Experimental Performance Analysis of Conventional and Horizontally Double Sloped Solar Still

Sumit Verma[1] Saumitra Kumar Sharma[2]
[1]PG Scholar [2]Assistant Professor
[1,2]Department of Mechanical Engineering
[1,2]Oriental College of Technology, Bhopal, India

Abstract— A desalination system works on electricity or a convention fossil fuel. Where thermal energy is extracted which leaves carbon residue and other greenhouse gases behind, which a major reason behind ozone depletion and global warming and may other health hazards for mankind. Desalination using a non-conventional resource will help. The desalination using solar energy is one-time investment for lifetime production of pure water up to 15 to 25 years. In this dissertation, multiple method of desalination has been discussed. The productivity of passive solar stills can be improved or enhanced by using various storage materials or by some simple modification in the design of still. These solar still can be used to convert brackish water into fresh water. Conventional solar still has low productivity and productivity of solar still many research iterates and puts their effort consistently. Many researchers have used metal particles of Nano sized to improve the thermal efficiency of the still. In this project, conventional solar still is compared with Horizontally Double Sloped solar still which resulted in increase in efficiency and productivity in the process of desalination which can be carried out by only using the energy from the sun.

Keywords: Economic Analysis, Solar Still, Solar Collectors, Nano Fluids

I. Introduction

A. *Overview of Energy*

Energy is defined as "the ability to do work". It plays a vital role in the development of any country. As we know, a living organism needs energy for its work. The degree of development of a country is measured by the scale of energy use for human survival. People are constantly doing research to find energy alternatives. So they can increase their comfort level. As a country grows and develops, the gross domestic product (GDP) grows almost in proportion to energy consumption. India's Human Development Index (HDI) is very low compared to other countries. However, it is expected to grow in the coming years. Energy intensity is defined by the ratio of energy consumption to GDP. This factor is higher in developing countries compared to developed countries. "India's energy intensity is 3.7 times that of Japan and 1.55 times that of the US."

To fully meet the demand for energy, people use various sources that can provide energy efficiently and effectively. However, as the population grows, so does the need for energy. If we use energy resources very soon, they will be fully exhausted from nature, so we have to look for alternatives to non-renewable energy, which is also called Renewable energy source.

B. *Method for Purification of Water*

There are various methods of water purification, divided into four main categories: separation, filtration, chemicals, oxidation. There are five types of contaminants and impurities found in water, i.e. bacteria, particulates, chemicals, minerals and pharmaceuticals. Existing methods of removing these elements range from simple, cheaper and inexpensive to complicated and expensive. Often used in the production of clean drinking water, several techniques must be combined in a certain order. The following methods are generally used to purify water.

Sedimentation, Boiling Water, Distillation, Ultraviolet Light

C. *Chemicals*

Chlorine It is common, cheap, but extremely toxic in nature. Does not reduce physical or chemical contamination; it increases cholesterol formation, is a carcinogen and causes heart disease.

Bromine It is used in pools and spas, doesn't smell or taste as bad and doesn't kill bacteria very well.

Hydrogen Peroxide It kills bacteria with oxygen, is chemically made and is very toxic. It is used in emergencies.

Lime and Mild Alkaline Agents It should also be used with caution only by large water plants, or only for laundry.

Coagulation-Flocculation This method implies to add chemical which helps to lump together suspended particles for filtration or separation.

D. *Ion Exchange*

It exchanges sodium from salt for calcium or magnesium, using glauconitic (greensand), precipitated synthetic organic resins, or gel zeolite, thus softening the water. Minerals, metals, chemicals or odours are not affected, and the water is salty to drink.

Filtration, Slow sand It is used to purify water and its capacity is 1 cubic meter passes about 2 litters/min, and does a limited bacteria removal.

Pressure sand It must be backwashed daily and can pass 1 cubic meter about 40gpm.

Boiling It is a process used to kill the microorganism by the heating of water in effective way. World health organization (WHO) recommends that vigorous boiling of water kills microorganism or inactivate most microorganism which causes diarrhoea. It has been seen that turbidity does not affect disinfection by boiling. In household, the boiling of water is mostly done in a pot on a stove.

