresh yield. It is measured to determine the efficiency of the still for that particular day.



	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM
26-04-2022	0	0.15	0.4	0.85	1.38	2.27	3.25	4.12	4.7
27-04-2022	0	0.12	0.37	0.85	1.39	2.26	3.23	4.08	4.52
28-04-2022	0	0.11	0.33	0.79	1.31	2.14	3.04	3.84	4.35
29-04-2022	0	0.12	0.36	0.84	1.38	2.23	3.15	3.97	4.51
30-04-2022	0	0.1	0.32	0.75	1.265	2.095	2.995	3.81	4.32

Time (Hrs.)

Figure 4.50. Time-dependent Change in Cumulative Fresh Yield (Case-4).

Figure 4.50 shows the variation of cumulative fresh output for inclined solar still having stepped absorber with corrugated fins integrated with vacuum tubes for different experimental days in summer season. From the graph, it's found that for all an experimental day the fresh distillate output is maximum at 3:00 pm. Because the fresh yield production is influenced by solar intensity, which rises from 9:00 am to 1:00 pm, and because evacuated tubes are employed, which cause the water temperature to rise more and stay higher for longer, the highest yield is attained at 3:00 pm. The maximum value of cumulative fresh yield obtained is 4.7 L/m^2/ day for 26th April 2022. Similarly, for 27th, 28th, 29th, and 30th April 2022 the value of cumulative fresh yield is 4.52 L per m^2 per day, 4.35 per m^2 per day, 4.51 per m^2 per day, and 4.32 per m^2 per day respectively.

4.4.8 Solar Intensity and Absorber Plate Temperature

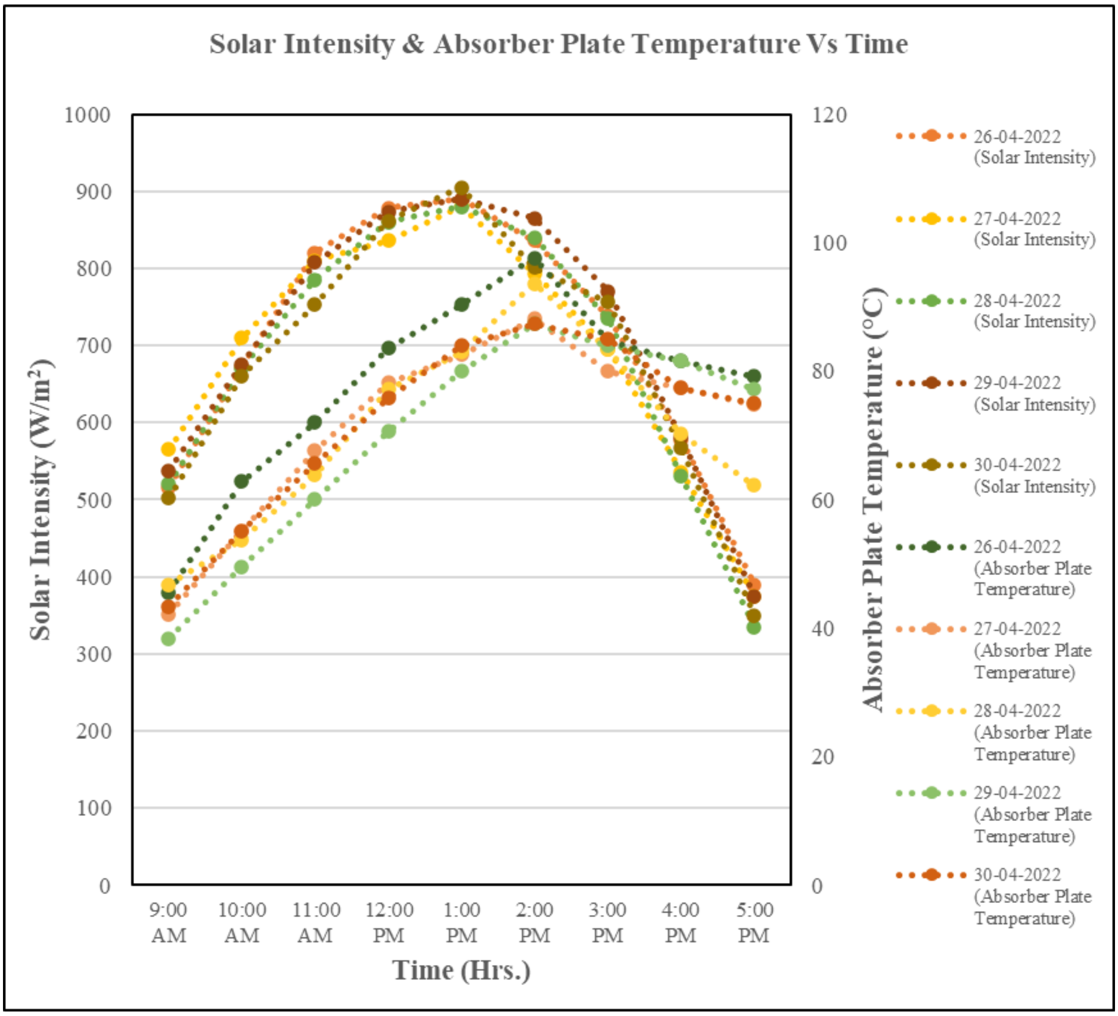


Figure 4.51. Solar Intensity and Absorber Plate Temperature with Time (Case-4).

For an inclined solar still with a stepped absorber, corrugated fins, and evacuated tubes combined during the summer for several testing day, Figure 4.51 depicts the variation of solar intensity and absorber plate temperature with respect to time. Similar to the way the temperature of the absorber plate increases for all testing days from 9:00 am to 2:00 pm and then slowly declines, it is observed that the solar insolation rises from 9:00 am to 1:00 pm for all testing days before beginning to decline. Since the absorber plate temperature is entirely dependent on solar intensity, we receive a greatest solar insolation at 1:00 pm on all testing days, which results in the highest temperature of the absorber plate is determined at 2:00 pm. Because after absorbing heat from the sun's rays, a temperature of an absorber plate remains greater for certain time periods.

4.4.9 Daily Efficiency of Still

As the efficiency is depends upon the fresh output of still and solar intensity, that's why the variation in efficiency for different experimental days is recorded and shown in below graph.

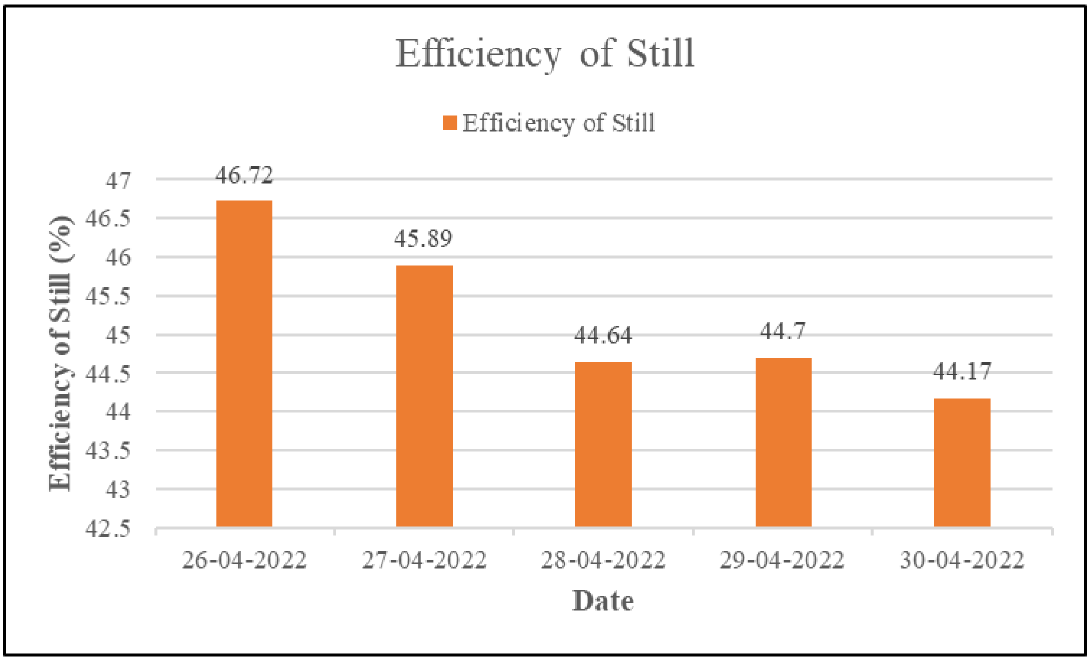


Figure 4.52. Daily Efficiency of Still (Case-4).

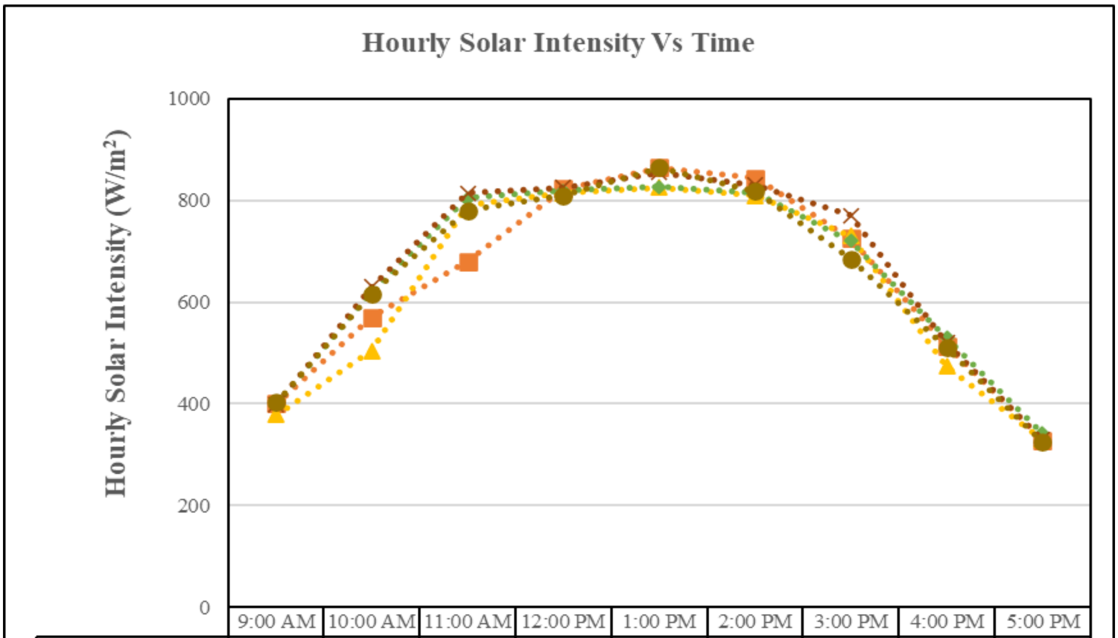
Figure 4.52 shows the daily efficiency for inclined solar still having stepped absorber with corrugated fins integrated with vacuum tubes for different experimental days in summer season. From the graph, it is found that the still's daily efficiency at its highest is 46.72% on 26th April 2022 and the minimum efficiency of the still is 44.17% on 30th April 2022.

4.5 CASE-5: INCLINED SOLAR STILL HAVING STEPPED ABSORBER WITH CORRUGATED FIN INTEGRATED WITH VACUUM TUBES BY USING NANOPARTICLES.

Based on the measured value of various components like solar radiation, temperature of absorber plate, glass temperature and basin water temperature. Various following observations has been plotted and discussed for inclined solar still having stepped absorber with corrugated fin integrated with vacuum tubes by using nanoparticles.

4.5.1 Hourly Solar Intensity

The quantity of energy that is collected from the sun in the form of electromagnetic waves is what is referred to as solar intensity. Increasing the temperature of the various components that are employed in a solar still requires solar intensity. The production of fresh produce received from still as well as the efficiency of still is largely dependent on the amount of sun intensity that is present.



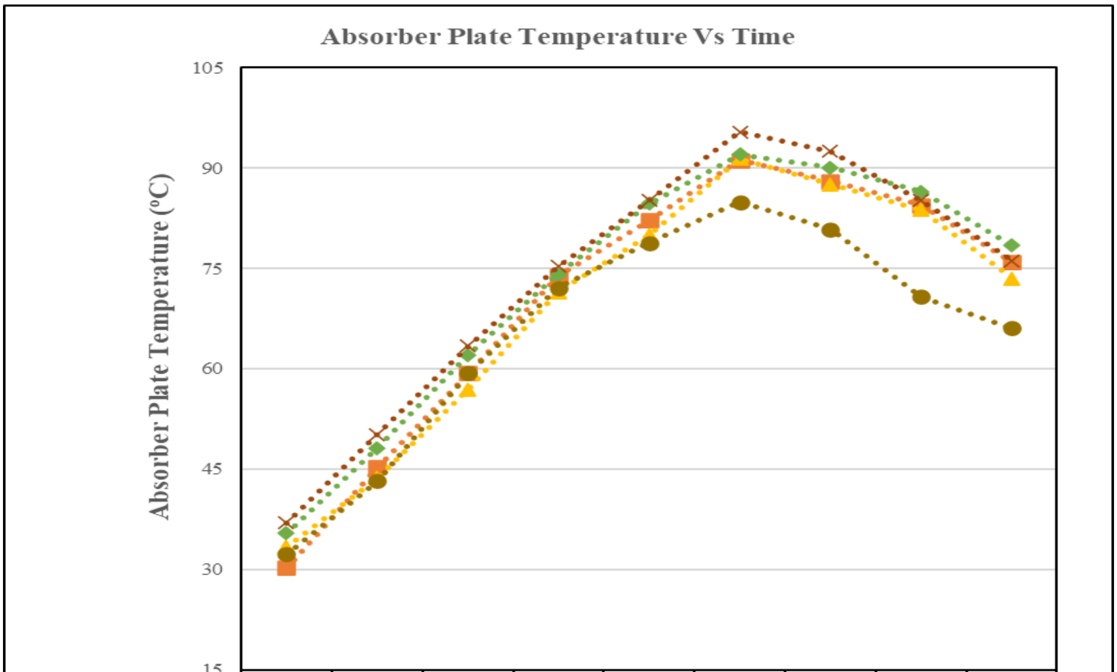
	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM
06-10-2022	400	570	680	823	865	844	725	514	329
07-10-2022	378	504	790	815	825	810	730	474	330
08-10-2022	399	620	805	820	827	815	720	530	342
09-10-2022	399	630	815	825	855	830	770	520	330
10-10-2022	403	616	780	810	865	818	685	510	325

Figure 4.53. Changes in Solar Intensity over Time (Case-5)

For several testing days, Figure 4.53 depicts the variation in hourly sun intensity for inclined solar stills with stepped absorbers and corrugated fins integrated with vacuum tubes by using aluminium oxide as nanoparticles. It is evident from the graph that on all of the trial days, the hourly sun intensity rises from 9:00 am until 1:00 pm, after which it begins to steadily decline. For all days, the highest and minimum values of the hourly sun intensity are respectively recorded at 1:00 pm and 5:00 pm. On October 6, 2022, at 1:00 pm and 5:00 pm, correspondingly, the highest value of 865 W/m^2 and the lowest value of 329 W/m^2 are measured. Similarly, for 07th, 08th, 09th, and 10th October 2022 a highest value of hourly solar rays is 825 W/m^2, 827 W/m^2, 855 W/m^2, and 865 W/m^2 respectively and the minimum value of hourly solar radiation is 330 W/m^2, 342 W/m^2, 330 W/m^2 and 325 W/m^2 respectively.

4.5.2 Absorber Plate Temperature

The critical temperature of the solar still is determined by the temperature of the absorber plate. Seeing as since the temperature of the absorber plate is the sole factor that determines the output of the still. As a result, the temperature of the absorber plate is recorded over the several days of the experiment and represented on the accompanying graph.



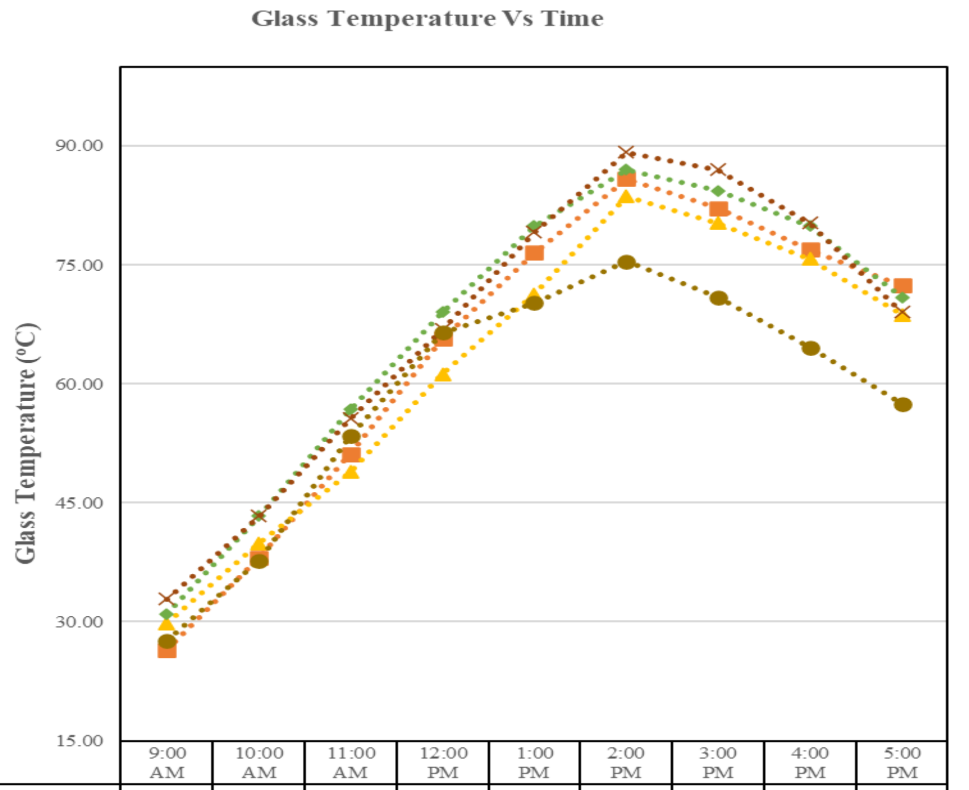
	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM
06-10-2022	30.24	45.248	59.36	73.92	82.208	91.168	88.032	84.448	75.936
07-10-2022	33.376	43.68	56.896	71.456	79.968	91.392	87.584	83.776	73.472
08-10-2022	35.392	48.16	62.048	74.144	84.672	92.064	90.048	86.464	78.4
09-10-2022	36.96	50.176	63.392	75.264	85.12	95.424	92.512	85.12	76.16
10-10-2022	32.256	43.232	59.36	72.128	78.848	84.896	80.864	70.784	66.08

Figure 4.54. Time-dependent Temperature Variation of the Absorber Plate (Case-5).

Figure 4.54 depicts the change in absorber plate temperature for inclined solar stills with stepped absorbers integrated corrugated fins and vacuum tubes by using aluminum oxide as nanoparticles on various experimental days. From the graph, it is evident that for each of the experiment days, the absorber plate temperature increases from 9:00 am to 2:00 pm before beginning to steadily fall, just as solar radiation rises from 9:00 am to 1:00 pm before falling. On October 9, 2022, at 2:00 pm, the highest temperature recorded on the absorber plate was 95.42^{o}C.

4.5.3 Glass Temperature

The temperature of the glass cover is a very crucial aspect in the solar still. because it determines the pace of condensation and, as a result, the amount of water that can be extracted from the solar still. The graph that follows illustrates how the temperature of the glass changed during the course of a single day. Its temperature is also dependent on the amount of sunlight that is received.



	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM
06-10-2022	26.51	38.08	51.15	65.71	76.53	85.87	82.13	76.91	72.43
07-10-2022	29.87	39.95	48.91	61.23	71.31	83.63	80.27	75.79	68.69
08-10-2022	30.99	43.31	56.75	69.07	79.89	86.99	84.37	79.89	70.93
09-10-2022	32.85	43.31	55.63	66.83	79.15	89.23	86.99	80.27	69.07
10-10-2022	27.63	37.71	53.39	66.45	70.19	75.41	70.93	64.59	57.49

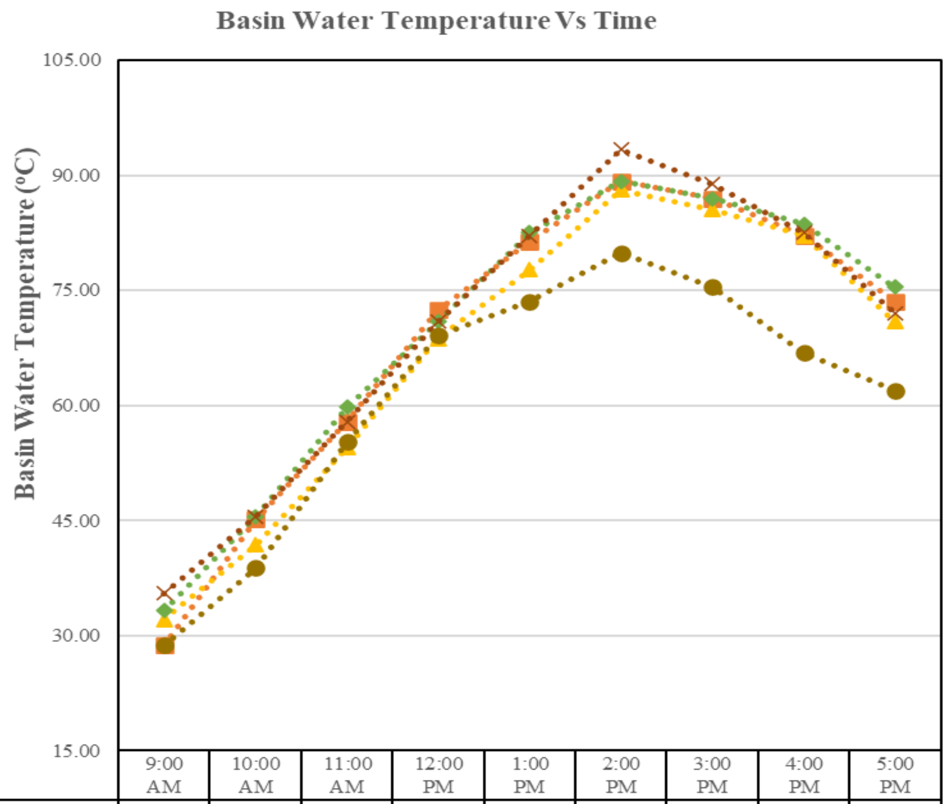
Time (Hrs.)

Figure 4.55. Temperature Change in Glass with Time (Case-5).

Figure 4.55 depicts the fluctuation in glass temperature for an inclined solar still with stepped absorbers integrated corrugated fins and vacuum tubes by using aluminum oxide as nanoparticles on various experimental days. It is evident from the graph that for each of the experiment days, the glass temperature increases from 9:00 am to 2:00 pm, after which it initiates to steadily fall, just as a solar insolation rises from 9:00 am to 1:00 pm, after which it falls. The highest glass temperature measured was 89.23ºC on October 9, 2022, at 2 o'clock.

4.5.4 Basin Water Temperature

The water which is stored inside the solar still for evaporation to get converted into fresh output is known as basin water. The temperature of this water is also very important, as fresh output is depending upon this water temperature only. Higher the basin water temperature more will be the evaporation rate and greater will be the output.



	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM
06-10-2022	28.75	45.17	57.87	72.43	81.39	89.23	86.99	82.13	73.55
07-10-2022	32.11	41.81	54.51	68.69	77.65	88.11	85.49	82.13	70.93
08-10-2022	33.23	45.55	59.73	70.93	82.51	89.23	86.99	83.63	75.41
09-10-2022	35.47	45.55	57.87	70.93	82.13	93.33	88.85	82.51	72.05
10-10-2022	28.75	38.83	55.25	69.07	73.55	79.89	75.41	66.83	61.97

Figure 4.56. Temperature Changes in the Basin water Over Time (Case-5).

