iJRASET
International Journal For Research in Applied Science and Engineering Technology



INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 11 **Issue:** VI **Month of publication:** June 2023

DOI: https://doi.org/10.22214/ijraset.2023.53641

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International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 11 Issue VI Jun 2023- Available at www.ijraset.com

Water Feeding System of Solar Desalination on Stepped Still: A Review

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***Abstract:** This paper presents a modification of stepped solar still with continuous water circulation using a storage tank for sea and salt water. Total dissolved solids (TDS) of seawater and salt water before desalination is 57,100 and 2370 mg/l.To assess the performance of the developed desalination system under the same climatic conditions, a comparison study bet ween modified stepped and conventional solar stills was conducted.To assess the performance of the developed desalination syste m under the same climatic conditions, a comparison study between modified stepped and conventional solar stills was conducted. The results indicate that, the productivity of the modified stepped still is higher than that for conventional still approximately by 43% and 48% for sea and salt water with black absorber respectively, while 53% and 47% of sea and salt water, respectively with cotton absorber. Also, the daily efficiency for modified stepped still is higher than that for conventional still approximately by 20%. The maximum efficiency of modified stepped still is occurring at a feed water flow rate of 1 LPM for sea water and 3 LPM for salt water. Total dissolved solids (TDS) of seawater and salt water after desalination is 41, and 27 mg/l.*

I. INTRODUCTION

Solar collectors, solar cooking, desalination, and cooling systems can all be used to generate heat using solar energy. Low productivi ty and efficiency are the main practical issues with the conventional solar sill that are seen in the first phase. The surface area of the solar distillation unit could be increased, which would increase efficiency and productivity.

Al-Hinai et al. [1] studied the effect of design, climatic, and operational parameters on the productivity of a simple solar still. The results show that the daily productivity increased by 8.2% with a rise in ambient temperature from 23 to 33 C. The water depth is batter in the range of 0.02–0.06 m.

Kumar and Tiwari [2] presented the newly design of the hybrid (PV/T) active solar still. The effect of water depth for passive and hybrid active solar still was studied. The maximum daily productivity from passive and hybrid active solar still was 2.26 kg and 7.22 kg at 0.05 m water depth. The productivity of a hybrid active solar still was about 3.2 and 5.5 times higher than the passive solar still in summer and winter month. The effect of tilt angle on productivity and the value of the optimum tilt angle were reviewed by Khalifa [3].

In winter, the cover tilt angle should be large; in summer, it should be small, according to the review's conclusions. Additionally, the different latitudes and seasons had an impact on selecting the right cover tilt angle.

ElSebaii investigated how wind speed affected the daily productivity of some basin type, vertical, active, and passive solar still desi gns[4].The findings demonstrated that wind speed has a value independent of brine heat capacity and still shape.At higher water mas ses and during the summer, the wind is more powerful.

Gude et al. [5] developed and evaluated the performance of the two-stage operation of the low temperature desalination process using a low-grade heat source. The results show that in a double stage configuration, the specific energy consumption of the process was less than 3.6 kJ/kg of mechanical energy and 1500 kJ/kg of thermal energy

In order to reduce condensation resistance and increase freshwater yield, Xiong et al. [6] developed a new multieffect solar still with an enhanced condensation surface. The results demonstrated that the model's seawater temperature change reveals the presence of a n adverse temperature difference in the second stacked tray, which can cause the seawater temperature to rise quickly and is advanta geous for increasing the yield of freshwater in the subsequent process.

The performance of a conventional single slope solar still was improved by three design modifications, according to research by Abdallah et al. [7]

First, all interior sides of the still should have internal reflecting mirrors added. Next, a stepwise water basin should be used rather th an a flat one. Finally, the solar still should be connected to a sun tracking system. Results showed that the stepwise basin and sun tra cking system coupled together provided the most efficient thermal performance, with an average efficiency of 38%.

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The effects of some modifications to single and double slope stills on productivity and efficiency were examined by Khalifa et al. [8]

The outcomes demonstrated improvements in the output and efficiency of the solar stills as a result of the use of the aforementioned changes.