Chlorination in Piped System t is a method used to disinfect water. In this method, chlorine inactivates pathogens in the water and creates a barrier against contamination. It is applied at the last stage of the drinking water treatment process. Two techniques are most commonly used in this method, i.e. batch chlorination and blanket chlorination.

During both chlorination, a concentrated chlorine solution is added to the water in the tank, the outlets and inlets remain closed. The water is mixed and the chlorine reacts when the tank is empty, refilled and the drains are closed. Usually, the container containing the chlorine solution is placed on top of the water tank and the solution is fed near the fresh water inlet.

Household Sand Filter In this arrangement, the water slowly passes through a layer of fine stones or sand and is processed by a mixed process of physical, biological and chemical. Using sand, fine particles are filtered out, but microorganisms grow on the surface of the sand and feed on the organic matter in the water. 200 liters of water can be cleaned with this filter. This overall system consists of three components, i.e. raw water supply tank, filter tank and fresh water tank. A floating weir is used to maintain a constant flow of water to the top of the filter tank. The water is purified by passing through a 45-60 cm bed of sand with a 5 cm layer of fine gravel. A perforated pipe is used at the outlet, from which the water flows into the clean water tank. Produces germ-free water in an effective and efficient manner.

Solar Disinfection The principle on which solar disinfection works says that "microorganisms are sensitive to light and heat". It is one of the simplest and easiest ways to disinfect water. It can be tested in the laboratory or in the field. A container with transparent walls is filled with water and exposed to sunlight for several hours. When the water temperature reaches 500 C, the inactivation process is initiated and the result is complete bacteriological disinfection. Solar distillation used the sun's heat directly to purify water to an optimal level. The arrangement commonly known as solar still includes a shallow tank with a transparent glass cover. The sun's heat is encapsulated in the still, creating a greenhouse effect that speeds up the process and raises the temperature of the water in the tank, causing evaporation. The moisture on the water vapor rises and condenses on the cover glass and flows down into the collection paths, leaving dirt and salts behind.

Storage and Sedimentation During storage, the quality of raw water has improved due to some physical processes. Non-colloidal and suspended particles slowly settle at the bottom of the tank and the incident radiation kills some of the harmful organisms and bacteria in the water. The microorganism "Schist Larvae" will die automatically if the water is stored for more than 48 hours and the colloidal particles remain in suspension. The size of suspended solids is inversely proportional to the time required for sedimentation. This means that smaller suspended particles need more time to settle compared to larger ones.

A sedimentation tank usually has two sections, one is used and the other can be cleaned at the same time. It has an entrance from below and an exit below the water level.

Nomenclature

Eb	Energy radiated per unit time
Σb	Stefan-boltzman constant
ϵ	Radiative property of the surface and is called emissivity
Q	Heat transfer rate
A	Surface area perpendicular to the direction of heat flow
Dt	Temperature difference
Dx	Short perpendicular distance
Qc	Convective heat flow rate
Ts & tf	surface and fluid temperatures
H	Coefficient of heat transfer
T	Absolute temperature
Qc;go -a	Convective heat transfer rate from glass cover outer surface to ambient
Hc;go-a	Convective heat transfer coefficient
Q r;go-a	Radiative heat transfer rate from glass cover outer surface tosurroundings(w/m2 k)
Hr;go-a	Radiative heat transfer coefficient from water to glass cover(w/m2 k)
Tgo	Initial temperature of glass cover (1c)
Ta	Temperature of air
A	Air or ambient
Go	Glass cover outer surface
Sky	Sky = ta- 6
Q c;go-a	Convective heat transfer rate from glass cover outer surface to ambient(w/m^2 k)
Qw	Heat transfer rate between basin liner and water mass (w/m^2)
Hw	Convective heat transfer coefficient from basin liner to the water
B	Basin liner
W	Water mass
Qb	Heat loss between basin liner and ambient(w/m2)
Hb	Heat transfer coefficient between basin liner and ambient (w/m2 k)
Ub	Overall bottom heat loss coefficient between water mass and atmosphere(w/m2 k)
Uss	Overall side heat loss coefficient between water mass and atmosphere(w/m2 k)
Ubs	Total bottom and side heat loss coefficient between water mass and ambient (w/m2 k)
Q cd;gi_go	Rate of energy received from glass cover inner surface by conduction
G	Glass cover
K	Thermal conductivity (w/m k)
L	Thickness (m)
Tgo	Initial temperature of glass cover(1c)
I (t)	Intensity of solar radiation (w/m2)
I(t)s	Intensity of solar radiation on inclined glass cover surface of solar still(w/m2)
A	Absorptivity
Tw	Initial temperature of water(0c)
Tgi	Initial temperature of glass cover (0c)