For inclined solar stills with stepped absorbers and corrugated fins integrated with vacuum tubes, Figure 4.56 illustrates the fluctuation in basin water temperature for various trial days utilizing aluminum oxide nanoparticles. The graph shows that, for all of the experiment days, the water temperature in the basin increases from 9:00 am to 2:00 pm, after which it initiates to fall steadily, just as a solar insolation increases from 9:00 am to 1:00 pm, after which it falls. The maximum basin water temperature obtained is 93.33°C for 09th October 2022 at 2.00 pm.

4.5.5 Absorber Plate, Glass and Basin Water Temperature for Different Experimental Days

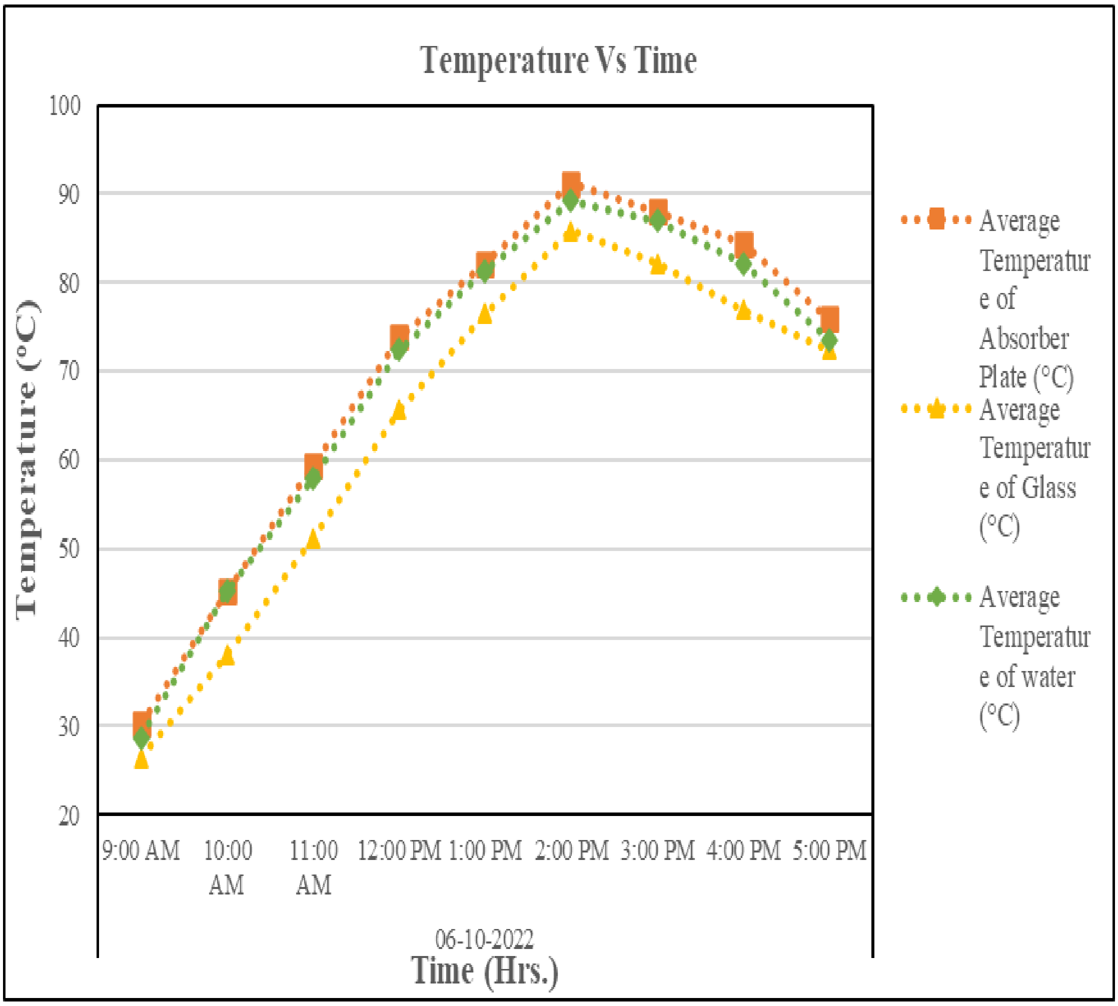


Figure 4.57. Shows the evolution of the water's temperature in the basin, glass, and absorber plate on October 06, 2022

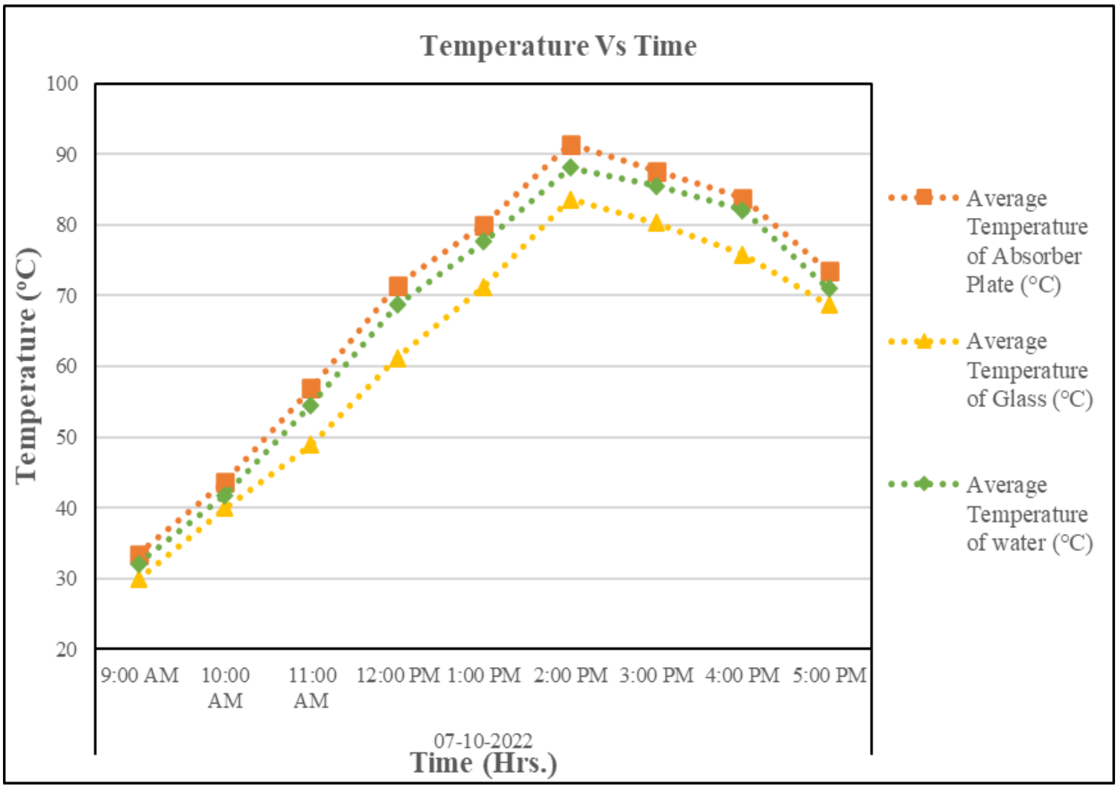


Figure 4.58. Shows the evolution of the water's temperature in the basin, glass, and absorber plate on October 07, 2022

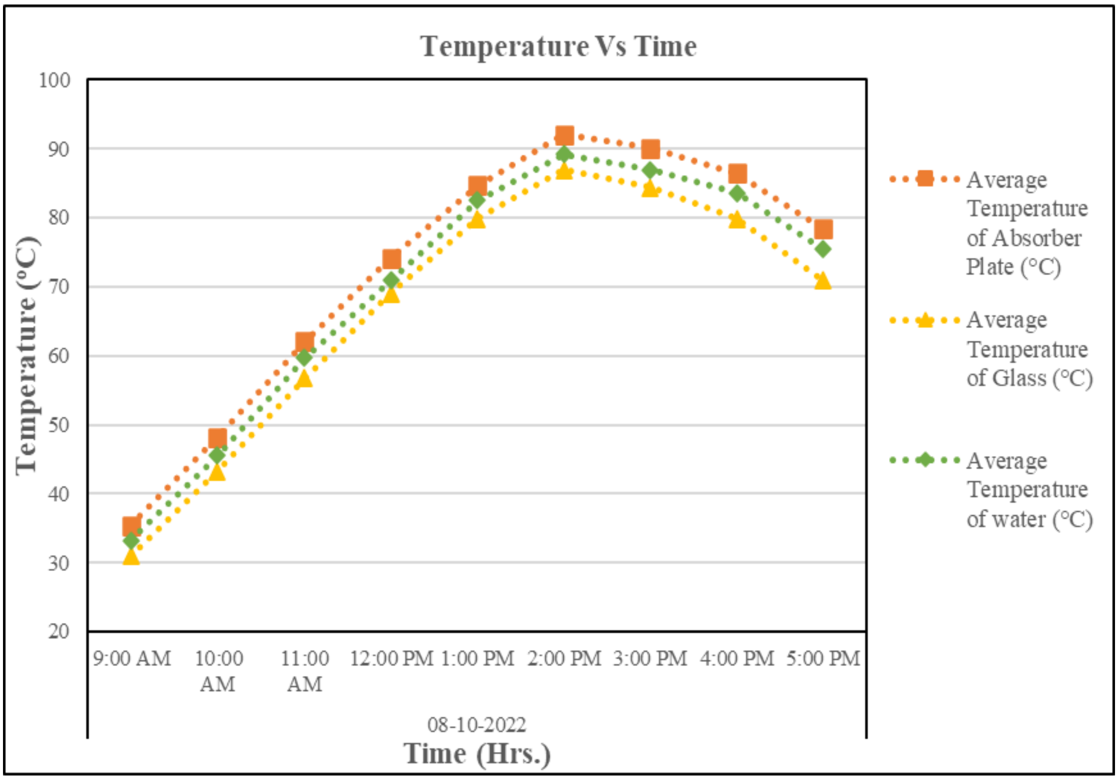


Figure 4.59. Shows the evolution of the water's temperature in the basin, glass, and absorber plate on October 08, 2022

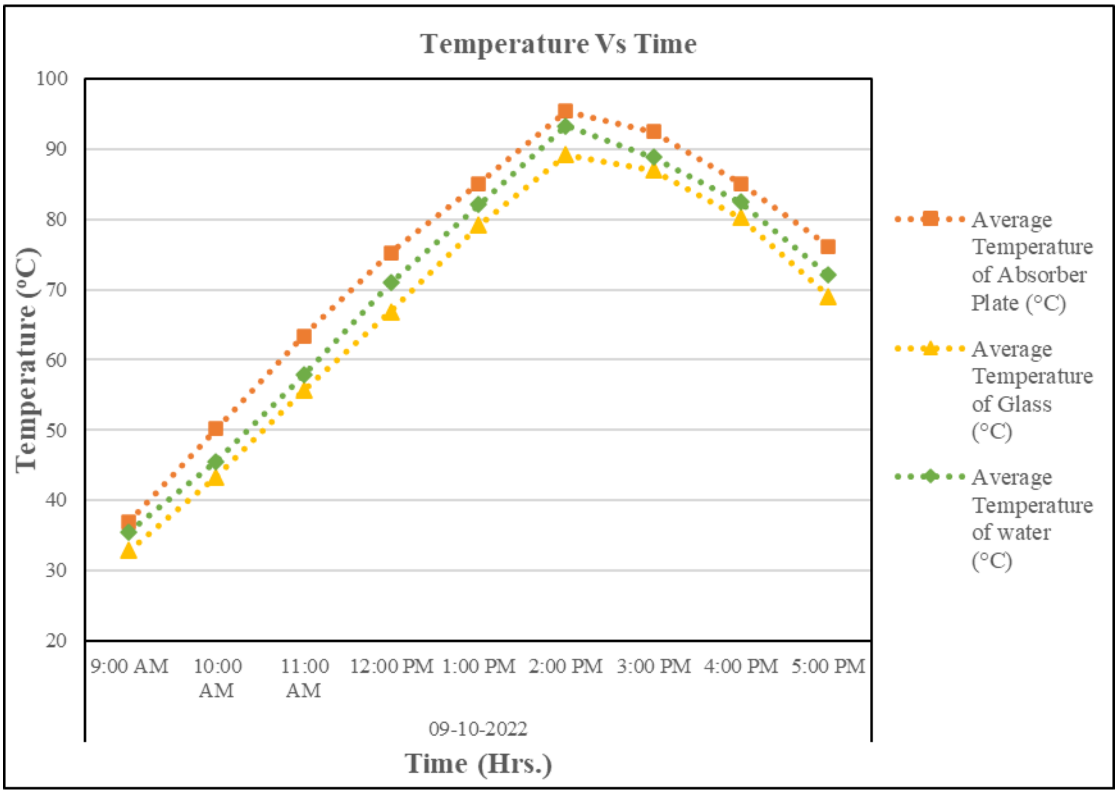


Figure 4.60. Shows the evolution of the water's temperature in the basin, glass, and absorber plate on October 09, 2022

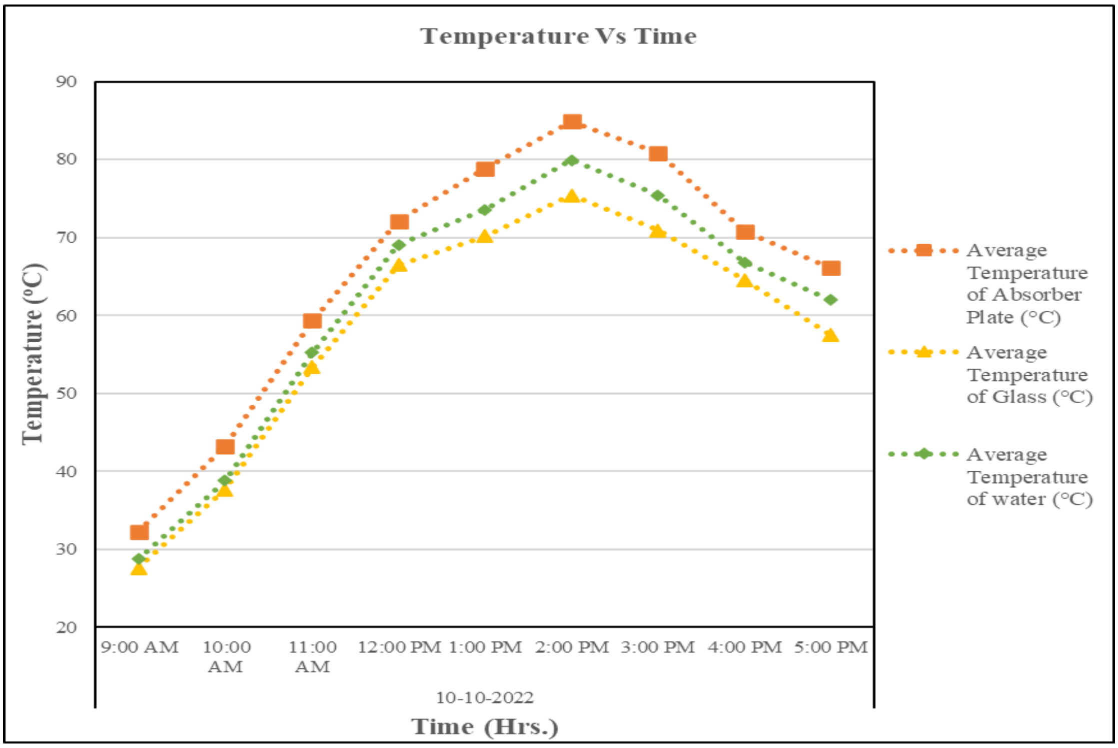
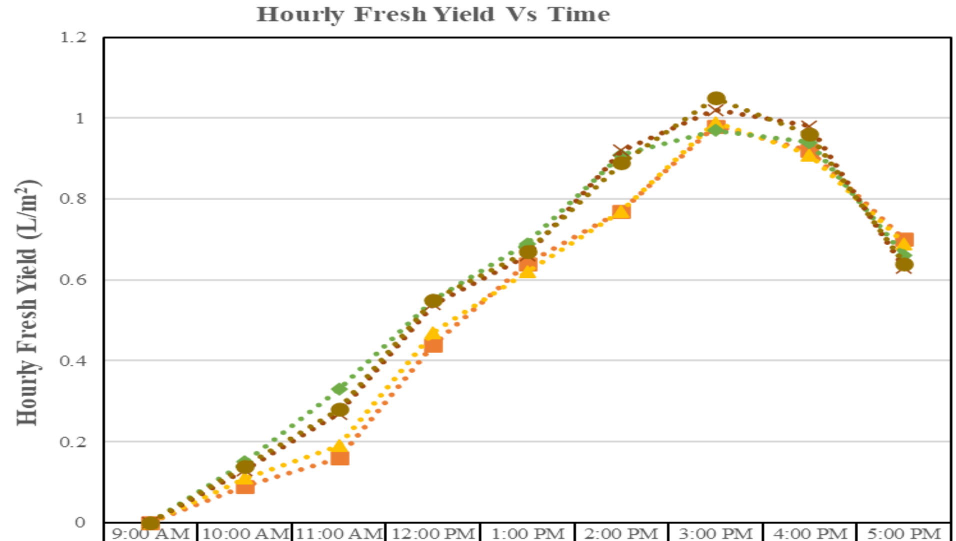


Figure 4.61. Shows the evolution of the water's temperature in the basin, glass, and absorber plate on October 10, 2022

A temperature change of an absorber plate, a glass, and a water in a basin for an inclined solar still with stepped absorbers and corrugated fins integrated with vacuum tubes by using Al_2O_3 nanoparticles is shown in Figures 4.57 to 4.61 for several testing days. From the graph, it is evident that for each of the experiment days, a temperature variation of a water in a basin, glass, and an absorber plate increases from 9:00 am to 2:00 pm, after which they begin to steadily decrease, just as the solar insolation does from 9:00 am to 1:00 pm, before decreasing. A highest value of an absorber plate, glass, and basin water temperature were recorded on October 6, 2022, at 2:00 pm, and they are 91.17°C, 85.87°C, and 89.23°C, respectively. Similar to this, the maximum absorber plate temperatures for the 7th, 8th, 9th, and 10th of October 2022 are 91.39°C, 92.06°C, 95.42°C, and 84.90°C, respectively, at 2:00 pm; the maximum glass temperatures are 83.63°C, 86.99°C, 89.23°C, and 75.41°C, respectively; and the maximum basin water temperatures are 88.11°C, 89.23°C, 93.33°C, and 79.89°C.

4.5.5 Hourly Fresh Yield

The fresh water obtained from still is measured on hourly basis, that measured quantity is known as hourly fresh yield. It is monitored hourly to assess the water's energy intake and how much water is turned into new output to establish the still's hourly efficiency.



	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM
06-10-2022	0	0.09	0.16	0.44	0.64	0.77	0.98	0.92	0.7
07-10-2022	0	0.11	0.19	0.47	0.62	0.77	0.99	0.91	0.69
08-10-2022	0	0.15	0.33	0.55	0.69	0.91	0.97	0.94	0.66
09-10-2022	0	0.13	0.27	0.54	0.66	0.92	1.02	0.98	0.63
10-10-2022	0	0.14	0.28	0.55	0.67	0.89	1.05	0.96	0.64

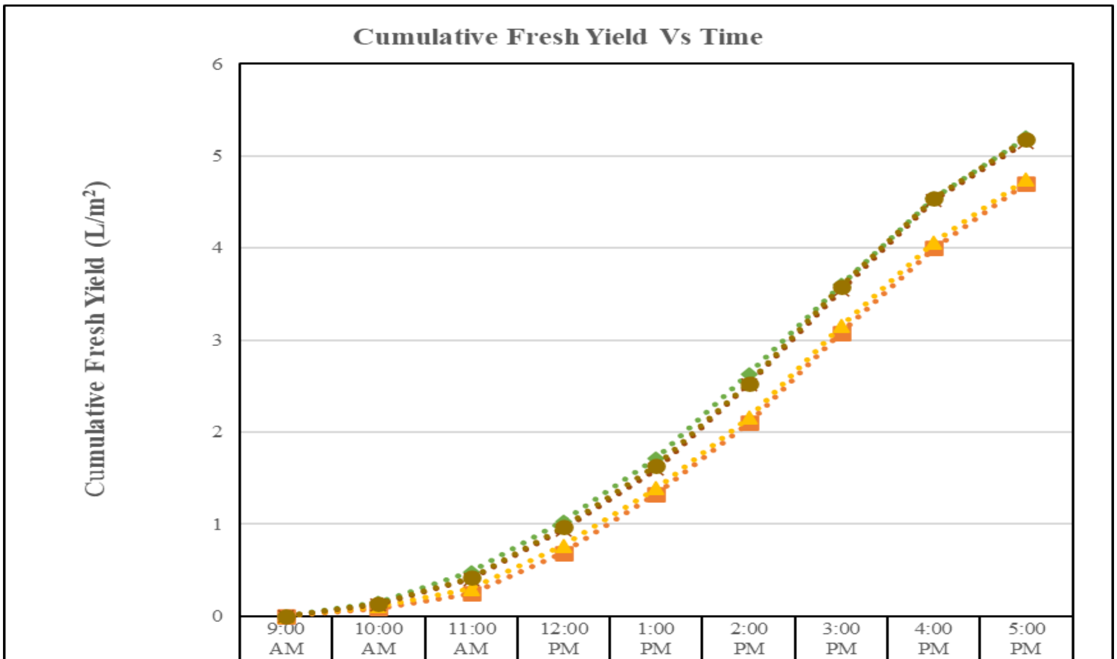
Time (Hrs.)

Figure 4.62. Hourly Fresh Yield Changes Over Time (Case-5).

In Figure 4.62, the hourly fresh yield fluctuation for an inclined solar still with a stepped absorber and corrugated fins combined with vacuum tubes by using Al_2O_3 nanoparticles for various testing days is depicted. The graph shows that during the experiment, an hourly fresh distillate output increases from 9:00 am until 3:00 pm, after which it begins to steadily decline. The maximum yield is achieved at 3:00 pm because the output of fresh yield is dependent on solar intensity, which increases from 9:00 am to 1:00 pm and then reduces. Additionally, evacuated tubes and nanoparticles are used, which cause the water temperature to increase more and stay greater for long periods of time. A maximum value of hourly fresh yield obtained is 1.05 L per m^2 for 10^{th} October 2022 at 3:00 pm. Similarly, for 06^{th}, 07^{th}, 08^{th} and 09^{th} October 2022 the maximum value of hourly fresh yield is 0.98 L per m^2, 0.99 L per m^2, 0.97 L per m^2, and 1.02 L per m^2 respectively at 3:00 pm.

4.5.6 Cumulative Fresh Yield

The total fresh water obtained from still for a particular experimental day is measured, that measured quantity is known as cumulative fresh yield. It is measured to determine the efficiency of the still for that particular day.



	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM
06-10-2022	0	0.09	0.25	0.69	1.33	2.1	3.08	4	4.7
07-10-2022	0	0.11	0.3	0.77	1.39	2.16	3.15	4.06	4.75
08-10-2022	0	0.15	0.48	1.03	1.72	2.63	3.6	4.54	5.2
09-10-2022	0	0.13	0.4	0.94	1.6	2.52	3.54	4.52	5.15
10-10-2022	0	0.14	0.42	0.97	1.64	2.53	3.58	4.54	5.18

Figure 4.63. Time-dependent Change in Cumulative Fresh Yield (Case-5).

According to the different trial days, Figure 4.63 depicts the variance in the cumulative fresh production for an inclined solar still with stepped absorbers and corrugated fins combined with vacuum tubes by using Al_2O_3 nanoparticles. It is evident from the graph that on all of the experimental days, the fresh yield peaks at about 3:00 pm. The highest output is achieved around 3:00 pm since the output of fresh yield is based on solar intensity, which increases from 9:00 am to 1:00 pm. Additionally, evacuated tubes and nanoparticles are utilized, which causes the water temperature to raise more and stay greater for long periods of time. A maximum value of cumulative fresh yield obtained is 5.2 L per m^2 per day for 08th October 2022. Similarly, for 06th, 07th, 09th, and 10th October 2022 the value of cumulative fresh yield is 4.7 L per m^2 per day, 4.75 L per m^2 per day, 5.15 L per m^2 per day, and 5.18 L per m^2 per day respectively.