The performance of a standard single basin solar still and a wick type still were compared by Velmurugan et al. [9]. Fins and spon ges were integrated into the still's basin to increase water evaporation.

Productivity was found to increase by about 29.6% when wicktype solar stills were used, by about 15.3% when sponges were used, and by about 45.5% when fins were used.

The integration of two different depths of trays from the fin at the basin solar air heater with the stepped solar still was studied by Velmurugan et al [11].They claimed that using stepped solar stills with fins increased production by 53.3%.

For sponge, productivity rises by 68%, and for pebble, it rises by 65%. The productivity of a fin type stepped solar still with both sp onge and pebble increases by 98% compared to a conventional stepped solar still. The productivity of the steppedsolar still was imp roved by Velmurugan et al. [10].

Stepped solar stills with fin, sponge, and combinations of fin and sponge types underwent experimental, theoretical, and economic a nalysis.

E8lZahaby et al. [11] presented a new design for a solar desalination system that makes use of two air heaters to increase the produc tivity of freshwater. The outcomes demonstrated that the power used and the inlet seawater temperature have a significant impact on the steppedstill performance.

ElZahaby et al. [12] also investigated the performance of the solar stepped still using the spray system for seawater at various holder and flow rate velocities. Phase change material (PCM) has been investigated in other studies as a storage medium for stepped solar stills. Radhawan [13] investigated how thermal energy storage affected the short-term performance of a solar still.

The findings indicate that the modification was still effective for water produced when there was no sunlight, particularly at night.

ElSebaii et al. [14] also created a new mathematical model to study the thermal performance of a single basin solar still with phase change material using simplifying assumptions (PCM).

To increase productivity, Dashtban and Tabrizi [15] investigated a weirtype cascade stepped solar still with phase change material a s a thermal energy storage system.

By taking into account a small set of data from a typical day, the results reveal that still with PCM was more productive (31% impro vement) than still without PCM.

Still using PCM led to an increase in daily productivity of about 32%.

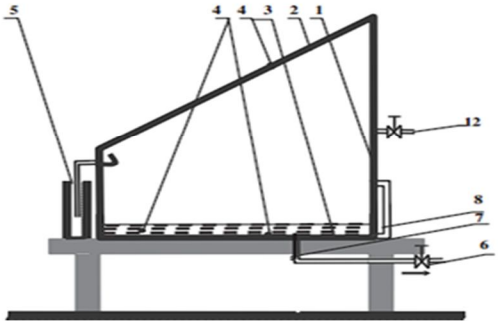
Internal and external reflectors were used to modify the stepped still, and they had an impact on how well it performed, according to Omara et al. [16]. The findings indicate that during the experiment, the productivity of the modified stepped solar still with internal and external reflectors was approximately 125% higher than that of the conventional still.

A suitable modification to the system design could increase the productivity of the solar desalination system in that location.

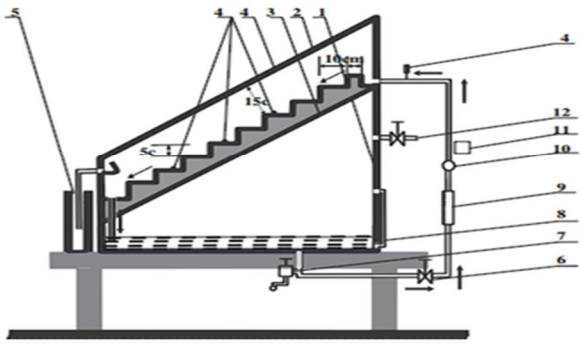
However, a high system cost and an increase in system productivity could result in an increase in the distillate's average annual cost.

Arunkumar et al. [17] investigated a tubular solar still design with flowing water and air over the cover. The effect of flowing coolin g air and water over the condensation surface was investigated. They discovered that productivity with airflow was 3050 ml/day, pro ductivity with cooling water flow was 5000 ml/day, and productivity without air or water flow was 2050 ml/day.

When compared to airflow, cooling water flow increased productivity by approximately 64%.