II. LITERATURE REVIEW

Various high and medium technologies such as reverse osmosis (RO), multi-stage flash distillation (MSF), multi-effect distillation (MED), vacuum distillation and vapor compression have been developed for water purification. However, solar distillation is a simple technology that uses solar energy (a sufficient source of non-conventional or renewable energy). It is an economical, efficient and environmentally friendly technology. The simplest and cheapest solar stills are passive solar stills.

Zakaria Haddad, Abla Chaker, Ahmed Rahmani [2017] Schematic description of the proposed solar still. It mainly consists of a single tilt pan solar still in which the VRW is integrated at the back of the still. The still tank area is 0.36 m2 (0.9 m × 0.4 m), made of 1.0 mm thick galvanized iron and painted with black spray paint to increase the absorption of solar radiation. The sink is placed inside a rectangular wooden box with a thickness of 4 cm, and the lower space between them is filled with 8 cm of glass wool to reduce the heat loss of the bottom.

Kamel Rabhi, Rached Nciri et al. [2017] In this work, a modified single tank solar still is developed. A pin absorber and condenser are integrated in the modified solar still. A detailed description of the static design and still functional description is made. An experimental comparative performance study is conducted between a conventional still, a condenser still, a pin absorber still, and a condenser and pin absorber still. An increase in water production of the order of 32.18% is noted for a condenser still (using air flow and an external condenser) compared to a conventional still. In the case of the pin plate single absorber still, the water production gain is only 14.53% compared to the conventional still.

Hitesh Panchal, Indra Mohan [2017] Stationary solar technology has been serving mankind for a very long time. Since the decade there have been many modifications to improve productivity. One of the significant improvements that have been made is the use of fins on the base of the still. The integration of fins in the solar panel increases the exposure area of the tank and thus leads to a higher heat transfer rate and a higher evaporation rate. This increases the distillate production of conventional solar stills. In a series of comparative experiments conducted earlier by V. Velumurugan et al. observed that when a wick was used in a single bowl solar still, productivity increased by up to 29.6% compared to using sponges which increased productivity by 15.3%. In the same still, when ribs were used, the increase observed was 45.5%.

Basharat Jamil, Naiem Akhtar [2017] The present work was carried out at the Heat and Solar Energy Transfer Laboratory, Department of Mechanical Engineering, Aligarh Muslim University, Aligarh, India (27.89°N, 78.08°E). A current view of the experimental setup, i.e. a conventional single slope solar still. A galvanized sheet with a thickness of 22 was used for the construction of the solar still. The area of the sink was kept at 1m² with an aspect ratio of 2:1. This is consistent with the fact that a 2:1 absorber aspect ratio provides optimal solar energy collection in a solar still.

Ravishankar Sathyamurthy, P.K.Nagarajan, B.Madhu [2017] It can be clearly seen that the effect of solar panel integration still improves the yield of fresh water from both solar stills. A constant gravity feed method was used to cool the casing of the tubular solar still, and the extracted heat from the water is sent to the tank of the pyramidal solar still. The heat extracted from the solar still (Tubular) was used to evaporate water from the single bowl pyramidal solar still. The experimental results also showed that the water flow rate for cooling the outer casing of the tubular solar still is limited from 10 to 100 mL/min because the heat extraction from the casing was minimal at increased mass flow rate.