4.5.8 Solar Intensity and Absorber Plate Temperature

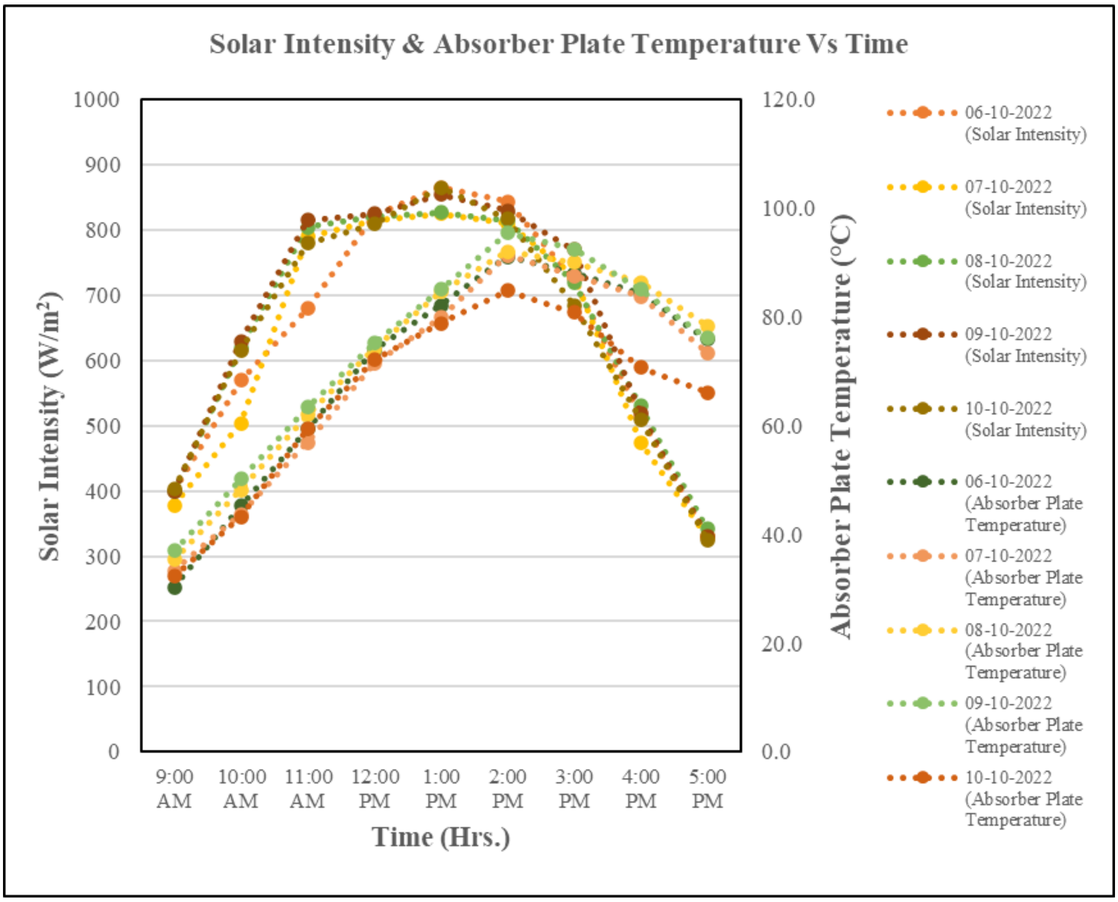


Figure 4.64. Solar Intensity and Absorber Plate Temperature with Time (Case-5).

Figure 4.64 depicts the variations in solar intensity and absorber plate temperature over time for inclined solar stills with stepped absorbers and corrugated fins integrated with vacuum tubes using aluminium oxide as nanoparticles over the course of several test days. On all testing days, it is found that the solar intensity rises from 9:00 am to 1:00 pm before beginning to decline. Similarly, it is discovered that temperature of an absorber plate rises from 9:00 am to 2:00 pm before beginning to slowly decline. We get the maximum absorber plate temperature at 2:00 pm on all testing days because it is completely dependent on the solar intensity which is maximum at 1:00 pm.

4.5.9 Daily Efficiency of Still

As the efficiency is depends upon the fresh output of still and solar intensity, that's why the variation in efficiency for different experimental days is recorded and shown in below graph.

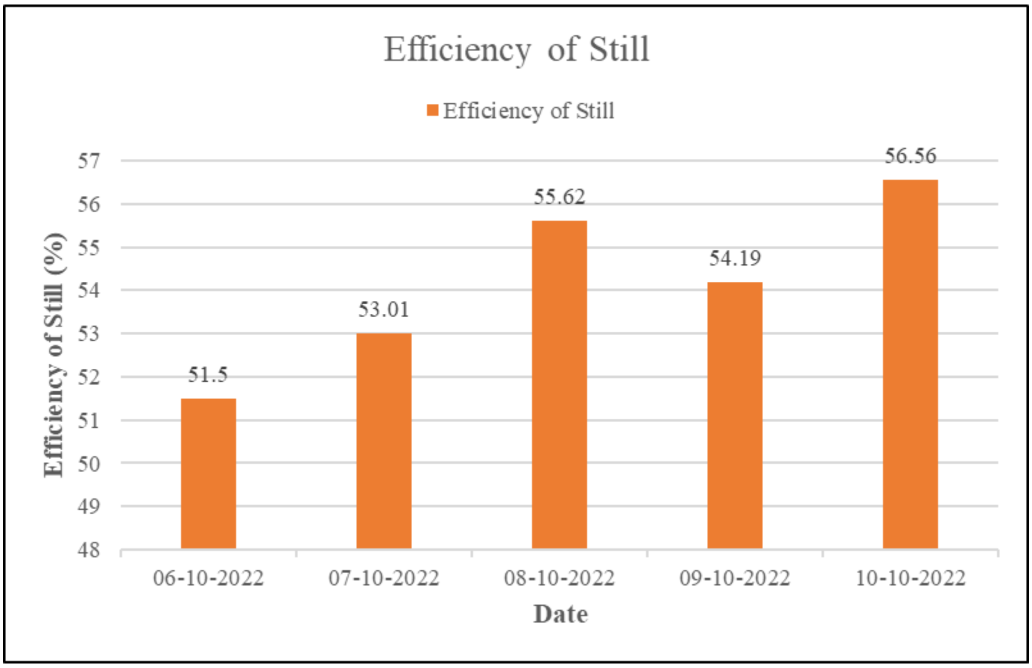
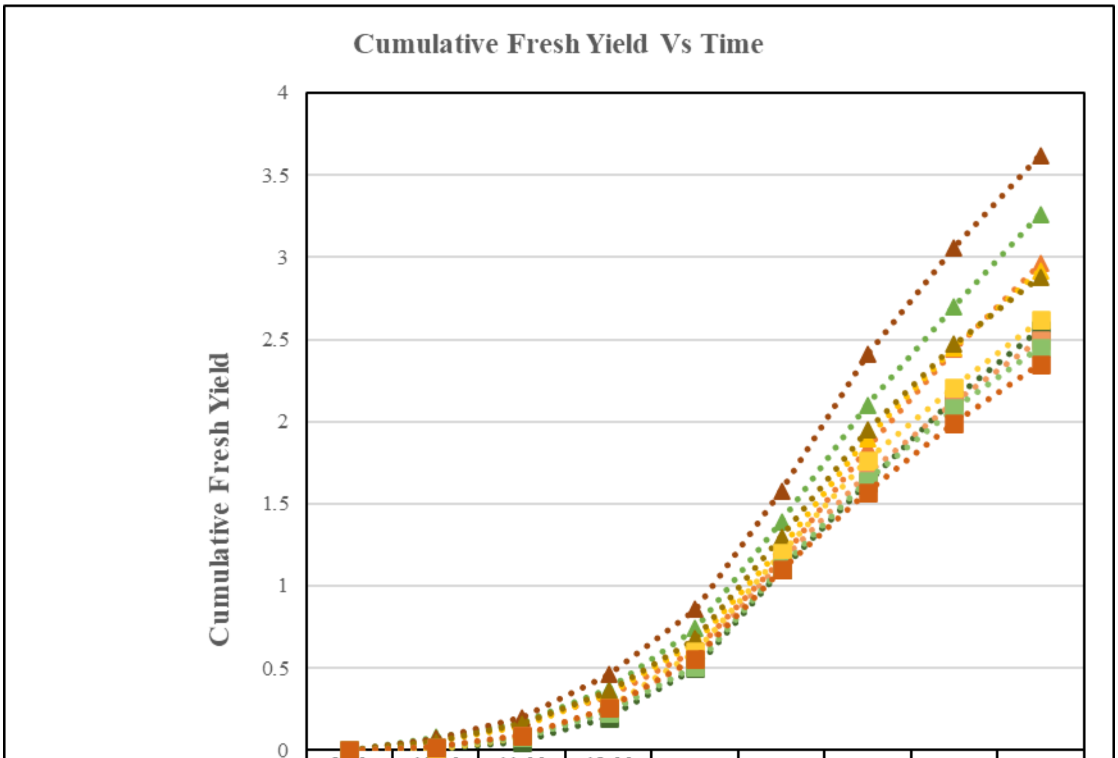


Figure 4.65. Daily Efficiency of Still (Case-5).

Figure 4.65 displays, for various testing days, the daily efficiency for inclined solar stills with stepped absorbers and corrugated fins integrated with vacuum tubes. According to a graph, still's daily highest efficiency is 56.56% for October 10, 2022, while its daily minimum efficiency is 51.5% for October 6.

4.6 CUMULATIVE FRESH YIELD

4.6.1 Comparison of Case 1 and Case 2

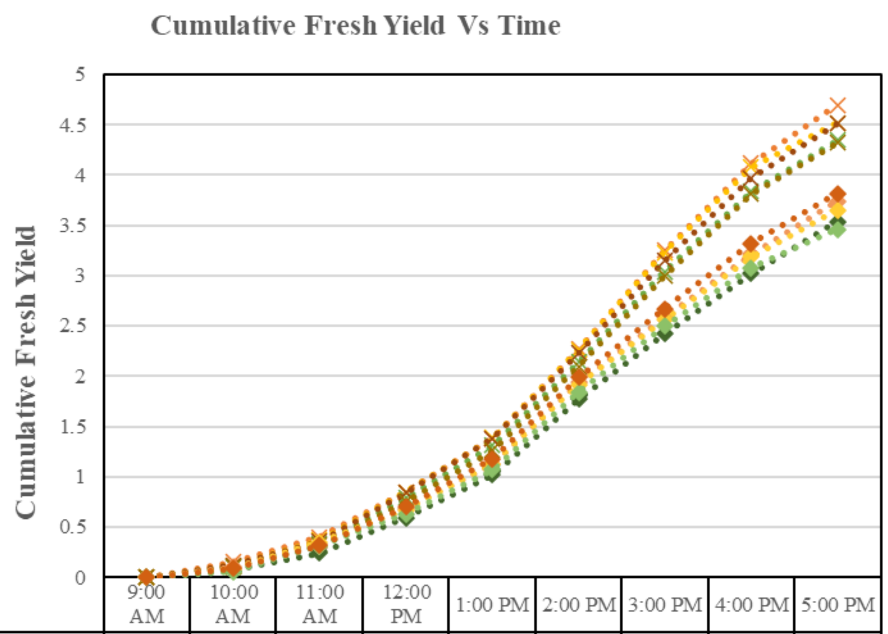


	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM
26-01-2022 Case-2	0	0.07	0.17	0.33	0.61	1.16	1.84	2.44	2.96
27-01-2022 Case-2	0	0.05	0.15	0.34	0.65	1.23	1.9	2.45	2.92
28-01-2022 Case-2	0	0.08	0.17	0.37	0.74	1.39	2.1	2.7	3.26
29-01-2022 Case-2	0	0.07	0.2	0.46	0.86	1.58	2.41	3.06	3.62
30-01-2022 Case-2	0	0.05	0.16	0.36	0.68	1.3	1.95	2.47	2.88
03-02-2022 Case-1	0	0.01	0.05	0.2	0.5	1.1	1.63	2.14	2.56
04-02-2022 Case-1	0	0.01	0.09	0.24	0.56	1.15	1.68	2.12	2.5
06-02-2022 Case-1	0	0.01	0.08	0.26	0.6	1.2	1.765	2.21	2.62
08-02-2022 Case-1	0	0.02	0.08	0.23	0.51	1.11	1.64	2.08	2.45
14-02-2022 Case-1	0	0.02	0.09	0.26	0.56	1.1	1.57	1.99	2.35

Figure 4.66. Variation of Cumulative Fresh Yield with Time for Case- 1 and Case- 2

The cumulative fresh yield for inclined sun stills with stepped absorbers and corrugated fins in the winter (Case-1) and for inclined solar stills with stepped absorbers and corrugated fins integrated with vacuum tubes in the winter (Case-2) is shown in Figure 4.66 for various testing days. The graph shows that for all of the trial days, the fresh yield from the integrated still with an evacuated tube is higher than the fresh yield from the integrated still without an evacuated tube. A temperature of a water rises as a result of an evacuated tube, increasing the still's production. The highest yields were achieved in Cases 1 and 2, at 2.62 L/m^2-day and 3.62 L per m2 per day, respectively.

4.6.2 Comparison of Case 3 and Case 4

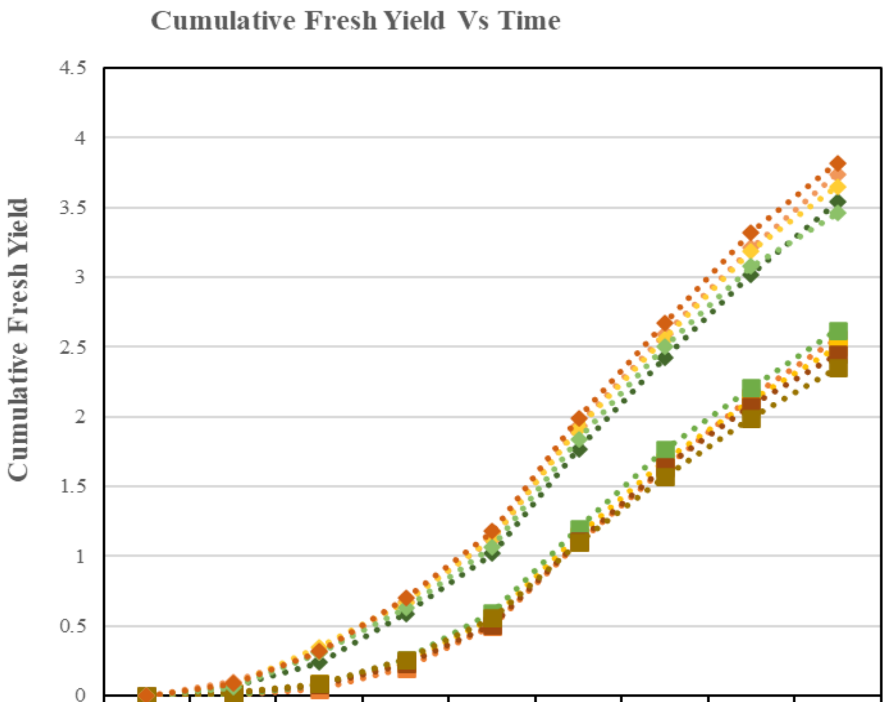


	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM
26-04-2022 Case-4	0	0.15	0.4	0.85	1.38	2.27	3.25	4.12	4.7
27-04-2022 Case-4	0	0.12	0.37	0.85	1.39	2.26	3.23	4.08	4.52
28-04-2022 Case-4	0	0.11	0.33	0.79	1.31	2.14	3.04	3.84	4.35
29-04-2022 Case-4	0	0.12	0.36	0.84	1.38	2.23	3.15	3.97	4.51
30-04-2022 Case-4	0	0.1	0.32	0.75	1.265	2.095	2.995	3.81	4.32
02-05-2022 Case-3	0	0.07	0.24	0.59	1.02	1.77	2.42	3.02	3.54
03-05-2022 Case-3	0	0.1	0.31	0.68	1.12	1.94	2.59	3.21	3.74
04-05-2022 Case-3	0	0.08	0.35	0.67	1.13	1.92	2.56	3.19	3.65
05-05-2022 Case-3	0	0.06	0.31	0.63	1.07	1.84	2.5	3.08	3.46
06-05-2022 Case-3	0	0.09	0.32	0.7	1.18	1.99	2.67	3.32	3.82

Figure 4.67. Variation of Cumulative Fresh Yield with Time for Case 3 and Case 4

The cumulative fresh yield for inclined solar stills with stepped absorbers and corrugated fins in the summer (Case-3) and cumulative fresh yield for stills with stepped absorbers and corrugated fins integrated with vacuum tubes in the summer (Case-4) are shown in Figure 4.67 for various experimental days. From the graph, it is obvious that throughout the whole testing period, the fresh yield achieved from the integrated still with an evacuated tube is greater than that of the still without an evacuated tube. The output from the still rises as a consequence of a water's temperature rising as a result of an evacuated tube. A maximum production of 3.82 L per m^2 per day and 4.7 L per m^2 per day, respectively, was attained for Cases 3 and 4.

4.6.3 Comparison of Case 1 and Case 3



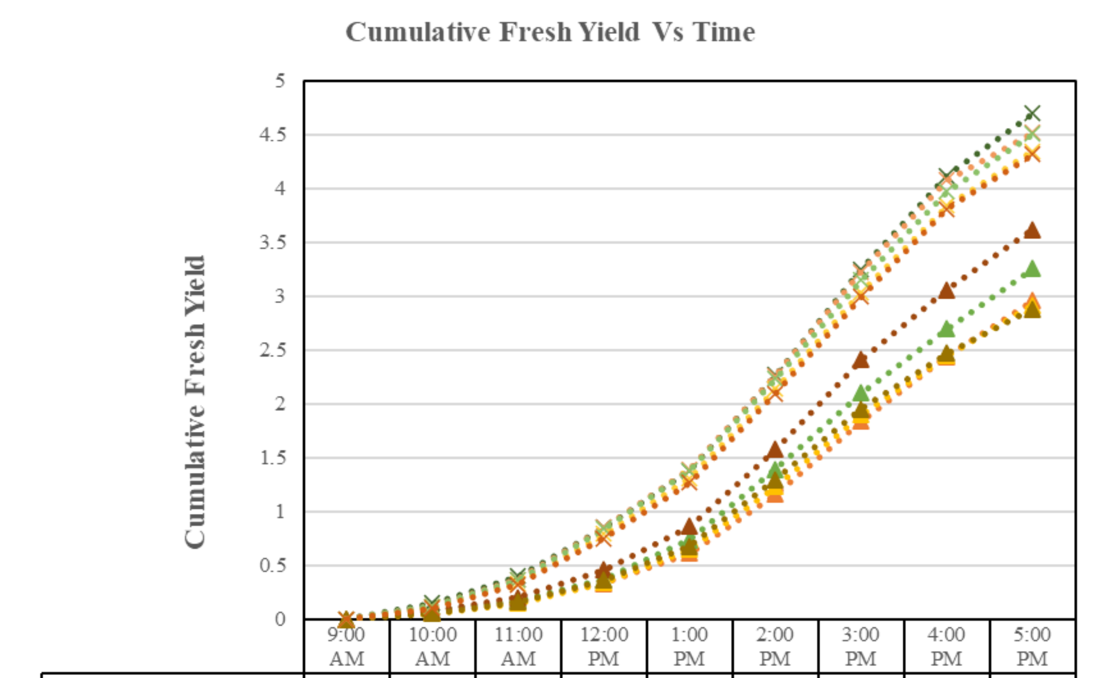
	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM
03-02-2022 Case-1	0	0.01	0.05	0.2	0.5	1.1	1.63	2.14	2.56
04-02-2022 Case-1	0	0.01	0.09	0.24	0.56	1.15	1.68	2.12	2.5
06-02-2022 Case-1	0	0.01	0.08	0.26	0.6	1.2	1.765	2.21	2.62
08-02-2022 Case-1	0	0.02	0.08	0.23	0.51	1.11	1.64	2.08	2.45
14-02-2022 Case-1	0	0.02	0.09	0.26	0.56	1.1	1.57	1.99	2.35
02-05-2022 Case-3	0	0.07	0.24	0.59	1.02	1.77	2.42	3.02	3.54
03-05-2022 Case-3	0	0.1	0.31	0.68	1.12	1.94	2.59	3.21	3.74
04-05-2022 Case-3	0	0.08	0.35	0.67	1.13	1.92	2.56	3.19	3.65
05-05-2022 Case-3	0	0.06	0.31	0.63	1.07	1.84	2.5	3.08	3.46
06-05-2022 Case-3	0	0.09	0.32	0.7	1.18	1.99	2.67	3.32	3.82

Time

Figure 4.68. Variation of Cumulative Fresh Yield with Time for Case 1 and Case 3

Figure 4.68 displays the fluctuation in cumulative fresh yield for inclined solar stills with stepped absorbers and corrugated fins during the winter season (Case-1) and summer season (Case-3) for various testing days. From the graph, it is obvious that for all of the testing days, a fresh distillate output from a summer still is greater than a fresh distillate output from the winter still. The production from the still rises in summer because the solar intensity is higher in summer compared to winter, which causes the water's temperature to be higher in summer and lower in winter. The maximum output obtained for Case-1 and Case-3 is 2.62 L per m^2 per day and 3.82 L per m^2 per day respectively.

4.6.4 Comparison of Case 2 and Case 4

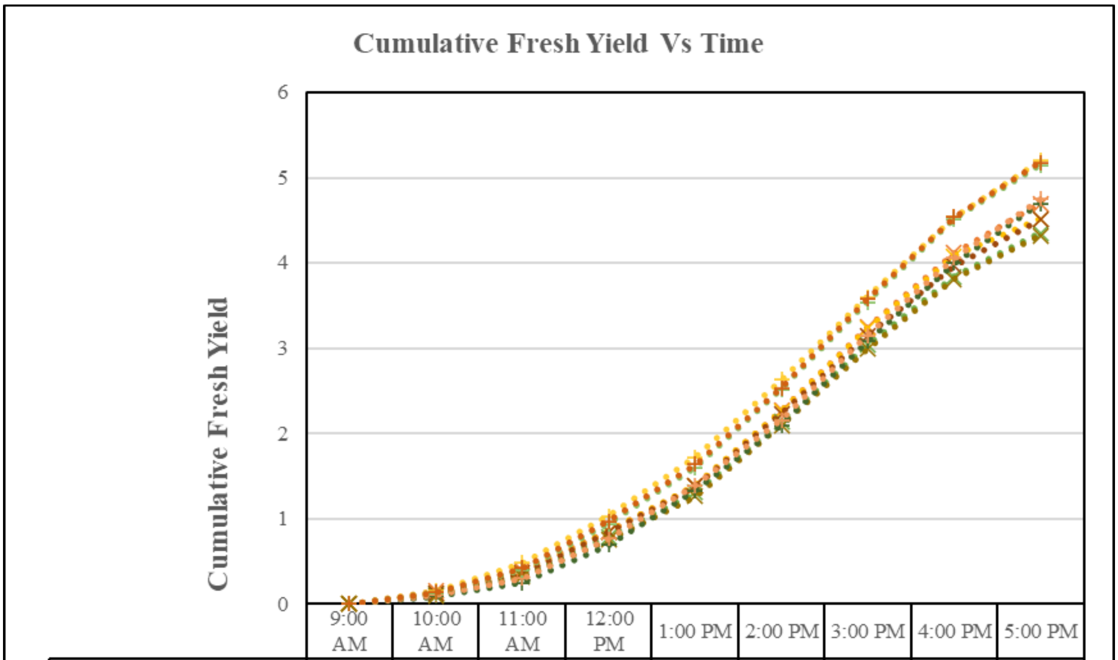


	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM
26-01-2022 Case-2	0	0.07	0.17	0.33	0.61	1.16	1.84	2.44	2.96
27-01-2022 Case-2	0	0.05	0.15	0.34	0.65	1.23	1.9	2.45	2.92
28-01-2022 Case-2	0	0.08	0.17	0.37	0.74	1.39	2.1	2.7	3.26
29-01-2022 Case-2	0	0.07	0.2	0.46	0.86	1.58	2.41	3.06	3.62
30-01-2022 Case-2	0	0.05	0.16	0.36	0.68	1.3	1.95	2.47	2.88
26-04-2022 Case-4	0	0.15	0.4	0.85	1.38	2.27	3.25	4.12	4.7
27-04-2022 Case-4	0	0.12	0.37	0.85	1.39	2.26	3.23	4.08	4.52
28-04-2022 Case-4	0	0.11	0.33	0.79	1.31	2.14	3.04	3.84	4.35
29-04-2022 Case-4	0	0.12	0.36	0.84	1.38	2.23	3.15	3.97	4.51
30-04-2022 Case-4	0	0.1	0.32	0.75	1.265	2.095	2.995	3.81	4.32

Figure 4.69. Variation of Cumulative Fresh Yield with Time for Case 2 and Case 4

Figure 4.69 displays the change in cumulative fresh yield for inclined solar stills with stepped absorbers with corrugated fins combined with vacuum tubes during the winter season (Case-2) and during the summer season (Case-4) for various testing days. From the graph, it is obvious that for all of the testing days, a fresh distillate output from the summer still is greater than a fresh distillate output from a winter still. Since the sun's rays are stronger in the summer, water temperatures are higher in the summer and lower in the winter. This is because the solar intensity is higher in the summer than it is in the winter. Additionally, an evacuated tube raises water temperatures, increasing the output of the still. A maximum production of 3.62 L per m^2 per day and 4.7 L per m^2 per day, respectively, was attained for Cases 2 and 4.