(a) Conventional Solar Still



(b) Stepped Solar Still

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Fig. 1. Schematic diagram of the experimental setup. (1) Solar still frame, (2) glass cover, (3) absorber plate, (4) digital thermometer, (5) water vessel, (6, 12) control valve, (7) water drain, (8) graduate level, (9) flow meter, (10) water pump and (11) control timer.

The new system is intended to efficiently capture solar heat and distil it. A new technique is used to increase the amount of water sur face exposed to solar heat. The goal of this study is to modify stepped solar still using a storage tank to increase production time. Furthermore, the cotton black absorber is used to improve water distribution on the absorber surface through continuous water circul ation. The experimental work investigated the effect of storage tank temperature and level, water flow rate, and solar radiation on de salination system performance. After sunset, the effect of energy in the storage tank is studied for two hours.

Feilizadeh et al. [18] investigated an evacuated energy absorber tube basin solar still. Water flowed from the basin to the tubes on th e basin's bottom in their solar still system, which was heated by solar energy. When the basin was filled with water, the production r ate increased by 14%, while the production rate increased by 46% when the condenser was filled with water. Furthermore, when th condenser and basin were both flled up, the system's output increased by 66%. Nasri et al. [19] investigated the performance of a single-slope glass-walled solar still experimentally.

They used sand, gravel, and polyethylene on the basin's bottom to absorb solar energy, which increased the distillate production rate. The highest product was 5 L/m2.day when gravel was used, while black polyethylene and sand produced 4.48 and 3.84 L/m2.day of distillate, respectively. The performance of a singleslope solar still was investigated by Bilal et al. [20]. Pumice stones were used in the basin to increase the rate of evaporation. They conducted tests with 5 and 10 kg of pumice stones.

Previous research indicates that the use of solar stills has piqued the interest of many people in recent years.

Although many methods for increasing water evaporation rate and evaporative distillation have been discussed in recent years, most studies have focused on production enhancement techniques for single-slope basin solar stills.

As a result, a stepped solar still with an external galvanised absorber plate condenser is experimentally investigated in this study.

To increase the rate of distillate production, weirs were installed in front of each step to direct the water through a helical path and k eep it in contact with the energy absorber plate for a longer period of time.Metal fIns were used on the steps to create hot spots and i ncrease the evaporation rate as a novel idea. Finally, the effect of the feedwater flow rate on the performance of the solar still was as sessed.

II. WATER SHORTAGE

A. Droughts and Climate Change

Water shortages occur due to a number of factors; one of the biggest drivers of water scarcity is drought. Drought is a natural phenomenon in which dry conditions and lack of precipitation – whether it is rain, snow or sleet – occur over certain areas for a period of time.

While the amount of rainfall can naturally vary between different regions and times of year, climate change and rising global temperatures are altering rainfall patterns, which in turn, impact the quality and spatial distribution of global water resources. Warmer temperatures mean that moisture in soil evaporates at faster rates, and more frequent and severe heat waves exacerbate drought conditions and contribute towards water shortages.

B. Poor Water Management and Growing Demand

Today, the world’s population is just short of eight billion people, which translates to a growing demand for water amid water stress from climate change. Urbanisation and an exponential increase in freshwater demand for households are both driving factors behind water shortages, especially in regions with a precarious water supply.

For example, in 2018, Cape Town, South Africa experienced a water crisis and became the first modern city to effectively run out of drinking water as a result of extreme drought, poor water resource management and overconsumption.

C. Water Pollution

Contaminated and unsafe water is another contributing factor of water shortages. Water pollution already kills more people each year than war and all other forms of violence combined. As we only have less than 1% of the Earth’s freshwater accessible to us, human activity is actively threatening our own water resources. Water pollution can come from a number of sources, including sewage and wastewater – more than 80% of the world’s wastewater flows back into the environment without being treated, and agricultural and industrial runoff, where pesticides and toxic chemicals leach into the groundwater and nearby freshwater systems. Consequently, precious water resources get contaminated, resulting in less freshwater and drinking water available.

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III. WATER PURIFICATION

It is the process of removing undesirable chemicals, biological contaminants, suspended solids and gases from contaminated water. The goal is to produce water fit for a specific purpose. Most water is purified for human consumption (drinking water), but water purification may also be designed for a variety of other purposes, including meeting the requirements of medical, pharmacological, chemical and industrial applications. In general the methods used include physical processes such as filtration, sedimentation, and distillation, biological processes such as slow sand filters or biologically active carbon, chemical processes such as flocculation and chlorination and the use of electromagnetic radiation such as ultraviolet light.

There are four possible ways of purifying water for drinking purpose:-

1) Distillation
2) Filtration
3) Chemical Treatment
4) Irradiative Treatment

Considering the areas where the technology is intended to be used we can rule out few of the above mentioned methods based on the unavailability of materials or costs. Chemical treatment is not a standalone procedure' and so is irradiative treatment. Both can act only remove some specific impurities and hence can only be implemented in coordination with other technologies. This analysis leaves us with two methods - Distillation and Filtration. By weighting the positive and negatives of both the methods we decided to go by the first one. The most important considerations were that of complexity, higher maintenance and subsequent costs coupled with need of other sophisticated supporting equipment.

The distillation method was selected as it produces water of high quality and the maintenance is almost negligible. Also any type of water can be purified into potable water by means of this process and the system will not involve any moving parts and will not require electricity to operate. Finally wastage of water will be minimum by using distillation method.

IV. NEEDS AND SPECIFICATION FOR WATER PURIFICATION

The project centres on converting the roughly 99.6% of water that is, in its natural form, undrinkable, into clean and usable water. After researching and investigation, we outlined our needs to be to efficiently produce at 2 gallons of potable water per day minimum; to purify water from virtually any source included the ocean and relatively inexpensive to remain accessible to a wide range of audiences. It is also necessary that it should be easy to use interface, intuitive setup and operation, provide clean useful drinking water without the need for an external energy source and reasonably compact and portable. Our aim is to accomplish this goal by utilizing and converting the incoming radioactive power of the sun's rays to heat and distil dirty and undrinkable water, converting it into clean drinkable water. A solar parabolic trough is utilized to effectively concentrate and increase the solid angle of incoming beam radiation, increasing the efficiency of the system and enabling higher water temperatures to be achieved.

V. CONCEPT OF SOLAR DISTILLATION

Desalination is the one of the most important methods of getting potable water from brackish and sea water by using free energy supply from the sun. Desalination is one of mankind's earliest forms of water treatment and it is still a popular treatment method throughout the world today. In nature, solar desalination produces rain when solar radiation is absorbed by the sea and causes water to evaporate. The evaporated water rises above the earth's surface and

is moved by the wind. Once this vapor cools down to its dew point, condensation occurs, and the fresh water comes down as rain. This same principle is used in all manmade distillation systems using alternative sources of heating and cooling. Various parameters affect both the efficiency and productivity of the still. The distilled water production rate can vary with the design of the solar still and location. The problem is to enhance the amount of water produced. The distilled water production rate can be increased by varying the design of the solar still, depth of water and location. The attempts are made to increase the productivity of the solar still by varying different material for design, water depths and evaporative techniques.