4.6.5 Comparison of Case 4 and Case 5

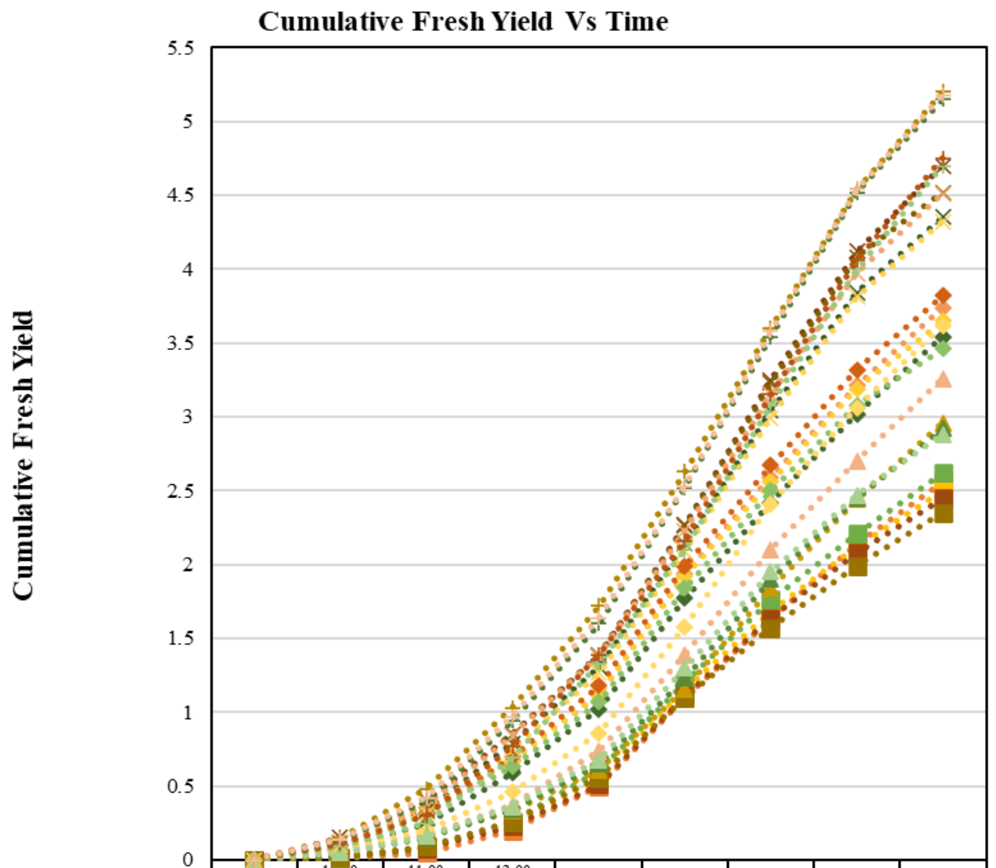


	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM
26-04-2022 Case-4	0	0.15	0.4	0.85	1.38	2.27	3.25	4.12	4.7
27-04-2022 Case-4	0	0.12	0.37	0.85	1.39	2.26	3.23	4.08	4.52
28-04-2022 Case-4	0	0.11	0.33	0.79	1.31	2.14	3.04	3.84	4.35
29-04-2022 Case-4	0	0.12	0.36	0.84	1.38	2.23	3.15	3.97	4.51
30-04-2022 Case-4	0	0.1	0.32	0.75	1.265	2.095	2.995	3.81	4.32
06-10-2022 Case-5	0	0.09	0.25	0.69	1.33	2.1	3.08	4	4.7
07-10-2022 Case-5	0	0.11	0.3	0.77	1.39	2.16	3.15	4.06	4.75
08-10-2022 Case-5	0	0.15	0.48	1.03	1.72	2.63	3.6	4.54	5.2
09-10-2022 Case-5	0	0.13	0.4	0.94	1.6	2.52	3.54	4.52	5.15
10-10-2022 Case-5	0	0.14	0.42	0.97	1.64	2.53	3.58	4.54	5.18

Figure 4.70. Variation of Cumulative Fresh Yield with Time for Case 4 and Case 5

Figure 4.70 displays the cumulative fresh yield variation for inclined solar stills with stepped absorbers and corrugated fins integrated with vacuum tubes during the summer (Case-4) and for inclined solar stills with corrugated fins and vacuum tubes integrated with aluminum oxide nanoparticles (Case-5) for various experimental days. The graph shows that for all of the trial days, the fresh yield from the still using aluminum oxide nanoparticles is higher than the fresh yield from the still using no nanoparticles during the summer. The water temperature rises in the still containing nanoparticles as opposed to the still without nanoparticles because nanoparticles have a higher thermal conductivity, which augmented an ability of a still to absorb heat as compared to stills in which nanoparticles are not employed. The maximum outputs for Cases 4 and 5 are 4.7 L per m^2 per day and 5.2 L per m^2 per day, respectively.

4.6.6 Comparison of Case 1, Case 2, Case 3, Case 4 and Case 5



	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM
03-02-2022 Case-1	0	0.01	0.05	0.2	0.5	1.1	1.63	2.14	2.56
04-02-2022 Case-1	0	0.01	0.09	0.24	0.56	1.15	1.68	2.12	2.5
06-02-2022 Case-1	0	0.01	0.08	0.26	0.6	1.2	1.765	2.21	2.62
08-02-2022 Case-1	0	0.02	0.08	0.23	0.51	1.11	1.64	2.08	2.45
14-02-2022 Case-1	0	0.02	0.09	0.26	0.56	1.1	1.57	1.99	2.35
02-05-2022 Case-3	0	0.07	0.24	0.59	1.02	1.77	2.42	3.02	3.54
03-05-2022 Case-3	0	0.1	0.31	0.68	1.12	1.94	2.59	3.21	3.74
04-05-2022 Case-3	0	0.08	0.35	0.67	1.13	1.92	2.56	3.19	3.65
05-05-2022 Case-3	0	0.06	0.31	0.63	1.07	1.84	2.5	3.08	3.46
06-05-2022 Case-3	0	0.09	0.32	0.7	1.18	1.99	2.67	3.32	3.82
26-01-2022 Case-2	0	0.07	0.17	0.33	0.61	1.16	1.84	2.44	2.96
27-01-2022 Case-2	0	0.05	0.15	0.34	0.65	1.23	1.9	2.45	2.92
28-01-2022 Case-2	0	0.08	0.17	0.37	0.74	1.39	2.1	2.7	3.26
29-01-2022 Case-2	0	0.07	0.2	0.46	0.86	1.58	2.41	3.06	3.62
30-01-2022 Case-2	0	0.05	0.16	0.36	0.68	1.3	1.95	2.47	2.88
26-04-2022 Case-4	0	0.15	0.4	0.85	1.38	2.27	3.25	4.12	4.7
27-04-2022 Case-4	0	0.12	0.37	0.85	1.39	2.26	3.23	4.08	4.52
28-04-2022 Case-4	0	0.11	0.33	0.79	1.31	2.14	3.04	3.84	4.35
29-04-2022 Case-4	0	0.12	0.36	0.84	1.38	2.23	3.15	3.97	4.51
30-04-2022 Case-4	0	0.1	0.32	0.75	1.265	2.095	2.995	3.81	4.32
06-10-2022 Case-5	0	0.09	0.25	0.69	1.33	2.1	3.08	4	4.7
07-10-2022 Case-5	0	0.11	0.3	0.77	1.39	2.16	3.15	4.06	4.75
08-10-2022 Case-5	0	0.15	0.48	1.03	1.72	2.63	3.6	4.54	5.2
09-10-2022 Case-5	0	0.13	0.4	0.94	1.6	2.52	3.54	4.52	5.15
10-10-2022 Case-5	0	0.14	0.42	0.97	1.64	2.53	3.58	4.54	5.18

Time

Figure 4.71. Variation of Cumulative Fresh Yield with Time for Case 1, Case 2, Case 3, Case 4 and Case 5

Figure 4.71 shows the variation of collective fresh produce for inclined solar still having stepped absorber with corrugated fins in the winter season (**Case-1**), collective fresh produce for inclined solar still having stepped absorber with corrugated fins integrated with vacuum tubes in the winter season (**Case-2**), collective fresh produce for inclined solar still having stepped absorber with corrugated fins in summer season (**Case-3**), collective fresh produce for inclined solar still having stepped absorber with corrugated fins integrated with vacuum tubes in summer season (**Case-4**) and collective fresh produce for inclined solar still having stepped absorber with corrugated fins integrated with vacuum tubes by using aluminium oxide as nanoparticles (**Case-5**) for different experimental days. From the graph, it is evident that for all of the experimental days, the still-existing stepped absorber with corrugated fins integrated with the evacuated tube and using aluminum oxide as nanoparticles (Case-5) produces the highest fresh yield, while the still-existing stepped absorber with corrugated fins for the winter season produces the lowest yield (Case-1). As a result of the nanoparticles' increased thermal conductivity, both the evacuated tube's capacity to absorb heat and a water's temperature rises as a result of an evacuated tube's reduced heat loss. The maximum outputs for Cases 1, 2, 3, 4, and 5 are, respectively, 2.62 L per m^2 per day, 3.62 L per m^2 per day, 3.82 L per m^2 per day, 4.7 L per m^2 per day, and 5.2 L per m^2 per day.

4.7 FRESH YIELD

4.7.1 Comparison of Case 1 and Case 2

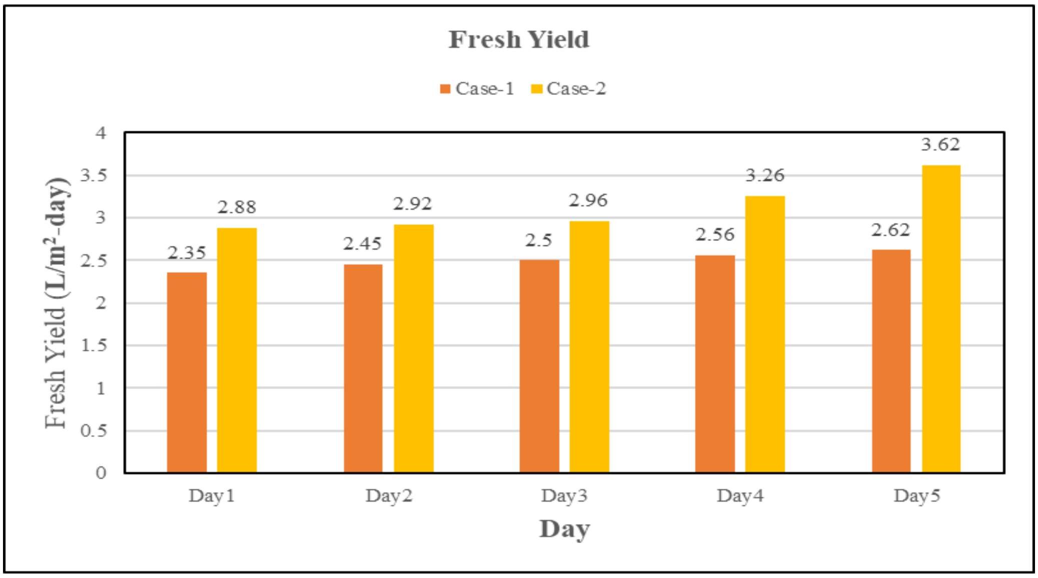


Figure 4.72 Comparison of Day Fresh Output of Still for Case 1 and Case 2

Figure 4.72 shows the day wise fresh output obtained from the still for different basin conditions in the winter season. From the graph, its visible that for all an experimental day the yield gained from the inclined solar still having stepped absorber with corrugated fins integrated with vacuum tubes in winter season (**Case-2**) is more as compared to an inclined solar still having stepped absorber with corrugated fins in winter season (**Case-1**). The maximum output obtained for case 2 is 3.62 L/m^2 and for case 1 is 2.62 L/m^2, while the minimum output obtained for case 2 is 2.88 L/m^2 and for case 1 is 2.35 L/m^2.

4.7.2 Comparison of Case 3 and Case 4

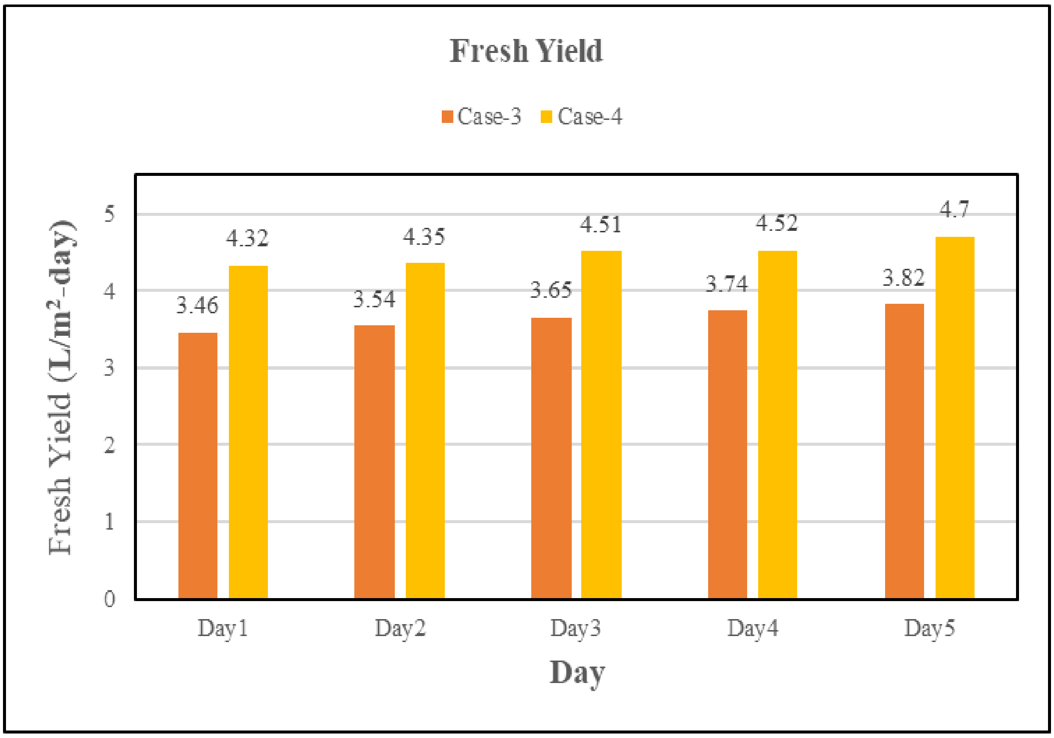


Figure 4.73 Comparison of Day Fresh Output of Still for Case 3 and Case 4

The fresh production received from the still daily for various basin conditions is shown in Figure 4.73. According to the graph, the output from an inclined solar still with stepped absorber and corrugated fins combined with vacuum tubes in the summer (Case-4) is more than an of the inclined solar still with stepped absorber and corrugated fins in the summer for all of the testing days (Case-3). The maximum output obtained for case 4 is 4.70 L/m^2 and for case 3 is 3.82 L/m^2, while the minimum output obtained for case 4 is 4.32 L/m^2 and for case 3 is 3.46 L/m^2.

4.7.3 Comparison of Case 1 and Case 3

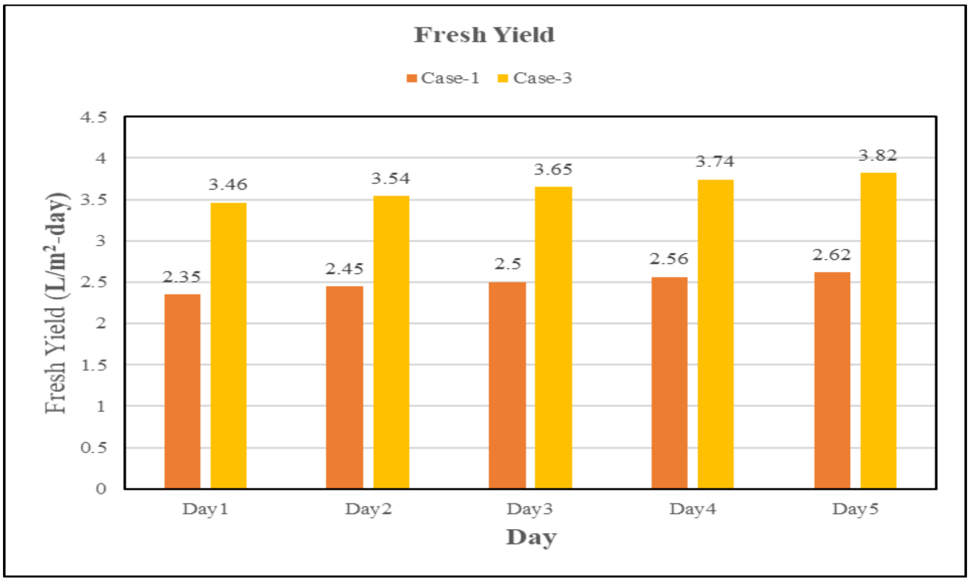


Figure 4.74. Comparison of Day Fresh Output of Still for Case 1 and Case 3

Figure 4.74 shows the day wise fresh output obtained from the still. From the graph, its visible that for all an experimental day the yield obtained from an inclined solar still having stepped absorber with corrugated fins in the summer season (**Case-3**) is more as associated to an inclined solar still having stepped absorber with corrugated fins in winter season (**Case-1**). The maximum output obtained for case 3 is 3.82 L/m^2 and for case 1 is 2.62 L/m^2, while the minimum output obtained for case 3 is 3.46 L/m^2 and for case 1 is 2.35 L/m^2.

4.7.4 Comparison of Case 2 and Case 4

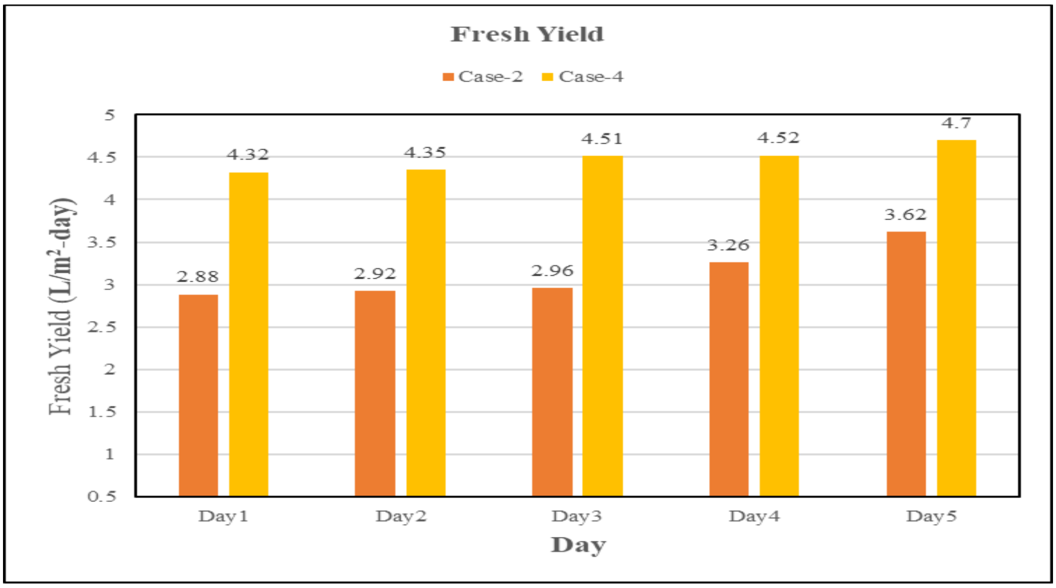


Figure 4.75. Comparison of Day Fresh Output of Still for Case 2 and Case 4

Figure 4.75 shows the day wise fresh output obtained from the still. From the graph, its visible that for all an experimental day the yield gotten from an inclined solar still having stepped absorber with corrugated fins integrated with vacuum tubes in the summer season (**Case-4**) is more as associated to an inclined solar still having stepped absorber with corrugated fins integrated with vacuum tubes in winter season (**Case-2**). The maximum output obtained for case 4 is 4.70 L/m^2 and for case 2 is 3.62 L/m^2, while the minimum output obtained for case 4 is 4.32 L/m^2 and for case 2 is 2.88 L/m^2.