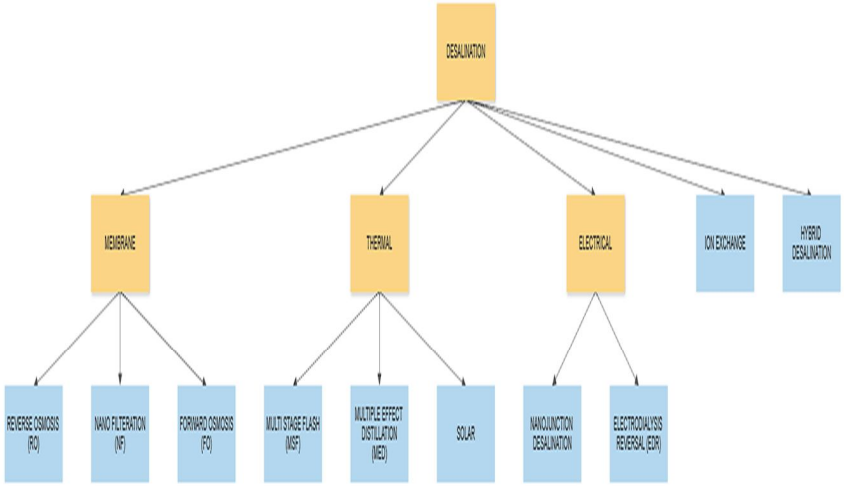
Sunlight has the advantage of zero fuel cost but it requires more space and generally more equipment. Solar distillation is used to produce low yield, but safe and pure supplies of water in remote areas. The basic principles of solar water distillation are simple yet effective, as distillation replicates the way nature makes rain. Solar energy heats water, evaporates it (salts and microbes left behind), and condenses as clouds to return to the earth as rain water. When solar radiation absorbed by the water in the river and sea, gets heated and evaporated. The evaporated water rises above the earth's surface and is moved by the wind. Once this vapor cools down to its dew point, condensation occurs, and the fresh water comes down as rain. This same principle is used in all manmade distillation systems.

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ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 11 Issue VI Jun 2023- Available at www.ijraset.com

The currently proven and widely used desalination technologies are generally classified into thermal and membrane processes. Thermal processes require a source of heat and electricity, while membrane processes require a driving power (normally electricity) to sustain the high pressure needed.

TECHNOLOGIES AVAILABLE FOR SOLAR DESALINATION



VI. ACCEPTANCE AND IMPORTANCE OF SOLAR DESALINATION

Solar desalination is increasingly being accepted over other desalination techniques for several reasons, including:

1) Cost-effectiveness: Solar desalination systems are cost-effective compared to other desalination techniques such as thermal and reverse osmosis desalination. This is because they utilize freely available solar energy to power the process, thereby reducing operational costs.
2) Sustainability: Solar desalination is a sustainable and environmentally friendly method of producing fresh water. The process does not produce any greenhouse gas emissions or other harmful byproducts.
3) Reliability: Solar energy is a reliable source of energy, and it can be harnessed in almost all parts of the world. Therefore, solar desalination is more reliable than other desalination techniques that require electricity or fuel to operate.
4) Flexibility: Solar desalination systems can be designed and installed to meet specific needs and can be easily expanded or modified as the demand for fresh water changes.
5) Accessibility: Solar desalination can be used to provide fresh water in remote areas where access to electricity and other energy sources is limited. This makes it an ideal solution for areas with water scarcity and high solar radiation.
6) Modularity and scalability: Solar desalination systems can be designed and installed to meet specific needs and can be easily expanded or modified as the demand for fresh water changes. This flexibility makes it possible to deploy solar desalination systems in a wide range of settings, from small-scale community projects to large-scale industrial applications.
7) Independence from fossil fuels: Solar desalination systems do not rely on fossil fuels for energy, which makes them a more sustainable and secure solution for producing fresh water.

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Overall, the importance of solar desalination over other desalination techniques lies in its cost-effectiveness, sustainability, reliability, accessibility, modularity, scalability, and independence from fossil fuels. These advantages make solar desalination a key technology for addressing water scarcity and improving access to clean water in a sustainable and environmentally friendly manner.

VII. TYPES OF FLOW SYSTEMS

A. Continuous Flow

A continuous flow inclined solar still desalination system is a technology used to desalinate water by using solar energy. It works by using a sloped or inclined surface covered with a transparent material, which allows sunlight to pass through and heat the water beneath it. As the water heats up, it evaporates and condenses on the inclined surface, where it collects and is channelled towards a collection point.

Unlike traditional solar stills, which use a batch process to desalinate water, the continuous flow inclined solar still system has a continuous flow of water, which allows for a more efficient and faster desalination process. Additionally, the inclined design of the system helps to improve the efficiency of the process by allowing for more sunlight to be absorbed and used to heat the water.