4.7.5 Comparison of Case 1, Case 2, Case 3, Case 4 and Case 5

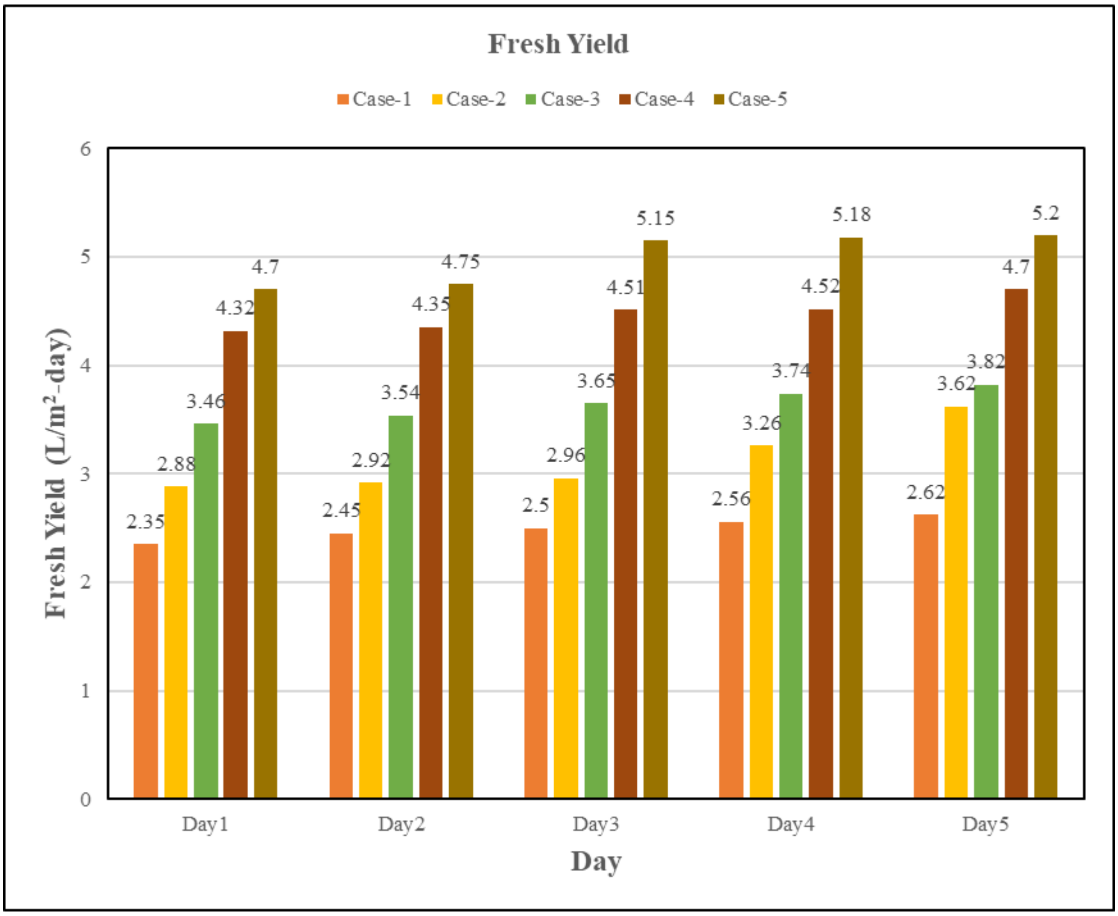


Figure 4.76. Comparison of Day Fresh Output of Still

The fresh production received from the still daily for various basin conditions is shown in Figure 4.76. The graph reveals that for the entire testing period, the output obtained from the inclined solar still having stepped absorber with corrugated fins integrated with vacuum tubes by using aluminium oxide as nanoparticles (**Case-5**) is more as associated to an inclined solar still having stepped absorber with corrugated fins integrated with vacuum tubes without nanoparticles in summer and winter season

(**Case-4 & Case-2**), the inclined solar still having stepped absorber with corrugated fins in summer season (**Case-3**) and the inclined solar still having stepped absorber with corrugated fins in winter season (**Case-1**). The maximum output obtained for case 5 is 5.2 L/m^2, for case 4 is 4.7 L/m^2, for case 3 is 3.82 L/m^2, for case 2 is 3.62 L/m^2 and for case 1 is 2.62 L/m^2 while the minimum output obtained for a case 5 is 4.7 L/m^2, for a case 4 is 4.32 L/m^2, for a case 3 is 3.46 L/m^2, for a case 2 is 2.88 L/m^2 and for a case 1 is 2.35 L/m^2.

4.8 TOTAL FRESH YIELD

4.8.1 Comparison of Case 1 and Case 2

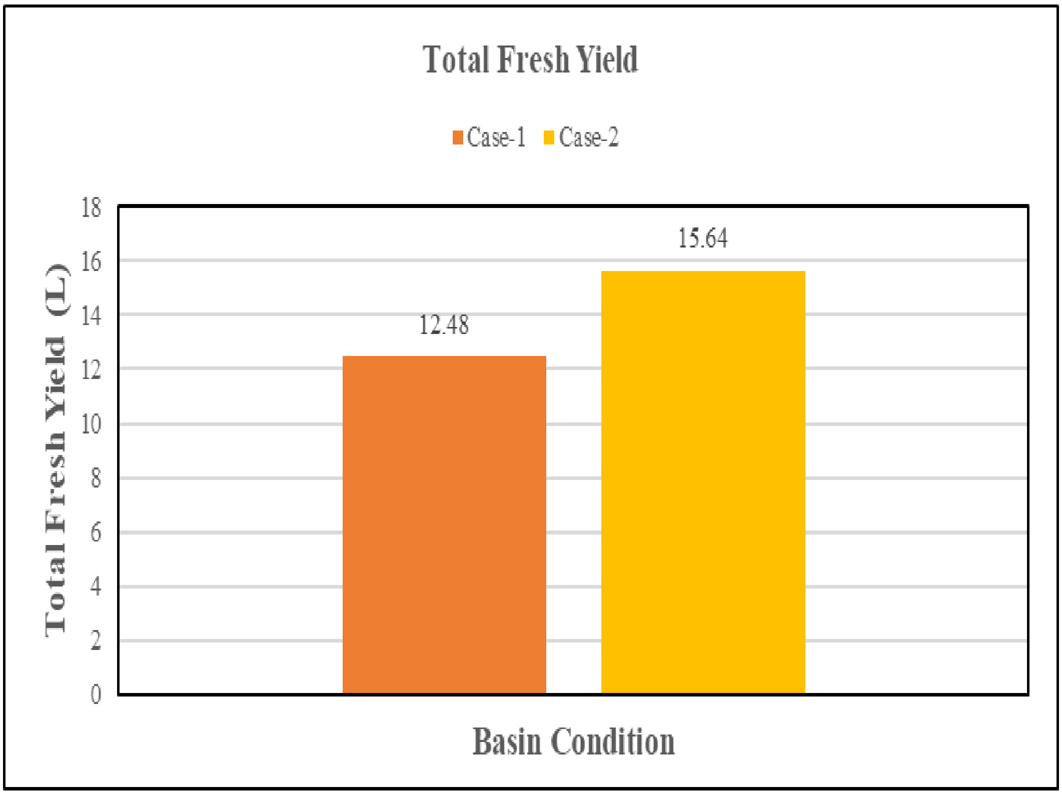


Figure 4.77. Comparison of Total Fresh Yield of Still for Case 1 and Case 2

Figure 4.77 shows the total fresh yield obtained from a still for various basin conditions. The chart reveals that in the inclined solar still, the total fresh yield had stepped absorbers and corrugated fins integrated with vacuum tubes in winter season (**Case-2**) is more as associated to an inclined solar still having stepped absorber with corrugated fins in winter season (**Case-1**). The total productivity obtained for Case- 2 is 15.64 L/m^2, while the total productivity obtained for case- 1 is 12.48 L/m^2.

4.8.2 Comparison of Case 3 and Case 4

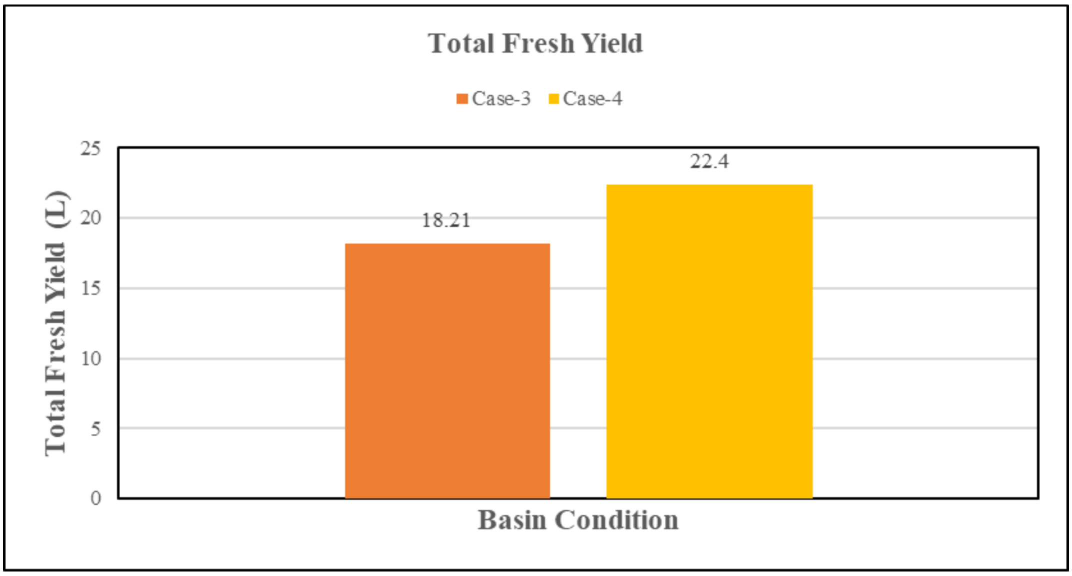


Figure 4.78. Comparison of Total Fresh Yield of Still for Case 3 and Case 4

Figure 4.78 displays the overall fresh yield from the still for various basin conditions. According to the graph, the inclined solar still in Case-4 has a higher total fresh yield in the summer than the inclined solar still with corrugated fins in Case-3. The total productivity obtained for Case- 4 is 22.4 L/m^2, while the total productivity obtained for case- 3 is 18.21 L/m^2.

4.8.3 Comparison of Case 1 and Case 3

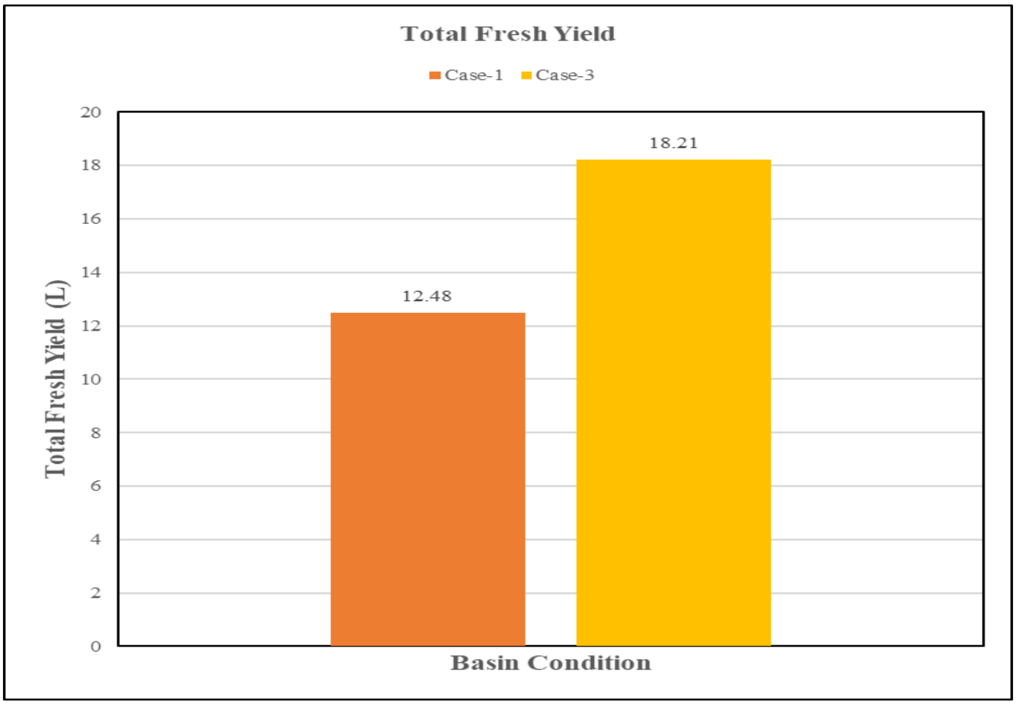


Figure 4.79. Comparison of Total Fresh Yield of Still for Case 1 and Case 3

Figure 4.79 shows the total fresh yield obtained from the still. From the graph, it can be seen that the inclined solar still in summertime, the total fresh yield had stepped absorbers and corrugated fins (**Case-3**) is more as associated to the inclined solar still having stepped absorber with corrugated fins in winter season (**Case-1**). The total productivity obtained for case- 3 is 18.21 L/m^2, while the total productivity obtained for case- 1 is 12.48 L/m^2.

4.8.4 Comparison of Case 2 and Case 4

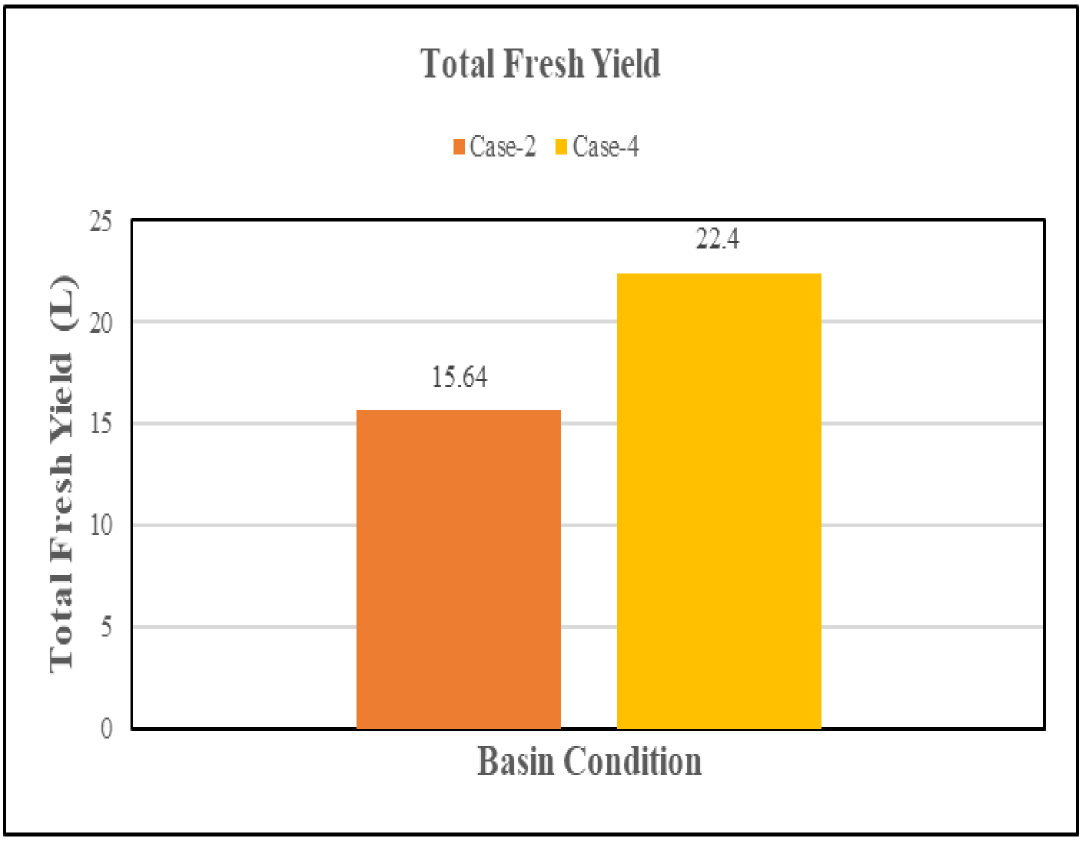


Figure 4.80. Comparison of Total Fresh Yield of Still for Case 2 and Case 4

Figure 4.80 shows the total fresh yield obtained from the still. From the chart, it can be seen that in the inclined solar still's summertime, the total fresh yield had stepped absorbers with corrugated fins attached to them (**Case-4**) is more as associated to the inclined solar still having stepped absorber with corrugated fins integrated with vacuum tubes in winter season (**Case-2**). The total productivity obtained for case- 4 is 22.4 L/m^2, while the total productivity obtained for case- 2 is 15.64 L/m^2.

4.8.5 Comparison of Case 1, Case 2, Case 3, Case 4 and Case 5

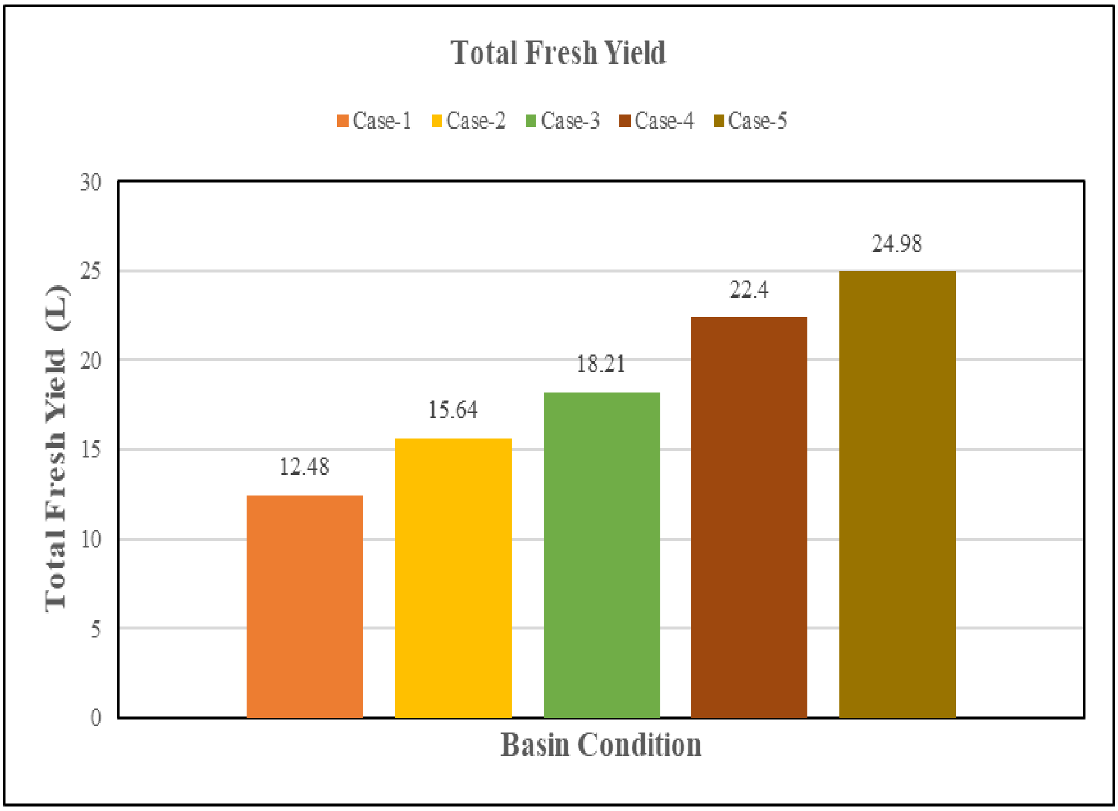


Figure 4.81. Comparison of Total Fresh Yield of Still

Figure 4.81 shows a total fresh distillate yield obtained from a still for different basin conditions. On the chart, it can be visible that a complete fresh yield was gotten by an inclined solar still with stepped absorbers and corrugated fins integrated with vacuum tubes and Al_2O_3 (**Case-5**) is more as associated to the inclined solar still having stepped absorber with corrugated fins integrated with vacuum tubes and without nanoparticles in summer season (**Case-4**), the inclined solar still having stepped absorber with corrugated fins integrated with vacuum tubes and without nanoparticles in winter season (**Case-2**), the inclined solar still having stepped absorber with corrugated fins in summer season (**Case-3**) and the inclined solar still having stepped absorber with corrugated fins in winter season (**Case-1**). The total fresh yield obtained for Case- 5 is 24.98 L/m^2, while the total fresh yield obtained for Case- 4 is 22.4 L/m^2, and the total fresh yield obtained for Case- 3 is 18.21 L/m^2. Similarly, for Case-2 and Case-1, the total fresh yield is 15.64 L/m^2 and 12.48 L/m^2 respectively.

4.8.6 Comparison of Fresh Distillate Output for Various Basin Conditions of Still

Table 4.1: Comparison of Fresh Distillate Output for Various Basin Conditions of Still

Sr. No.	Important characteristics environment for inclined type solar still	Fresh Distillate Output	
		L /day	% Increase
1	Stepped Absorber with Corrugated Fins (Winter) (Case-1)	12.48	Reference
2	Stepped Absorber with Corrugated Fins and Evacuated Tube (Winter) (Case-2)	15.64	25.32 %
3	Stepped Absorber with Corrugated Fins (Summer) (Case-3)	18.21	45.91%
4	Stepped Absorber with Corrugated Fins and Evacuated Tube (Summer) (Case-4)	22.4	79.48%
5	Stepped Absorber with Corrugated Fins and Evacuated Tube by using Nano particles (Case-5)	24.98	100.16%

4.9 EFFICIENCY OF STILL

4.9.1 Comparison of Case 1 and Case 2

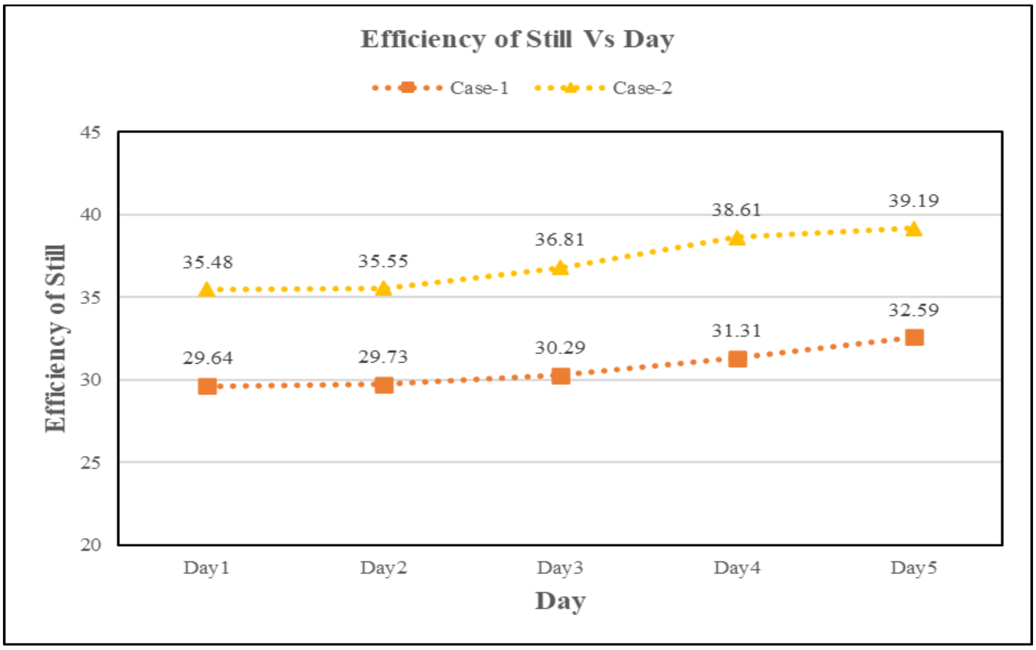


Figure 4.82 Comparison of Efficiency of Still for Case 1 and Case 2

Figure 4.82 shows the comparison of the efficiency of the still for different conditions of still. From the graph, it is found that the efficiency obtained from the inclined solar still having stepped absorber with corrugated fins integrated with vacuum tubes in winter season (**Case-2**) is more as associated to the inclined solar still having stepped absorber with corrugated fins in winter season (**Case-1**). The maximum efficiency obtained for Case- 2 is 40.65 % and for Case 1 is 32.59%, while the minimum efficiency obtained for case- 2 is 35.48 % and for case- 1 is 29.64 %.

4.9.2 Comparison of Case 3 and Case 4

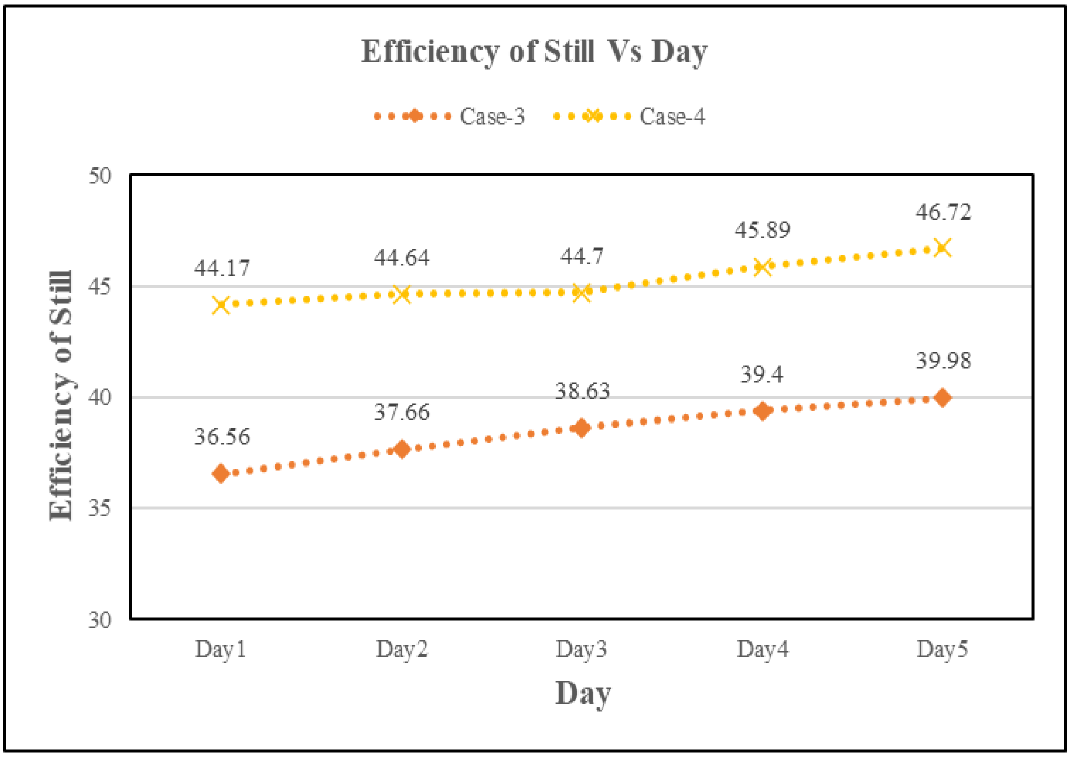


Figure 4.83. Comparison of Efficiency of Still for Case 3 and Case 4

The effectiveness of stills for various basin conditions is compared in Figure 4.83. The efficiency of the inclined solar still with stepped absorber corrugated fins and integrated with vacuum tubes in the summer can be seen from the graph (**Case-4**) is more as associated to an inclined solar still having stepped absorber with corrugated fins in the summer season (**Case-3**). The maximum efficiency obtained for case- 4 is 46.72 % and for case 3 is 39.19%, while the minimum efficiency obtained for case- 4 is 43.75 % and for case- 3 is 35.79 %.