The system is particularly useful in areas where access to fresh water is limited and solar energy is abundant. It can be used in a variety of settings, including rural communities, disaster zones, and remote locations. However, the system has some limitations, including the fact that it may not be as effective in areas with limited sunlight, and it requires regular maintenance to ensure optimal performance.

B. Batch Flow

A batch flow system is a type of flow system used in solar desalination that involves the intermittent introduction of a fixed volume of seawater into a solar still. The seawater flows through the still, which is typically a stepped solar still, in a cycle and is collected as freshwater in a collection basin. In a batch flow system, the still is typically filled with seawater in the morning, and the water is allowed to flow down through each successive basin until it reaches the final basin, where it is collected as freshwater. The still operates in a cycle, with the freshwater being collected at the end of each cycle. Once the freshwater is collected, the system is emptied and refilled with seawater for the next cycle. The advantage of a batch flow system is that it is relatively simple and easy to construct.

It does not require a continuous flow of seawater, which means that it can be used in areas where the water supply is limited or irregular. Batch flow systems are also less susceptible to scaling and fouling than continuous flow systems, as the still is emptied and refilled with fresh seawater at the beginning of each cycle. However, batch flow systems also have some disadvantages. They are typically less productive than continuous flow systems, as the still is not continuously exposed to solar irradiation. They also require manual intervention to refill the still with seawater at the beginning of each cycle, which can be time-consuming and labor-intensive.

Overall, the choice of flow system will depend on the specific needs and constraints of the solar desalination project. Batch flow systems are a viable option for smaller-scale projects or in areas where the water supply is limited or irregular. However, for larger-scale projects, continuous flow systems may be more appropriate due to their higher productivity and continuous operation.

VIII. BENEFITS OF CONTINIOUS FLOW OVER BATCH FLOW

There are several advantages of using a continuous flow system in a stepped solar still for solar desalination.

Firstly, a continuous flow system can produce a greater amount of freshwater per unit of surface area than a batch flow system. This is because in a continuous flow system, the still is continuously exposed to solar irradiation, which increases the efficiency of the still and allows it to produce a more consistent flow of freshwater.

Secondly, a continuous flow system operates continuously, which means that it can be used in areas where the water supply is more reliable or where a continuous flow of freshwater is required. This makes it more suitable for larger-scale desalination projects or for applications where a constant supply of freshwater is necessary.

Thirdly, a continuous flow system can be designed with multiple basins, which allows for a higher degree of control over the desalination process. The number of basins can be optimized to achieve the desired level of freshwater production and to control the salinity of the freshwater produced.

Finally, a continuous flow system is less susceptible to scaling and fouling than a batch flow system, as the still is continuously exposed to seawater. This reduces the need for cleaning and maintenance and can increase the lifespan of the still.

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Overall, the advantages of using a continuous flow system in a stepped solar still make it a viable option for larger-scale desalination projects or for applications where a continuous flow of freshwater is necessary. However, the choice of flow system will depend on the specific needs and constraints of the solar desalination project.

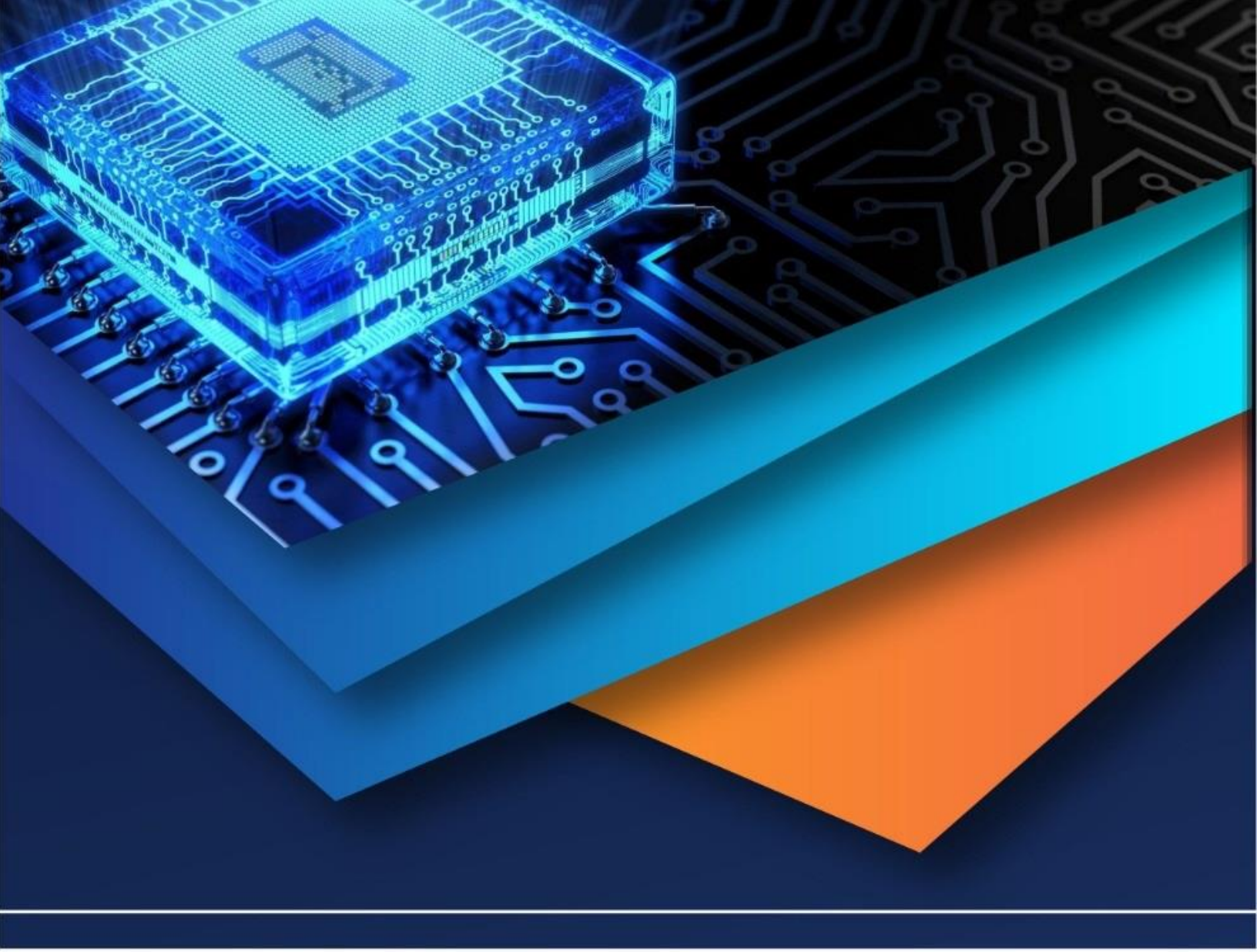
IX. CONCLUSION

1) The productivity of the modified stepped still is approximately 43% and 48% higher than that of the conventional still for sea a nd salt water, respectively, with the black absorber, while 53% and 47% higher for sea and salt water, respectively, with cotton.
2) The daily efficiency of modified stepped still is approximately 20% higher than that of conventional still
For sea and salt water at black absorber.
3) The daily efficiency for modified stepped and conventional solarstills is approximately 61%, 42%, and 55%, 37%, respectively.
4) The maximum efficiency of a modified stepped still occurs at a feed water flow rate of 1 LPM for sea water and 3 LPM for fres h water. [21]
5) At lower flow rates, temperature rises in different sections of the solar still occurred, and the ultimate distillate production rate i ncreased as the fow rate decreased. [21]
6) After 150 minutes, even after the solar simulator was turned off, distillate continued to be produced at the end of the test. The to tal distillate output was reported.
7) In all tests, the distillate collected in the internal condenser accounted for the majority of total distillate production.
8) The ideal flow rate (OFR) was defined as the flow rate at which the evaporation rate is high enough to prevent drying of the steps while evaporation continues at a high rate.As production increase ed,it was found that the so lar still's efficiency increased. [22]
9) The application of inclined solar still with open water loop is recommended when combined with a certain still system due to high water temperature output.[21]

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