4.9.3 Comparison of Case-1 and Case 3

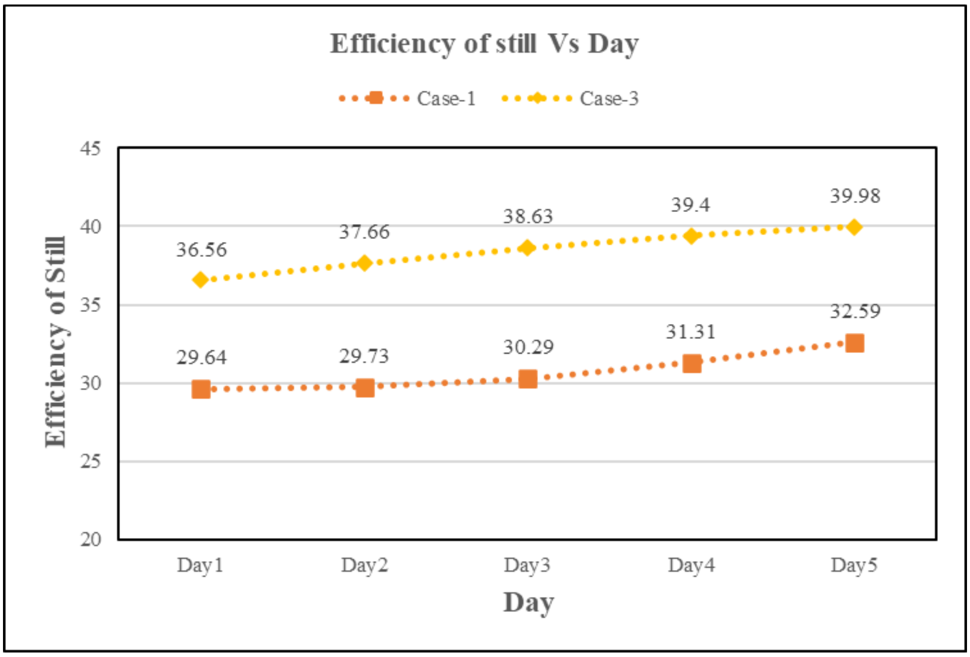


Figure 4.84. Comparison of Efficiency of Still for Case 1 and Case 3

Figure 4.84 shows the comparison of the efficiency of the still. From the graph, it is found that the efficiency obtained from the inclined solar still having stepped absorber with corrugated fins in the summer season (**Case-3**) is more as associated to an inclined solar still having stepped absorber with corrugated fins in winter season (**Case-1**). The maximum efficiency obtained for Case- 3 is 39.19 % and for Case 1 is 32.59%, while the minimum efficiency obtained for case- 3 is 35.79 % and for case- 1 is 29.64 %.

4.9.4 Comparison of Case-2 and Case-4

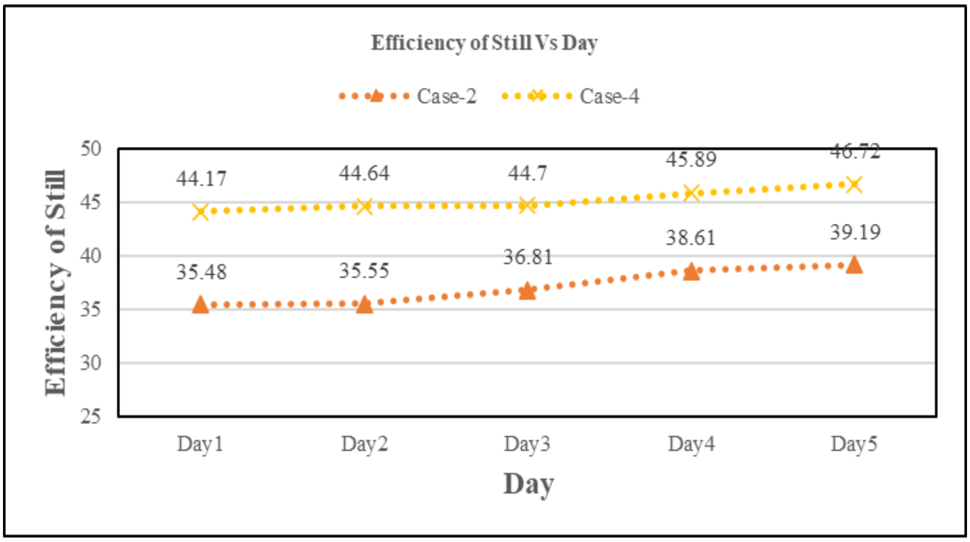


Figure 4.85. Comparison of Efficiency of Still for Case 2 and Case 4

Figure 4.85 shows the comparison of the efficiency of the still. From the graph, it is found that the efficiency obtained from the inclined solar still having stepped absorber with corrugated fins integrated with vacuum tubes in the summer season (**Case-4**) is more as associated to an inclined solar still having stepped absorber with corrugated fins integrated with vacuum tubes in winter season (**Case-2**). The maximum efficiency obtained for Case- 4 is 46.72 % and for Case 2 is 40.65 %, while the minimum efficiency obtained for case- 4 is 43.75 % and for case- 2 is 35.48 %.

4.9.5 Comparison of Case 1, Case 2, Case 3, Case 4 and Case 5

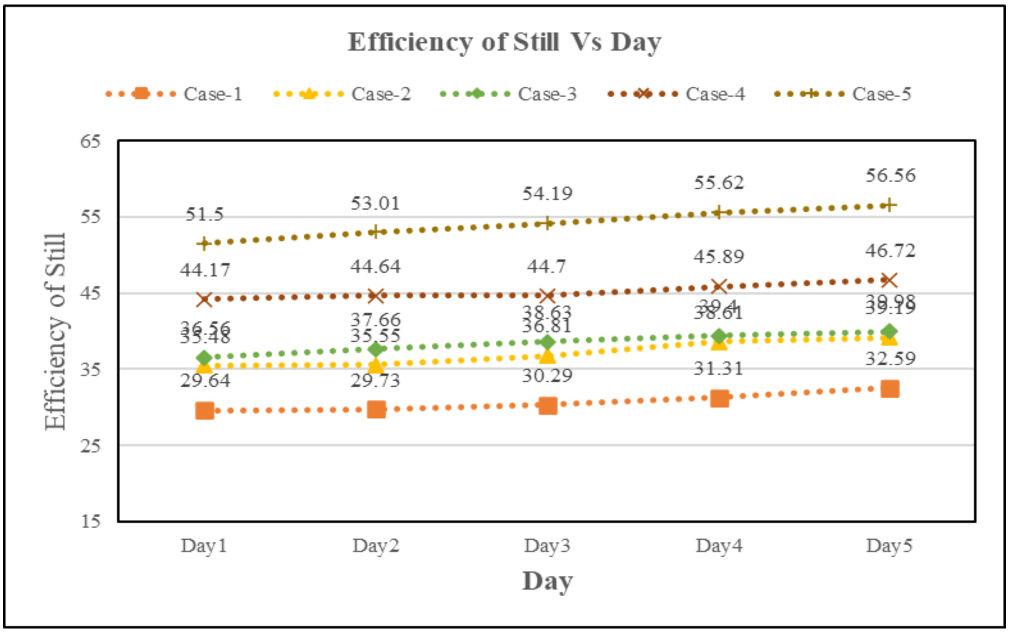


Figure 4.86. Comparison of Efficiency of Still

Figure 4.86 shows the comparison of the efficiency of the still. From the graph it is found that the efficiency obtained from the inclined solar still having stepped absorber with corrugated fins integrated with vacuum tubes by using aluminium oxide as nanoparticles (**Case-5**) is more as related to an inclined solar still having stepped absorber with corrugated fins integrated with vacuum tubes in summer season (**Case-4**) and the inclined solar still having stepped absorber with corrugated fins integrated with vacuum tubes in winter season (**Case-2**), the inclined solar still having stepped absorber with corrugated fins in summer season (**Case-3**) and the inclined solar still having stepped absorber with corrugated fins in winter season (**Case-1**). The maximum efficiency obtained for Case- 5 is 56.56 %, for Case- 4 is 46.72 %, for Case- 3 is 39.98 %, for Case- 2 is 39.19 % and for Case 1 is 32.59%, while the minimum efficiency obtained for Case- 5 is 51.5 %, for Case- 4 is 44.17 %, for Case- 3 is 36.56 %, for case-2 is 35.48 % and for case- 1 is 29.64 %.

4.9.6 Comparison of Energy Efficiency Output for Various Basin Conditions of Still

Table 4.2: Comparison of Energy Efficiency for Various Basin Conditions of Still

Sr. No.	Important characteristics environment for the inclined type solar still	Efficiency	
		%	% Increase
1	Stepped Absorber with Corrugated Fins (Winter) (Case-1)	32.59	Reference
2	Stepped Absorber with Corrugated Fins and Evacuated Tube (Winter) (Case-2)	39.19	20.25%
3	Stepped Absorber with Corrugated Fins (Summer) (Case-3)	39.98	22.67%
4	Stepped Absorber with Corrugated Fins and Evacuated Tube (Summer) (Case-4)	46.72	43.36%
5	Stepped Absorber with Corrugated Fins and Evacuated Tube by using Nano particles (Case-5)	56.56	73.55%

4.10 TDS and pH VALUE

4.10.1 TDS Value

Table 4.3: TDS Value Comparison of Fresh Distillate Output for Various Basin Conditions of Still

Sr. No.	Important characteristics environment for the inclined type solar still	TDS Value	
		Before	After
1	Stepped Absorber with Corrugated Fins (Winter) (Case-1)	450 to 500	60 to 100

2	Stepped Absorber with Corrugated Fins and Evacuated Tube (Winter) (Case-2)	450 to 500	60 to 100
3	Stepped Absorber with Corrugated Fins (Summer) (Case-3)	450 to 500	60 to 100
4	Stepped Absorber with Corrugated Fins and Evacuated Tube (Summer) (Case-4)	450 to 500	60 to 100
5	Stepped Absorber with Corrugated Fins and Evacuated Tube by using Nano particles (Case-5)	450 to 500	60 to 100

4.10.2 pH Value

Table 4.4: pH Value Comparison of Fresh Distillate Output for Various Basin Conditions of Still

Sr. No.	Important characteristics environment for the inclined type solar still	pH Value	
		Before	After
1	Stepped Absorber with Corrugated Fins (Winter) (Case-1)	10 to 12	6 to 7.5
2	Stepped Absorber with Corrugated Fins and Evacuated Tube (Winter) (Case-2)	10 to 12	6 to 7.5
3	Stepped Absorber with Corrugated Fins (Summer) (Case-3)	10 to 12	6 to 7.5
4	Stepped Absorber with Corrugated Fins and Evacuated Tube (Summer) (Case-4)	10 to 12	6 to 7.5
5	Stepped Absorber with Corrugated Fins and Evacuated Tube by using Nano particles (Case-5)	10 to 12	6 to 7.5

4.11 ECONOMIC ANALYSIS OF STILL

In order to determine whether solar energy is commercially viable, the economic analysis will evaluate the solar industry while it is still in operation. A cost of distillate water with a solar still is determined by it is initial purchase and ongoing operating expenses. The following assumptions are used in the economic analysis of solar stills, and the equations can be solved as indicated in Table 4.5. A total cost of an inclined solar still having stepped absorber with corrugated fins is estimated as 8800 Rs., a total cost of an inclined solar still having stepped absorber with corrugated fins integrated with evacuated tube is estimated as 10300 Rs and a total cost of an inclined solar still having stepped absorber with corrugated fins integrated with evacuated tube by using aluminium oxide as nanoparticles is estimated as 13300 Rs.

The following presumptions are made during economic analysis:

a. The solar still has a 10-year lifespan.
b. 15% of the annual expenditure goes toward maintenance.
c. There is a 10% interest charge.
d. A salvage value equals 10% of the initial costs of the component.
e. A number of available clear, sunny days in Nagpur City is considered to be 310.
f. The cost of selling water is set at Rs. 2.

Table 4.5: Different Parameters for Economic Study [118], [124],[125].

Sr. No.	Basic Considerations	Formulations	Inferences
1	First Annual Cost (FAC)	FAC = CS x CRF	Where: CS = total cost of still
2	Capital recovery factor (CRF)	$\mathrm{CRF} = \frac{\mathrm{i}\,(1+\mathrm{i})^{\mathrm{N}}}{(1+\mathrm{i})^{\mathrm{N}}-1}$	Where: i = interest rate N = number of years
3	Annual Operating and maintenance cost (AMC)	AMC = 15% x FAC	
4	Sinking fund factor (SFF)	$\mathrm{SFF} = \frac{i}{((1+i)^{N}-1)}$	
5	Annual salvage value (ASV)	ASV = SFF x S	Where: S = salvage value and it is taken

			as 10% of capital cost
6	Annual total cost (TAC)	TAC = FAC + AMC – ASV	
7	Cost of freshwater per litre	$CPL = \frac{TAC}{L}$	Where: L= Yearly fresh water output.
8	Net payback period	$\eta_p = \frac{\ln\left(\frac{CF}{CF - (FACx\ i)}\right)}{\ln(1+i)}$	Where: CF = cash flow and calculated as below CF = yearly yield x selling price

Table 4.6: Economic study of an angled solar still for various basin conditions is compared.

Sr. No.	Equation	Inclined solar still having stepped absorber with corrugated fins	Inclined solar still having stepped absorber with corrugated fins integrated with evacuated tubes	Inclined solar still having stepped absorber with corrugated fins integrated with evacuated tubes by using Nanoparticles.
1	Total Cost of Still (CS)	8800 Rs.	10300 Rs.	13300 Rs.
2	$\mathrm{CRF} = \frac{\mathrm{i}\,(1+\mathrm{i})^{\mathrm{N}}}{(1+\mathrm{i})^{\mathrm{N}}-1}$	$\mathrm{CRF} = \frac{0.1\,(1+0.1)^{10}}{(1+0.1)^{10}-1}$ = 0.163	$\mathrm{CRF} = \frac{0.1\,(1+0.1)^{10}}{(1+0.1)^{10}-1}$ = 0.163	$\mathrm{CRF} = \frac{0.1\,(1+0.1)^{10}}{(1+0.1)^{10}-1}$ = 0.163
3	FAC = CS x CRF	FAC = 0.163 x 8800 = 1434.4	FAC = 10300 x 0.163 = 1678.9	FAC = 13300 x 0.163 = 2167.9
4	AMC = 15% x FAC	AMC = 0.15 x 1434.4 = 215.16	AMC = 0.15 x 1678.9 = 251.84	AMC = 0.15 x 2167.9 = 325.19
5	$\mathrm{SFF} = \frac{i}{((1+i)^{N}-1)}$	$\mathrm{SFF} = \frac{0.1}{((1+0.1)^{10}-1)}$ = 0.063	$\mathrm{SFF} = \frac{0.1}{((1+0.1)^{10}-1)}$ = 0.063	$\mathrm{SFF} = \frac{0.1}{((1+0.1)^{10}-1)}$ = 0.063
6	ASV = SFF x S	ASV = 0.063 x 0.1 x 8800 = 55.44	ASV = 0.063 x 0.1 x 10300 = 64.89	ASV = 0.063 x 0.1 x 13300 = 83.79
7	TAC = FAC + AMC – ASV	TAC = 1434.4 + 215.16 – 55.44 = 1594.12	TAC = 1678.9 + 251.84 – 64.89 = 1865.85	TAC = 2167.9 + 325.19 – 83.79 = 2409.3

8	$CPL = \frac{TAC}{L}$	$CPL = \frac{1594.12}{951.39}$ = 1.67 Rs/ Litre	$CPL = \frac{1865.85}{1179.24}$ = 1.58 Rs/ Litre	$CPL = \frac{2409.3}{1548.76}$ = 1.55 Rs/ Litre
9	Cash flow CF = yearly yield x selling price	CF = 951.39 x 2 = 1902.78	CF = 1179.24 x 2 = 2358.48	CF = 1548.76 x 2 = 3097.52
10	$\eta_p = \frac{\ln\left(\frac{CF}{CF-(FACx\,i)}\right)}{\ln(1+i)}$	$\eta_p = \frac{\ln\left(\frac{1902.78}{1902.78-(1434.4x\,0.1)}\right)}{\ln(1+0.1)}$ = 0.82 Years	$\eta_p = \frac{\ln\left(\frac{2358.48}{2358.48-(1678.9x\,0.1)}\right)}{\ln(1+0.1)}$ = 0.77 Years	$\eta_p = \frac{\ln\left(\frac{3097.52}{3097.52-(2167.9x\,0.1)}\right)}{\ln(1+0.1)}$ = 0.76 Years

Payback time is 299 days for inclined solar stills with stepped absorbers and corrugated fins, 281 days for inclined solar stills with stepped absorbers and corrugated fins integrated with vacuum tubes, and 277 days for inclined solar stills with stepped absorbers and corrugated fins integrated with vacuum tubes that use aluminum oxide nanoparticles.

The next chapter will focus on the primary takeaways from this research and what they mean.

CHAPTER 5

CONCLUSIONS AND SCOPE FOR FUTURE WORK

Thorough experimentation was carried out, and adequate data was created and evaluated, in order to determine the amount of fresh distillate produced by the still as well as the energy efficiency of its operation under a variety of basin circumstances. The main conclusions of the present experimental study are as under.

5.1 FRESH DISTILLATE OUTPUT

- The maximum distillate yield found from an inclined solar still having stepped absorber with corrugated fin in winter season (Case-1) is 2.62 L/m^2-day.
- The maximum distillate yield found from an inclined solar still having stepped absorber with corrugated fin and evacuated tube in winter season (Case-2) is 3.62 L/m^2-day.
- The maximum distillate yield found from an inclined solar still having stepped absorber with corrugated fin in summer season (Case-3) is 3.82 L/m^2-day.
- The maximum distillate yield found from an inclined solar still having stepped absorber with corrugated fin and evacuated tube in summer season (Case-4) is 4.7 L/m^2-day.
- The maximum distillate yield found from an inclined solar still having stepped absorber with corrugated fin integrated with vacuum tubes by using aluminium oxide as nanoparticles (Case-5) is 5.2 L/m^2-day.
- The total fresh distillate yield found from an inclined solar still having stepped absorber with corrugated fin and evacuated tube in winter (Case-2) is 15.64 L which is 25.32% more as compared to an inclined solar still having stepped absorber with corrugated fin in winter (Case-1) is 12.48 L.
- The total fresh distillate yield found from an inclined solar still having stepped absorber with corrugated fin and evacuated tube in summer (Case-4) is 22.4 L which is 79.48% more as compared to an inclined solar still having stepped absorber with corrugated fin in winter (Case-1) is 12.48 L.

- The total fresh distillate yield found from an inclined solar still having stepped absorber with corrugated fin integrated with vacuum tubes by using aluminium oxide as nanoparticles (Case-5) is 24.98 L which is 100.16% more as compared to the inclined solar still having stepped absorber with corrugated fin in winter season (Case-1).
- From experimentation, it is found that inclined solar still having stepped absorber with corrugated fin integrated with vacuum tubes by using aluminium oxide as Nanoparticles (Case-5) is the best basin conditions to obtain maximum fresh distillate output.
- In accordance with the recommendations provided by the WHO for the quality of water to be used for drinking, the TDS value of the fresh distillate yield that is achieved from an inclined solar still falls within the range of 60 to 100 ppm for all basin circumstances. This is inside the range that ensures the water is safe to drink.
- Similar to this, the fresh distillate output obtained from the inclined solar still has a pH value that, for all basin conditions, falls between 6 to 7.5, which is within the permissible range for the water that is safe to drink according to WHO drinking water guidelines.

5.2 ENERGY EFFICIENCY

- From experimentation, it is found that the inclined solar still having stepped absorber with corrugated fin integrated with vacuum tubes by using aluminium oxide as nanoparticles has maximum thermal efficiency as compared to the other basin condition of the still.
- The maximum efficiency obtained from the inclined solar still having stepped absorber with corrugated fin integrated in winter season (Case-1) is 32.59%.
- The maximum efficiency obtained from the inclined solar still having stepped absorber with corrugated fin integrated with vacuum tubes in winter season (Case-2) is 39.19%.
- The maximum efficiency obtained from the inclined solar still having stepped absorber with corrugated fin integrated in summer season (Case-3) is 39.98%.

- The maximum efficiency obtained from the inclined solar still having stepped absorber with corrugated fin integrated with vacuum tubes in summer season (Case-4) is 46.72%.
- The maximum efficiency obtained from the inclined solar still having stepped absorber with corrugated fin integrated with vacuum tubes by using aluminium oxide as nanoparticles (Case-5) is 56.56%.
- The 73.55% of thermal efficiency is increased from the inclined solar still having stepped absorber with corrugated fin integrated with vacuum tubes by using aluminium oxide as nanoparticles (Case-5) as associated to an inclined solar still having stepped absorber with corrugated fin in winter season (Case-1).

5.3 ECONOMIC ANALYSIS

- The price of producing distillate water using an inclined solar still with a stepped absorber and corrugated fin integrated with vacuum tubes is 1.55 Rupees per Liter. In contrast, the prices for inclined solar still having stepped absorbers with corrugated fins combined with vacuum tubes are 1.58 rupees per liter and 1.67 rupees per liter, respectively.
- The payback time period for the angled solar still with a stepped absorber with corrugated fins is 299 days, while regarding the angled solar still having a stepped absorber with corrugated fins integrated with vacuum tubes is 281 days and regarding the angled solar still having stepped absorber with corrugated fins integrated with vacuum tubes by using aluminum oxide as nanoparticles is 277 days.
- So finally, it is concluded that the distillate output obtained from the inclined solar still having stepped absorber with corrugated fins integrated with vacuum tubes by using aluminum oxide as nanoparticles is more also the cost of production of fresh distillate output is more and the net payback period time is less. Therefore, these basin conditions are considered the best design for fresh distillate.

5.4 SCOPE FOR FUTURE WORK

- To investigate the effect on fresh distillate output, a Phase change material (PCM) can be utilized in an inclined solar still with a stepped absorber integrated with corrugated fins and evacuated tubes.
- To observe the effects of various factors under various operating situations, mathematical modelling can also be used.
- A mathematical model can be used to compare the variances with the experimental readings.

RESEARCH PUBLICATIONS

1. Published Research article in a journal**, "**Materials Today: Proceedings*" having* https://doi.org/10.1016/j.matpr.2021.08.138 **(Scopus Indexed).**
   Name of the article Published:
   A study on the effect of absorbing medium on solar desalination system.
2. Published Research article in a journal**, "**Journal of Physics: Conference Series*" having* https://doi:10.1088/1742-6596/2267/1/012121 **(Scopus Indexed)**.
   Name of the article Published:
   A review of the use of nanoparticles on performance of solar stills.
3. Published Research article in journal, "International Journal of Renewable Energy Research" *having* https://doi.org/10.20508/ijrer.v13i3.14165.g8803 (**Scopus Indexed**).
   Name of the article Published:
   An Experimental Investigation on an Inclined Solar Distiller with a Stepped-Corrugated Absorber and Evacuated Tubes.
4. Published Research article in a journal, "Journal of East China University of Science and Technology" *having* https://doi:10.5281/ZENODO.725408 (**Scopus Indexed**).
   Name of the article Published:
   Comparative study of inclined solar still having corrugated fins stepped absorber with and without evacuated tube.
5. Presented Research article at the International Conference, on "Recent Advances in Fundamental and Applied Sciences" (RAFAS 2021) held on June 25 - 26, 2021, organized by the School of Chemical Engineering and Physical Sciences, Lovely Faculty of Technology and Sciences, Lovely Professional University, Punjab.
   Name of the article Presented:
   A review of the use of nanoparticles on performance of solar stills.
6. Presented Research article at the 2nd International Conference, on "Functional Materials, Manufacturing and Performances (ICFMMP - 2021)" held on 17th to

18th September 2021 organized by the School of Mechanical Engineering at Lovely Professional University, Punjab.

Name of the article Presented:

A study on the effect of absorbing medium on solar desalination system.

REFERENCES

[1] U. WATER, "The United Nations World Water Development Report 2019," 2019.

[2] F. E. Ahmed, R. Hashaikeh, and N. Hilal, "Solar powered desalination – Technology, energy and future outlook," *Desalination*, vol. 453, no. October 2018, pp. 54–76, 2019, doi: 10.1016/j.desal.2018.12.002.

[3] "Water supply and sanitation in Saudi Arabia."

[4] V. P. Katekar and S. S. Deshmukh, "A review of the use of phase change materials on performance of solar stills," *J Energy Storage*, vol. 30, no. March, p. 101398, 2020, doi: 10.1016/j.est.2020.101398.

[5] J. K. Bedi, R. S. Ghuman, and A. S. Bhullar, "Health and Economic Impact of Unsafe Drinking Water A Study of Ludhiana," 2015.

[6] R. K. Sharma, M. Yadav, and R. Gupta, "Water Quality and Sustainability in India: Challenges and Opportunities," in *Chemistry and Water: The Science Behind Sustaining the World's Most Crucial Resource*, Elsevier Inc., 2017, pp. 183–205. doi: 10.1016/B978-0-12-809330-6.00005-2.

[7] S. Kumar, "Water scarcity: Not Enough to Drink," *International Journal on Emerging Technologies*, vol. 8, no. 1, pp. 568–574, 2017, [Online]. Available: www.researchtrend.net

[8] Dr. Naresh Kumar, "Reassessment of water availability in basins using space inputs ii," 2017.

[9] A. Malik, A. Yasar, A. B. Tabinda, and M. Abubakar, "Water-Borne Diseases, Cost of Illness and Willingness to Pay for Dis-eases Interventions in Rural Communities of Developing Countries," 2012. [Online]. Available: http://ijph.tums.ac.ir

[10] P. H. Narnaware, R. G. Surose, and S. v Gaikwad, "Current status and the future potentials of renewable energy in India-A Review," 2015.

[11] A. K. Singh, G. N. Tiwari, P. B. Sharma, and E. Khan, "Optimization of orientation for higher yield of solar still for a given location," 1995.

[12] K. Kant, A. Shukla, and A. Sharma, “Advancement in phase change materials for thermal energy storage applications,” *Solar Energy Materials and Solar Cells*, vol. 172, pp. 82–92, Dec. 2017, doi: 10.1016/j.solmat.2017.07.023.

[13] G. Srilakshmi, V. Venkatesh, N. C. Thirumalai, and N. S. Suresh, “Challenges and opportunities for Solar Tower technology in India,” *Renewable and Sustainable Energy Reviews*, vol. 45. Elsevier Ltd, pp. 698–709, 2015. doi: 10.1016/j.rser.2015.02.016.

[14] P. K. S. Rathore, D. S. Chauhan, and R. P. Singh, “Decentralized solar rooftop photovoltaic in India: On the path of sustainable energy security,” *Renew Energy*, vol. 131, pp. 297–307, Feb. 2019, doi: 10.1016/j.renene.2018.07.049.

[15] G. Raina and S. Sinha, “Outlook on the Indian scenario of solar energy strategies: Policies and challenges,” *Energy Strategy Reviews*, vol. 24. Elsevier Ltd, pp. 331–341, Apr. 01, 2019. doi: 10.1016/j.esr.2019.04.005.

[16] Desalination & Water Purification Technologies: Technical Information Document, “Nanocomposite Ultrafiltration Membrane Device for Domestic Drinking Water Purification with respect to Arsenic, Iron and Microbial Contaminations,” 2010. Accessed: Nov. 03, 2022. [Online]. Available: https://www.barc.gov.in/pubaware/pub_water.pdf

[17] V. G. Gude, “Energy storage for desalination processes powered by renewable energy and waste heat sources,” *Appl Energy*, vol. 137, pp. 877–898, Jan. 2015, doi: 10.1016/j.apenergy.2014.06.061.

[18] H. Sharon and K. S. Reddy, “A review of solar energy driven desalination technologies,” *Renewable and Sustainable Energy Reviews*, vol. 41, pp. 1080–1118, 2015, doi: 10.1016/j.rser.2014.09.002.

[19] A. K. Kaviti, A. Yadav, and A. Shukla, “Inclined solar still designs: A review,” *Renewable and Sustainable Energy Reviews*, vol. 54, pp. 429–451, 2016, doi: 10.1016/j.rser.2015.10.027.

[20] T. He and L. Yan, “Application of alternative energy integration technology in seawater desalination,” *Desalination*, vol. 249, pp. 104–108, 2009, doi: 10.1016/j.desal.2008.07.026.

[21] M. T. Mito, X. Ma, H. Albuflasa, and P. A. Davies, “Reverse osmosis (RO) membrane desalination driven by wind and solar photovoltaic (PV) energy:

State of the art and challenges for large-scale implementation," *Renewable and Sustainable Energy Reviews*, vol. 112. Elsevier Ltd, pp. 669–685, Sep. 01, 2019. doi: 10.1016/j.rser.2019.06.008.

[22] S. Manju and N. Sagar, "Renewable energy integrated desalination: A sustainable solution to overcome future fresh-water scarcity in India," *Renewable and Sustainable Energy Reviews*, vol. 73. Elsevier Ltd, pp. 594–609, 2017. doi: 10.1016/j.rser.2017.01.164.

[23] G. Verma, A. K. Singh, P. Kumar, S. Kumar, and R. Maurya, "Development of Solar Still System: A Review," vol. 07, no. 03, pp. 1526–1535, 2019.

[24] K. Kalidasa Murugavel and K. Srithar, "Performance study on basin type double slope solar still with different wick materials and minimum mass of water," *Renew Energy*, vol. 36, no. 2, pp. 612–620, Feb. 2011, doi: 10.1016/j.renene.2010.08.009.

[25] P. Anburaj, R. Samuel Hansen, and K. Kalidasa Murugavel, "Performance of an inclined solar still with rectangular grooves and ridges," *Applied Solar Energy (English translation of Geliotekhnika)*, vol. 49, no. 1, pp. 22–26, Jan. 2013, doi: 10.3103/S0003701X13010027.

[26] 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.

[27] A. Alaudeen, K. Johnson, P. Ganasundar, A. Syed Abuthahir, and K. Srithar, "Study on stepped type basin in a solar still," *Journal of King Saud University - Engineering Sciences*, vol. 26, no. 2, pp. 176–183, Jul. 2014, doi: 10.1016/j.jksues.2013.05.002.

[28] R. S. Hansen, C. S. Narayanan, and K. K. Murugavel, "Performance analysis on inclined solar still with different new wick materials and wire mesh," *Desalination*, vol. 358, pp. 1–8, 2015, doi: 10.1016/j.desal.2014.12.006.

[29] Z. M. Omara, A. E. Kabeel, A. S. Abdullah, and F. A. Essa, "Experimental investigation of corrugated absorber solar still with wick and reflectors," *Desalination*, vol. 381, pp. 111–116, 2016, doi: 10.1016/j.desal.2015.12.001.

[30] 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.

[31] C. Tiris, “WREiC 1996 Improvement of basin type solar still performance: Use of Various Absorber Materials and Solar Collector Integration,” pp. 758–761, 1996.

[32] R. Sathyamurthy, P. K. Nagarajan, S. A. El-Agouz, V. Jaiganesh, and P. Sathish Khanna, “Experimental investigation on a semi-circular trough-absorber solar still with baffles for fresh water production,” *Energy Convers Manag*, vol. 97, pp. 235–242, 2015, doi: 10.1016/j.enconman.2015.03.052.

[33] S. Shanmugan, B. Janarthanan, and J. Chandrasekaran, “Performance of single-slope single-basin solar still with sensible heat storage materials,” *Desalination Water Treat*, vol. 41, no. 1–3, pp. 195–203, 2012, doi: 10.1080/19443994.2012.664714.

[34] H. N. Panchal, “Performance analysis of solar still with cow dung cakes and blue metal stones,” *Frontiers in Energy*, vol. 9, no. 2, pp. 180–186, 2015, doi: 10.1007/s11708-015-0361-y.

[35] S. J. P. Gnanaraj and V. Velmurugan, “Experimental investigation on the performance of modified single basin double slope solar stills,” *International Journal of Ambient Energy*, vol. 0, no. 0, pp. 1–10, 2019, doi: 10.1080/01430750.2019.1636861.

[36] B. Nasri, A. Benatiallah, S. Kalloum, and D. Benatiallah, “Improvement of glass solar still performance using locally available materials in the southern region of Algeria,” *Groundw Sustain Dev*, vol. 9, no. March, p. 100213, 2019, doi: 10.1016/j.gsd.2019.100213.

[37] S. Abdallah, M. M. Abu-Khader, and O. Badran, “Effect of various absorbing materials on the thermal performance of solar stills,” *Desalination*, vol. 242, no. 1–3, pp. 128–137, 2009, doi: 10.1016/j.desal.2008.03.036.

[38] 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.

[39] A. A. El-Sebaii, S. J. Yaghmour, F. S. Al-Hazmi, A. S. Faidah, F. M. Al-Marzouki, and A. A. Al-Ghamdi, "Active single basin solar still with a sensible storage medium," *Desalination*, vol. 249, no. 2, pp. 699–706, 2009, doi: 10.1016/j.desal.2009.02.060.

[40] Z. M. Omara, M. H. Hamed, and A. E. Kabeel, "Performance of finned and corrugated absorbers solar stills under Egyptian conditions," *Desalination*, vol. 277, no. 1–3, pp. 281–287, Aug. 2011, doi: 10.1016/j.desal.2011.04.042.

[41] P. K. Srivastava and S. K. Agrawal, "Winter and summer performance of single sloped basin type solar still integrated with extended porous fins," *Desalination*, vol. 319, pp. 73–78, 2013, doi: 10.1016/j.desal.2013.03.030.

[42] W. M. Alaian, E. A. Elnegiry, and A. M. Hamed, "Experimental investigation on the performance of solar still augmented with pin-finned wick," *Desalination*, vol. 379, pp. 10–15, 2016, doi: 10.1016/j.desal.2015.10.010.

[43] S. J. P. Gnanaraj and V. Velmurugan, "An experimental study on the efficacy of modifications in enhancing the performance of single basin double slope solar still," *Desalination*, vol. 467, no. May, pp. 12–28, 2019, doi: 10.1016/j.desal.2019.05.015.

[44] H. K. Jani and K. V. Modi, "Experimental performance evaluation of single basin dual slope solar still with circular and square cross-sectional hollow fins," *Solar Energy*, vol. 179, no. December 2018, pp. 186–194, 2019, doi: 10.1016/j.solener.2018.12.054.

[45] K. M. Bataineh and M. A. Abbas, "Performance analysis of solar still integrated with internal reflectors and fins," *Solar Energy*, vol. 205, no. April, pp. 22–36, 2020, doi: 10.1016/j.solener.2020.04.059.

[46] A. E. Kabeel, Z. M. Omara, and F. A. Essa, "Improving the performance of solar still by using nanofluids and providing vacuum," *Energy Convers Manag*, vol. 86, pp. 268–274, 2014, doi: 10.1016/j.enconman.2014.05.050.

[47] 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.

[48] 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.

[49] L. Sahota and G. N. Tiwari, "Effect of Al2O3 nanoparticles on the performance of passive double slope solar still," *Solar Energy*, vol. 130, pp. 260–272, 2016, doi: 10.1016/j.solener.2016.02.018.

[50] K. V. Modi, D. L. Shukla, and D. B. Ankoliya, "A Comparative Performance Study of Double Basin Single Slope Solar Still with and Without Using Nanoparticles," *Journal of Solar Energy Engineering, Transactions of the ASME*, vol. 141, no. 3, 2019, doi: 10.1115/1.4041838.

[51] R. Sathyamurthy, A. E. Kabeel, M. Balasubramanian, M. Devarajan, S. W. Sharshir, and A. M. Manokar, "Experimental study on enhancing the yield from stepped solar still coated using fumed silica nanoparticle in black paint," *Mater Lett*, vol. 272, p. 127873, 2020, doi: 10.1016/j.matlet.2020.127873.

[52] H. Panchal *et al.*, "Annual performance analysis of adding different nanofluids in stepped solar still," *J Therm Anal Calorim*, vol. 138, no. 5, pp. 3175–3182, 2019, doi: 10.1007/s10973-019-08346-x.

[53] S. Kumar, A. Dubey, and G. N. Tiwari, "A solar still augmented with an evacuated tube collector in forced mode," *Desalination*, vol. 347, pp. 15–24, 2014, doi: 10.1016/j.desal.2014.05.019.

[54] H. N. Panchal, "Enhancement of distillate output of double basin solar still with vacuum tubes," *Journal of King Saud University - Engineering Sciences*, vol. 27, no. 2, pp. 170–175, 2015, doi: 10.1016/j.jksues.2013.06.007.

[55] H. Panchal, K. Kumar Sadasivuni, M. Suresh, S. Yadav, and S. Brahmbhatt, "Performance analysis of evacuated tubes coupled solar still with double basin solar still and solid fins," *International Journal of Ambient Energy*, vol. 0, no. 0, pp. 1–16, 2018, doi: 10.1080/01430750.2018.1501745.

[56] A. Ali, M. Deyab, A. Ahmad, A. Saeed, and A. Muhanna, "Solar Desalination Augmented with Evacuated-Tube Collector," *JIMEC 2018*, pp. 1–10, 2018.

[57] H. Panchal, R. Sathyamurthy, A. K. Pandey, M. Kumar, T. Arunkumar, and D. K. Patel, "Annual performance analysis of a single-basin passive solar still coupled with evacuated tubes: comprehensive study in climate conditions of Mahesana, Gujarat," *International Journal of Ambient Energy*, vol. 40, no. 3, pp. 229–242, 2019, doi: 10.1080/01430750.2017.1378720.

[58] A. I. Shehata *et al.*, "Enhancement of the productivity for single solar still with ultrasonic humidifier combined with evacuated solar collector: An experimental study," *Energy Convers Manag*, vol. 208, no. February, p. 112592, 2020, doi: 10.1016/j.enconman.2020.112592.

[59] H. Panchal, S. S. Hishan, R. Rahim, and K. K. Sadasivuni, "Solar still with evacuated tubes and calcium stones to enhance the yield: An experimental investigation," *Process Safety and Environmental Protection*, vol. 142, pp. 150–155, 2020, doi: 10.1016/j.psep.2020.06.023.

[60] M. Patel, C. Patel, and H. Panchal, "Performance analysis of conventional triple basin solar still with evacuated heat pipes, corrugated sheets and storage materials," *Groundw Sustain Dev*, vol. 11, p. 100387, 2020, doi: 10.1016/j.gsd.2020.100387.

[61] A. N. Minasian and A. A. Al-Karaghouli, "An improved solar still: The wick-basin type," *Energy Convers Manag*, vol. 36, no. 3, pp. 213–217, 1995, doi: 10.1016/0196-8904(94)00053-3.

[62] T. Rajaseenivasan, T. Elango, and K. Kalidasa Murugavel, "Comparative study of double basin and single basin solar stills," *Desalination*, vol. 309, pp. 27–31, 2013, doi: 10.1016/j.desal.2012.09.014.

[63] T. Rajaseenivasan, K. Kalidasa Murugavel, and T. Elango, "Performance and exergy analysis of a double-basin solar still with different materials in basin," *Desalination Water Treat*, vol. 55, no. 7, pp. 1786–1794, 2015, doi: 10.1080/19443994.2014.928800.

[64] A. Saravanan and M. Murugan, "Performance evaluation of square pyramid solar still with various vertical wick materials – An experimental approach," *Thermal Science and Engineering Progress*, vol. 19, no. May, p. 100581, 2020, doi: 10.1016/j.tsep.2020.100581.

[65] C. E. Okeke, S. U. Egarievwe, and A. O. E. Animalu, "Effects of coal and charcoal on solar-still performance," *Energy*, vol. 15, no. 11, pp. 1071–1073, 1990, doi: 10.1016/0360-5442(90)90035-Z.

[66] A. A. El-Sebaii, S. Aboul-Enein, and E. El-Bialy, "Single basin solar still with baffle suspended absorber," *Energy Convers Manag*, vol. 41, no. 7, pp. 661–675, 2000, doi: 10.1016/S0196-8904(99)00141-7.

[67] A. S. Nafey, M. Abdelkader, A. Abdelmotalip, and A. A. Mabrouk, "Solar still productivity enhancement," *Energy Convers Manag*, vol. 42, no. 11, pp. 1401–1408, 2001, doi: 10.1016/S0196-8904(00)00107-2.

[68] M. Sakthivel and S. Shanmugasundaram, "SHORT COMMUNICATION Effect of energy storage medium (black granite gravel) on the performance of a solar still," no. July 2006, pp. 68–82, 2008, doi: 10.1002/er.

[69] B. Madhu *et al.*, "Experimental investigation on the effect of sensible heat energy storage in an inclined solar still with baffles," *Desalination Water Treat*, vol. 116, pp. 49–56, 2018, doi: 10.5004/dwt.2018.22474.

[70] G. Raj, D. Prabhansu, R. Kumar, P. Chandra, and S. Saurabh, "Experimental study of solar still augmented with low-cost energy absorbing and releasing materials," *Energy Sources, Part A: Recovery, Utilization and Environmental Effects*, vol. 42, no. 1, pp. 56–65, 2020, doi: 10.1080/15567036.2019.1587054.

[71] S. W. Sharshir *et al.*, "Improving the performance of solar still using different heat localization materials," *Environmental Science and Pollution Research*, vol. 27, no. 11, pp. 12332–12344, 2020, doi: 10.1007/s11356-020-07800-w.

[72] B. A. K. Abu-Hijleh, M. Abu-Qudias, and S. Al-Khateeb, "Experimental study of a solar still with sponge cubes in basin," *International Journal of Solar Energy*, vol. 21, no. 4, pp. 257–266, 2003, doi: 10.1080/01425910108914374.

[73] T. V. Arjunan, H. Ş. Aybar, and N. Nedunchezhian, "Effect of sponge liner on the internal heat transfer coefficients in a simple solar still," *Desalination Water Treat*, vol. 29, no. 1–3, pp. 271–284, 2011, doi: 10.5004/dwt.2011.1638.

[74] 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.

[75] R. Panomwan Na Ayuthaya, P. Namprakai, and W. Ampun, “The thermal performance of an ethanol solar still with fin plate to increase productivity,” *Renew Energy*, vol. 54, pp. 227–234, Jun. 2013, doi: 10.1016/j.renene.2012.08.004.

[76] S. M. Elshamy and E. M. S. El-Said, “Comparative study based on thermal, exergetic and economic analyses of a tubular solar still with semi-circular corrugated absorber,” *J Clean Prod*, vol. 195, pp. 328–339, 2018, doi: 10.1016/j.jclepro.2018.05.243.

[77] H. Panchal and R. Sathyamurthy, “Experimental analysis of single-basin solar still with porous fins,” *International Journal of Ambient Energy*, vol. 41, no. 5, pp. 563–569, 2020, doi: 10.1080/01430750.2017.1360206.

[78] H. Panchal, D. Mevada, K. K. Sadasivuni, F. A. Essa, S. Shanmugan, and M. Khalid, “Experimental and water quality analysis of solar stills with vertical and inclined fins,” *Groundw Sustain Dev*, vol. 11, p. 100410, 2020, doi: 10.1016/j.gsd.2020.100410.

[79] S. W. Sharshir, A. W. Kandeal, M. Ismail, G. B. Abdelaziz, A. E. Kabeel, and N. Yang, “Augmentation of a pyramid solar still performance using evacuated tubes and nanofluid: Experimental approach,” *Appl Therm Eng*, vol. 160, no. June, p. 113997, 2019, doi: 10.1016/j.applthermaleng.2019.113997.

[80] 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*, vol. 208, pp. 1041–1052, 2019, doi: 10.1016/j.jclepro.2018.10.194.

[81] A. Shafieian, M. Rizwan Azhar, M. Khiadani, and T. Kanti Sen, “Performance improvement of thermal-driven membrane-based solar desalination systems using nanofluid in the feed stream,” *Sustainable Energy Technologies and Assessments*, vol. 39, no. April, 2020, doi: 10.1016/j.seta.2020.100715.

[82] A. Behura and H. Gupta, “Use of nanoparticle-embedded phase change material in solar still for productivity enhancement,” *Mater Today Proc*, pp. 10–13, 2020, doi: 10.1016/j.matpr.2020.06.285.

[83] D. Dsilva Winfred Rufuss, S. Arulvel, S. Iniyan, and L. Suganthi, “Numerical study of titanium oxide nanoparticle enhanced energy storage material in solar

desalination,” *Mater Today Proc*, pp. 10–13, 2020, doi: 10.1016/j.matpr.2020.06.448.

[84] M. Bhargva and A. Yadav, “Experimental comparative study on a solar still combined with evacuated tubes and a heat exchanger at different water depths,” *International Journal of Sustainable Engineering*, vol. 13, no. 3, pp. 218–229, 2020, doi: 10.1080/19397038.2019.1653396.

[85] C. L. Saw, *Advancement in Emerging Technologies and Engineering*. 2020.

[86] Z. Saadi, A. Rahmani, S. Lachtar, and H. Soualmi, “Performance evaluation of a new stepped solar still under the desert climatic conditions,” *Energy Convers Manag*, 2018, doi: 10.1016/j.enconman.2018.06.114.

[87] A. Shyora, K. Patel, and H. Panchal, “Comparative analysis of stepped and single basin solar still in climate conditions of Gandhinagar Gujarat during winter,” *International Journal of Ambient Energy*, vol. 0, no. 0, pp. 1–11, 2019, doi: 10.1080/01430750.2019.1612781.

[88] A. E. Kabeel, M. M. Khairat Dawood, T. Nabil, and B. E. Alonafal, “Improving the performance of stepped solar still using a graphite and PCM as hybrid store materials with internal reflectors coupled with evacuated tube solar collector,” *Heat and Mass Transfer/Waerme- und Stoffuebertragung*, 2019, doi: 10.1007/s00231-019-02741-8.

[89] S. W. Sharshir, M. A. Eltawil, A. M. Algazzar, R. Sathyamurthy, and A. W. Kandeal, “Performance enhancement of stepped double slope solar still by using nanoparticles and linen wicks: Energy, exergy and economic analysis,” *Appl Therm Eng*, vol. 174, no. October 2019, p. 115278, 2020, doi: 10.1016/j.applthermaleng.2020.115278.

[90] V. P. Katekar and S. S. Deshmukh, “Thermoeconomic analysis of solar distillation system with stepped-corrugated absorber plate,” *Proc Inst Mech Eng C J Mech Eng Sci*, vol. 0, no. 0, pp. 1–20, 2020, doi: 10.1177/0954406220943227.

[91] V. K. Ramalingam, A. Karthick, M. P. V. Jeyalekshmi, A. M. M. A. J. Decruz, A. M. Manokar, and R. Sathyamurthy, “Enhancing the fresh water produced from inclined cover stepped absorber solar still using wick and energy storage

materials," *Environmental Science and Pollution Research*, vol. 28, no. 14, pp. 18146–18162, 2021, doi: 10.1007/s11356-020-12030-1.

[92] A. M. Gandhi *et al.*, "Performance enhancement of stepped basin solar still based on OSELM with traversal tree for higher energy adaptive control," *Desalination*, vol. 502, p. 114926, Apr. 2021, doi: 10.1016/J.DESAL.2020.114926.

[93] M. Abdelgaied, A. S. Abdulla, G. B. Abdelaziz, and A. E. Kabeel, "Performance improvement of modified stepped solar distillers using three effective hybrid optimization modifications," *Sustainable Energy Technologies and Assessments*, vol. 51, p. 101936, Jun. 2022, doi: 10.1016/J.SETA.2021.101936.

[94] A. S. Abdullah *et al.*, "Enhancing trays solar still performance using wick finned absorber, nano- enhanced PCM," *Alexandria Engineering Journal*, vol. 61, no. 12, pp. 12417–12430, Dec. 2022, doi: 10.1016/J.AEJ.2022.06.033.

[95] M. Sobhani and H. Ajam, "Experimental performance evaluation of a novel design solar desalination device equipped with air stones," *Desalination*, vol. 543, p. 116086, Dec. 2022, doi: 10.1016/J.DESAL.2022.116086.

[96] T. Arunkumar *et al.*, "An experimental study on a hemispherical solar still," *Desalination*, vol. 286, pp. 342–348, 2012, doi: 10.1016/j.desal.2011.11.047.

[97] A. S. Abdullah, "Improving the performance of stepped solar still," *Desalination*, vol. 319, pp. 60–65, 2013, doi: 10.1016/j.desal.2013.04.003.

[98] A. Somwanshi and A. K. Tiwari, "Performance enhancement of a single basin solar still with flow of water from an air cooler on the cover," *Desalination*, vol. 352, pp. 92–102, 2014, doi: 10.1016/j.desal.2014.08.011.

[99] M. M. Morad, H. A. M. El-Maghawry, and K. I. Wasfy, "Improving the double slope solar still performance by using flat-plate solar collector and cooling glass cover," *Desalination*, vol. 373, pp. 1–9, 2015, doi: 10.1016/j.desal.2015.06.017.

[100] K. Srithar, T. Rajaseenivasan, N. Karthik, M. Periyannan, and M. Gowtham, "Stand alone triple basin solar desalination system with cover cooling and parabolic dish concentrator," *Renew Energy*, vol. 90, pp. 157–165, 2016, doi: 10.1016/j.renene.2015.12.063.

[101] M. Abu-arabi, M. Al-harahsheh, M. Ahmad, and H. Mousa, “Theoretical modeling of a glass-cooled solar still incorporating PCM and coupled to fl at plate solar collector,” *J Energy Storage*, vol. 29, no. November 2019, p. 101372, 2020, doi: 10.1016/j.est.2020.101372.

[102] T. Arunkumar, R. Jayaprakash, A. Ahsan, D. Denkenberger, and M. S. Okundamiya, “Effect of water and air flow on concentric tubular solar water desalting system,” *Appl Energy*, vol. 103, pp. 109–115, 2013, doi: 10.1016/j.apenergy.2012.09.014.

[103] H. Mousa and M. A. Arabi, “Desalination and hot water production using solar still enhanced by external solar collector,” *Desalination Water Treat*, vol. 51, no. 4–6, pp. 1296–1301, 2013, doi: 10.1080/19443994.2012.699237.

[104] Y. A. F. El-Samadony and A. E. Kabeel, “Theoretical estimation of the optimum glass cover water film cooling parameters combinations of a stepped solar still,” *Energy*, vol. 68, pp. 744–750, 2014, doi: 10.1016/j.energy.2014.01.080.

[105] P. U. Suneesh, R. Jayaprakash, T. Arunkumar, and D. Denkenberger, “Effect of air flow on ‘V’ type solar still with cotton gauze cooling,” *Desalination*, vol. 337, no. 1, pp. 1–5, 2014, doi: 10.1016/j.desal.2013.12.035.

[106] T. Arunkumar *et al.*, “Effect of heat removal on tubular solar desalting system,” *Desalination*, vol. 379, pp. 24–33, 2016, doi: 10.1016/j.desal.2015.10.007.

[107] A. A. F. Al-Hamadani and S. K. Shukla, “Water Distillation Using Solar Energy System with Lauric Acid as Storage Medium,” *International Journal of Energy Engineering*, vol. 1, no. 1, pp. 1–8, 2012, doi: 10.5923/j.ijee.20110101.01.

[108] A. A. F. Al-Hamadani and S. K. Shukla, “Modelling of solar distillation system with phase change material storage medium,” *Thermal Science*, vol. 18, no. SUPPL.2, pp. 347–362, 2014, doi: 10.2298/TSCI120102110A.

[109] A. K. Rai and V. Sachan, “Experimental Study of a Tubular Solar Still with Phase Change Material,” *International Journal of Mechanical Engineering and Technology (IJMET)*, vol. 6, no. 1, pp. 42–46, 2015.

[110] R. Sathyamurthy, P. K. Nagarajan, J. Subramani, D. Vijayakumar, and K. Mohammed Ashraf Ali, “Effect of water mass on triangular pyramid solar still using phase change material as storage medium,” *Energy Procedia*, vol. 61, pp. 2224–2228, 2014, doi: 10.1016/j.egypro.2014.12.114.

[111] G. Rajasekhar and M. Eswaramoorthy, “Performance evaluation on solar still integrated with nano-composite phase change materials,” *Applied Solar Energy (English translation of Geliotekhnika)*, vol. 51, no. 1, pp. 15–21, 2015, doi: 10.3103/S0003701X15010119.

[112] S. M. Shalaby, E. El-Bialy, and A. A. El-Sebaii, “An experimental investigation of a v-corrugated absorber single-basin solar still using PCM,” *Desalination*, vol. 398, pp. 247–255, 2016, doi: 10.1016/j.desal.2016.07.042.

[113] M. Dashtban and F. F. Tabrizi, “Thermal analysis of a weir-type cascade solar still integrated with PCM storage,” *Desalination*, vol. 279, no. 1–3, pp. 415–422, 2011, doi: 10.1016/j.desal.2011.06.044.

[114] T. Arunkumar, D. Denkenberger, R. Velraj, R. Sathyamurthy, H. Tanaka, and K. Vinothkumar, “Experimental study on a parabolic concentrator assisted solar desalting system,” *Energy Convers Manag*, vol. 105, pp. 665–674, 2015, doi: 10.1016/j.enconman.2015.08.021.

[115] M. T. Chaichan and H. A. Kazem, “Water solar distiller productivity enhancement using concentrating solar water heater and phase change material (PCM),” *Case Studies in Thermal Engineering*, vol. 5, pp. 151–159, 2015, doi: 10.1016/j.csite.2015.03.009.

[116] A. E. Kabeel, M. Abdelgaied, and M. Mahgoub, “The performance of a modified solar still using hot air injection and PCM,” *Desalination*, vol. 379, pp. 102–107, 2016, doi: 10.1016/j.desal.2015.11.007.

[117] A. E. Kabeel and M. Abdelgaied, “Improving the performance of solar still by using PCM as a thermal storage medium under Egyptian conditions,” *Desalination*, vol. 383, pp. 22–28, 2016, doi: 10.1016/j.desal.2016.01.006.

[118] P. Joshi and G. N. Tiwari, “Energy matrices, exergo-economic and enviro-economic analysis of an active single slope solar still integrated with a heat exchanger: A comparative study,” *Desalination*, vol. 443, no. May, pp. 85–98, 2018, doi: 10.1016/j.desal.2018.05.012.

[119] H. Panchal *et al.*, “Economic and exergy investigation of triangular pyramid solar still integrated to inclined solar still with baffles,” *International Journal of Ambient Energy*, vol. 40, no. 6, pp. 571–576, 2019, doi: 10.1080/01430750.2017.1422143.

[120] O. Bait, “Exergy, environ–economic and economic analyses of a tubular solar water heater assisted solar still,” *J Clean Prod*, 2019, doi: 10.1016/j.jclepro.2018.12.015.

[121] A. F. Mohamed, A. A. Hegazi, G. I. Sultan, and E. M. S. El-said, “Solar Energy Materials and Solar Cells Enhancement of a solar still performance by inclusion the basalt stones as a porous sensible absorber: Experimental study and thermo-economic analysis,” *Solar Energy Materials and Solar Cells*, vol. 200, no. May, p. 109958, 2019, doi: 10.1016/j.solmat.2019.109958.

[122] N. T. Alwan, S. E. Shcheklein, and O. M. Ali, “Case Studies in Thermal Engineering Experimental investigation of modified solar still integrated with solar collector,” *Case Studies in Thermal Engineering*, vol. 19, no. February, p. 100614, 2020, doi: 10.1016/j.csite.2020.100614.

[123] H. Panchal, “Performance Investigation on Variations of Glass Cover Thickness on Solar Still: Experimental and Theoretical Analysis,” *Technology and Economics of Smart Grids and Sustainable Energy*, vol. 1, no. 1, 2016, doi: 10.1007/s40866-016-0007-0.

[124] G. N. Tiwari and A. T. Shyam, “Energy Systems in Electrical Engineering Handbook of Solar Energy Theory, Analysis and Applications.” [Online]. Available: http://www.springer.com/series/13509

[125] G. N. Tiwari and L. Sahota, “Green Energy and Technology Advanced Solar-Distillation Systems Basic Principles, Thermal Modeling, and Its Application.” [Online]. Available: http://www.springer.com/series/8059.

[126] S. M. Fale, S. Dogra, “A review of the use of nanoparticles on performance of solar stills,” in *Journal of Physics: Conference Series*, Jun. 2022, vol. 2267, no. 1. doi: 10.1088/1742-6596/2267/1/012121.

[127] Les. Kirkup and R. B. (Robert B.) Frenkel, An introduction to uncertainty in measurement using the GUM (guide to the expression of uncertainty in measurement). Cambridge University Press, 2006.

APPENDIX I

UNCERTAINITY ANALYSIS

The degree of uncertainty demonstrates the accuracy of measurements and measuring tools. Our experimental study only accounts for the uncertainty that is connected to the systematic error since we have assumed that the measurements are distributed uniformly. The standard uncertainty is defined as follows [90], [127].

$$U = \frac{a}{\sqrt{3}}$$

Where:

a = accuracy of the measuring instrument

u = the standard uncertainty.

A type and description of measurement tools used during experiments are shown in Table I. It demonstrates that every uncertainty falls inside the allowable range.

Table I: The Uncertainty of measuring instrument

Equipment	Range	Accuracy	Uncertainty
PT100 Thermocouple	0^oC to 100^oC	± 1^oC	0.57^oC
Solar Meter	0 W/m^2 to 2000 W/m^2	± 10 W/m^2	5.77 W/m^2
pH meter	0 pH to 14 pH	± 0.1 PH	0.057 pH
Calibrated Flask	0 ml to 1000 ml	± 10 ml	5.77 ml
TDS meter	0 PPM to 990 PPM	± 1 PPM	0.577 PPM

APPENDIX II
CALIBRATION CERTIFICATE

RPK / FT / 13

Certificate No. CC-2475

Calibration Certificate

ULR No.	CC247521000004048F	ELECTROTECHNICAL CALIBRATION	
Certificate No.	**Calibration Date**	**Next Calibration Date (As suggested by customer)**	**Page**
RPK/NABL/3989/01/21-22	25.08.2021	25.08.2022	1 of 2

Name & Address of Customer
M/s. Shri Ramdeobaba College of Engineering and Management,
Nagpur 440013

Customer Reference
Work order no. : --
Date : --
Date of Receipt : 21.08.2021
Physical condition on Receipt : Satisfactory
Location of Calibration Lab/~~Site~~

Description & Identification of Unit Under Calibration (UUC) :

Name of UUC	Sr.No	Range	L. C	Make
12 CH .DIGITAL TEMPERATURE INDICATOR (WITH SENSOR)	DTI-3012	0 to 1000 °C	1 °C	CREATIVE

Reference Equipment used for Calibration :

Equipment	Sr. No.	Traceable to	Certificate No.	Valid Upto
Universal Calibrator	21080786	CC-2294	NI/2108/070/001	22.08.2022

Note: Measurements are metro logically traceable through NABL Traceability certificate of Master Equipment used.

Calibration Procedure & Ref. Documents : RPK/CM – ET/01 & EURAMET Cg-11

Environmental Condition Temperature : 30.4 °C Humidity : 70 % RH

Observation Table: -

CHANNEL NO:- 1 INPUT TYPE: K

SR. NO.	VALUE ON UUC (°C)	VALUE ON STANDARD (°C)	DEVIATION (°C)	* UOM (°C)
1.	100	100.2	-0.2	± 1.40°C
2.	200	200.1	-0.1	
3.	400	400.2	-0.2	
4.	600	600.3	-0.3	
5.	800	800.5	-0.5	
6.	1000	1000.5	-0.5	

Deviation = Value on UUC – Value on Standard
UUC = Unit Under Calibration
Uncertainty of Measurement at coverage factor $k = 2$ at 95.45% of Confidence Level.
Note: The certificate is issued subject to the condition stated overleaf.
Remark :- The Value on UUC / Standard Mentioned in observation Table are average of 5 reading.

Calibrated By
S. R. Bhowate
Tech. Asst.

R. P. KHEDKAR CALIBRATION & TESTING CENTRE NAGPUR

Approved By
D. B. Bhalerao
Deputy Manager

Place : Nagpur
Issue Date : 25.08.2021

-----END OF CERTIFICATE-----

R. P. KHEDKAR CALIBRATION & TESTING CENTRE
85, Azad Hind Nagar, (Trimurti Nagar) Jaitala Road, Nagpur- 440 022.
Ph. : 0712-2227318, 9822289333, E-mail : rpkhedkarlab@gmail.com

APPENDIX III
CHARACTERIZATION OF ALUMINIUM OXIDE

Intelligent Materials Pvt. Ltd.
www.nanoshel.com, sales@nanoshel.com

NANOSHEL
Creating Miracles in Black

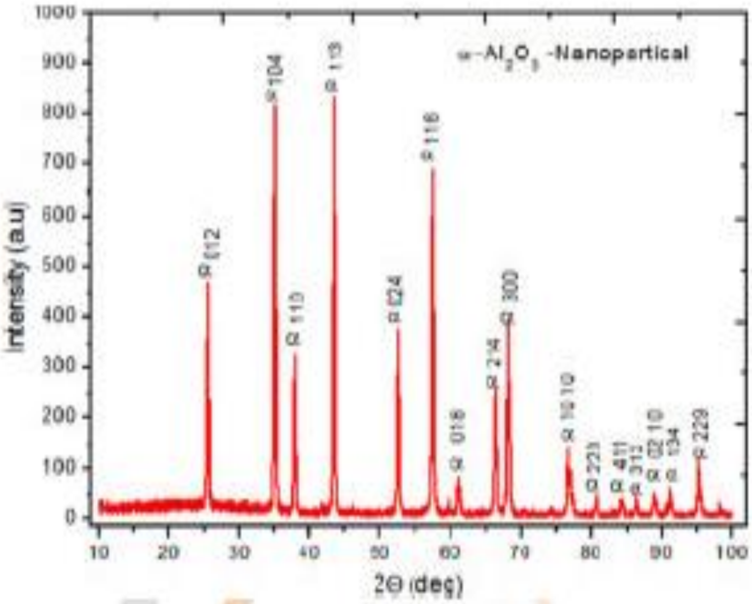
Specification Sheet

Aluminium Oxide Nanopowder
(Al_2O_3, Alpha, 99.9%, APS: <100nm)
Stock No. NS6130-03-300, CAS: 1344-28-1

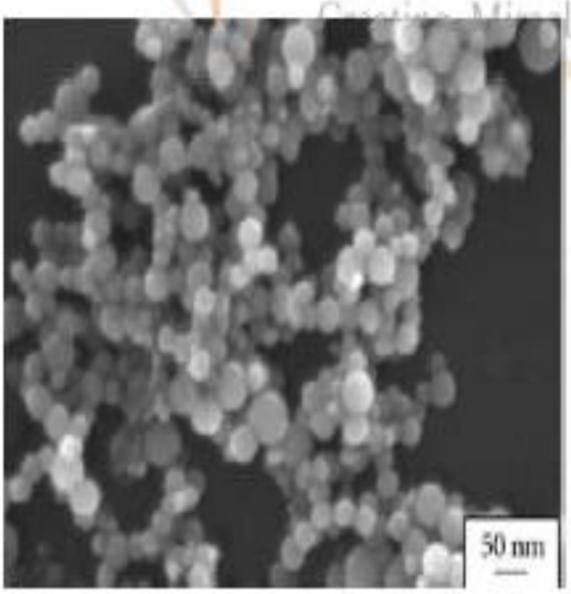
Product	:	**Aluminium Oxide Nanopowder**
Stock No	:	NS6130-03-300
CAS	:	1344-28-1
Purity	:	99.9%
Average Particle Size (APS)	:	<100nm
Molecular Formula	:	Al_2O_3
Molecular Weight	:	101.96 g/mol
Form	:	Powder
Color	:	White
Crystal Form	:	Alpha
Density	:	3.9g/cm^3
Bulk Density	:	0.52-0.83g/cm^3
Specific Surface Area (SSA)	:	5 - 10 m^2/g
Melting Point	:	2045 °C
Thermal Conductivity	:	30 $W \cdot m^{-1} \cdot K^{-1}$
Solubility	:	Insoluble in water, ethanol
Main Inspect Verifier	:	**Manager QC**
Date of Print	:	**October 27, 2020**
Version	:	**1.1**

Note: Product Specification are subject to amendment and may change over time

Aluminum Oxide Nanopowder XRD



Aluminum Oxide Nanopowder SEM



Intelligent Materials Pvt. Ltd.
www.nanoshel.com, sales@nanoshel.com

NANOSHEL
Creating Miracles in Black

Certificate of Analysis

Aluminium Oxide Nanopowder
(Al_2O_3, Alpha, 99.9%, APS: <100nm)
Stock No. NS6130-03-300, CAS: 1344-28-1

Product	**:**	**Aluminium Oxide Nanopowder**
Stock No	:	NS6130-03-300
CAS	:	1344-28-1
Average Particle Size (APS)	:	<100nm
Molecular Formula	:	Al_2O_3
Assay	:	99.9%
Total Metal Impurities	:	850 ppm
Shelf life	:	12 Months

Note 1: Values are given in ppm unless otherwise specified.

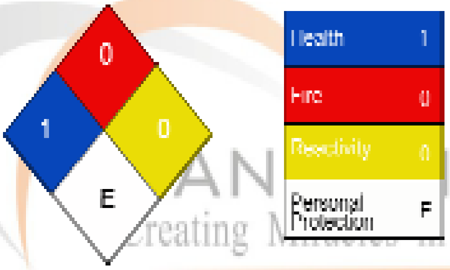
Note 2: All figures above are weight for weight as determined by ICP

MATERIAL SAFETY DATA SHEET

ALUMINUM OXIDE NANOPOWDER
Stock #: NS6130-03-300

1. IDENTIFICATION OF THE PRODUCT AND THE COMPANY

Product Name	:	Aluminum Oxide Nanopowder
Use	:	Research and Development
Address	:	Nanoshel LLC 3422 Old Capitol Suit 1305 Willmington DE – 19808 United States
Emergency	:	+1.532.253.9878



2. COMPOSITION & INFORMATION ON INGREDIENTS

Chemical Characterisation	:	Al_2O_3
Hazardous Ingredients	:	Nil

3. HAZARD IDENTIFICATION

Toxicity	:	No Data Available
Eye Contact	:	Dust may cause irritation

4. FIRST AID MEASURES

Skin	:	Wash skin with soap and copious amounts of water
Eyes	:	Imediate and prolonged irritation treat with copious amounts of water.
Ingestion	:	Wash out mouth with water provided person Is Conscious.
Inhalation	:	If inhaled, remove to fresh air. If not breathing give artificial respiration. If

breathing is difficult, give oxygen

5. FIREFIGHTING MEASURES

Extinguishing Data	:	Water Spray
Unsuitable Extinguishing Data	:	Carbon Dioxide, Dry Chemical Powder, Polymer Foam
Unusual Firefighting Hazards	:	Capable of creating a dust explosion
Special Firefighting Procedures	:	Use normal procedures which include wearing self-contained breathing apparatus and protective clothing to prevent contact with skin and eyes.

6. ACCIDENTAL RELEASE MEASURES

Personal Precautions	:	Wear respirator, chemical safety goggles, rubber boots and gloves.
Precautions to the Environment	:	Sweep up, place in a bag and hold for waste disposal.
Cleanup Procedures	:	Avoid raising dust. Ventilate area and wash spill site after material pickup is complete.

7. HANDLING AND STORAGE

Handling Precautions	:	Chemical Safety Goggles. Compatible with Chemical-resistant Gloves
Storage	:	Store in a cool dry place.
Unusable Packaging Materials	:	Wash thoroughly after handling. Irritating dust, Keep tightly closed

8. EXPOSURE CONTROLS AND PERSONAL PROTECTION

<u>**Personal Protective Equipment**</u>

Respiratory	:	Self-contained breathing apparatus
Hand	:	Chemical-resistant Gloves
Eye	:	Avoid contact with eyes
Skin	:	Wash thoroughly after handling

9. PHYSICAL AND CHEMICAL PROPERTIES

Appearance

Form	:	Powder
Colour	:	White
Odour	:	No Odour

Safety Related Information

FlashPoint	:	N/A
Boiling Point	:	2977 °C
Melting Point	:	2072 °C
pH	:	N/A

10. STABILITY AND REACTIVITY

Stability	:	Completely Stable
Reactivity	:	Non Reactive/ Non Soluble

11. TOXICOLOGICAL INFORMATION

Possible Health Effects

Skin	:	No effect
Eyes	:	Irritation
Inhalation	:	No Chocking Hazard
Toxicity	:	Non-Toxic

12. ECOLOGICAL IMPACT

Avoid raising dust. Ventilate area and wash spill site after material pickup is complete. No Negative Ecological Impact, Data not Available

13. WASTE DISPOSAL

Dissolve or mix the material with a combustible solvent and burn in a chemical incinerator, equipped with an afterburner and scrubber

14. TRANSPORT INFORMATION (UN ORNEK OLARAK VERİLMİŞTİR)

HS Code	:	28182090
CAS	:	1344-28-1
Proper Shipping Name	:	Aluminum Oxide Nanopowder
Air Transport (ICAO & IATA)	:	Oxide Nanopowder
Class	:	Non Hazardeous
Packing group	:	Normal Packing
Transport information	:	Not regulated for IATA (AIR)

15. OHTER REGULATORY INFORMATION

Federal and State Regulations: TSCA 8(b) inventory: Aluminum Oxide Nanopowder

Other Regulations: EINECS: This product is on the European Inventory of Existing Commercial Chemical Substances.

Other Classifications:

WHMIS (Canada): Not controlled under WHMIS (Canada)

DSCL (EEC):
- R36- Irritating to eyes
- S2- Keep out of the reach of children
- S46- If swallowed, seek medical advice immediately & show container or label

HMIS (U.S.A.):
- Health Hazard: 1
- Fire Hazard: 0
- Reactivity: 0
- Personal Protection: E

National Fire Protection Association (U.S.A.):
- Health: 1
- Flammability: 0
- Reactivity: 0
- Specific hazard:

Protective Equipment:
- Gloves.
- Lab coat.
- Dust respirator. Be sure to use an approved/certified respirator or equivalent.
- Splash goggles.

16. OTHER INFORMATION

References: Not available
Other Special Considerations: Not available