Nisrin Abdelal, Yazan Taamneh [2017] In this research, four pyramid-shaped solar stills with the same shape, dimensions, and materials, but with different absorber plate base materials, were designed and fabricated. The first absorber plate was made of black painted galvanized steel, the second tank plate was made of CF/2.5 wt% CNT modified epoxy composite, the third plate was made of CF/5 wt% CNT modified epoxy composite, and the fourth plate was made of CF/2.5 wt% GNP modified epoxy composite. The experiments were conducted on 4 days in September in the outdoor climatic conditions of the city of Irbid, Jordan. Brackish water was used in all experiments. Each solar distillation unit consisted of several parts: a galvanized steel container painted black and filled with 5 cm thick foam for insulation purposes. A 70 × 70 cm2 galvanized steel sheet painted black was used as the base for the first solar still, while the remaining three stills were based on a composite sheet attached to a galvanized steel sheet.

III. METHODOLOGY AND EXPERIMENTAL SET UP

The experimental setup consists in 4 devices:

- Solar still combined to a condenser
- Compressor
- Thermometer
- Graduated bottle

A. Solar still

The placement of solar still is key here, the side with transparent glass section is placed facing South direction while the opaque triangular section must face north. The actual picture of experimental setup is shown in fig below:

B. Conventional still with saline water

C. Thermocouple wire used

The thermocouple used here to measure the temperature at different parts of the still is a K-type thermocouple. The thermocouple works on the principle of the Seebeck effect, according to which "when two different metals are connected in two junctions and both junctions are kept at different temperatures, then a voltage is induced in the circuit" this voltage can be used to calculate/measure the temperature of the hot section. A thermocouple helps in plotting the temperature distribution in different parts of the still.

D. Sun Meter

A sun meter is used to measure the intensity of incident solar radiation during the experiment. The intensity of sunlight affects the amount of distillate produced by the still. In general, it varies in direct proportion to the intensity of the radiation.

E. Temperature Indicator

The temperature indicator used here has a least count of 10 C and have 12 channels which allow us to take reading at 12 different sections at once.

F. Solar still efficiency

There are two types of efficiency of solar radiators: hourly efficiency and daily efficiency. The hourly efficiency reflects the ratio between the average latent heat generated by the produced water per hour and the total amount of solar energy absorbed. Fluctuations in solar radiation during the day naturally cause hourly fluctuations in the efficiency of the solar distillate.

$$\text{Efficiency } (\eta) = (M \times L)/(A \times I)$$

Where,
M = yield in Kg/s
L = Latent heat of vaporization in J/Kg
A = Area of base of still in m2
I = Intensity of radiation in W/m2

IV. RESULTS AND DISCUSSION

Experimentation took place during the sunny days of June 13, 14, and 15 between 8:00 a.m. and 8:00 p.m.

Experiments were conducted in 1 cm, 2 cm and 3 cm water depths on June 13, 14 and 15 on three different solar stills. One is a conventional solar still whose tilt is arranged along the length, and the other two stills are modified stills whose tilt is arranged along the width.

On the first day in the case of a normal glass cover, water was collected in the main container through an outlet valve with a water level of 1 cm: 630 ml was collected in a conventional still.

On the second day, the collected condensate in 2 cm water depth is 570 ml in case of conventional still, 570 ml in modified still.

On the last day, the experiments were carried out in 3 cm depth of water and amount of condensate using different material as: 505 ml through conventional still.

On all three days, the solar intensity was also measured in the time interval between 8:00 and 20:00. On the first day, the maximum solar intensity was 1150 W/m² at 13:00. On the second day, the maximum solar intensity was 1157 W/m² at 13:00 and on the last day, the maximum solar intensity was measured at 1248 W/m² at 13:00.

A k-type thermocouple wire with a digital display unit was used for temperature measurement and these were placed at 5 different points for temperature measurement and another one thermocouple point was arranged for ambient temperature measurement.

Where,
T1 = Bottom surface temperature with black body
T2 = Air temperature inside the solar still
T3 = Inside glass surface temperature
T4 = Outside glass surface temperature
T5 = Atmospheric temperature

Latent heat of vaporization of fluid (L) =

$$2.4935\times10^{6}[1-(9.4779\times10^{-4}\times(T2)+1.3132\times10^{7}\times(T2^{2}) -4.7974\times10^{-9}\times(T_{2})^{3})] \text{ for } T2 < 70oC$$

Measurement of temperature, solar radiation and yield with time atdifferent water level

Graph between Time Temperature and solar radiation at 1 cm of water depth

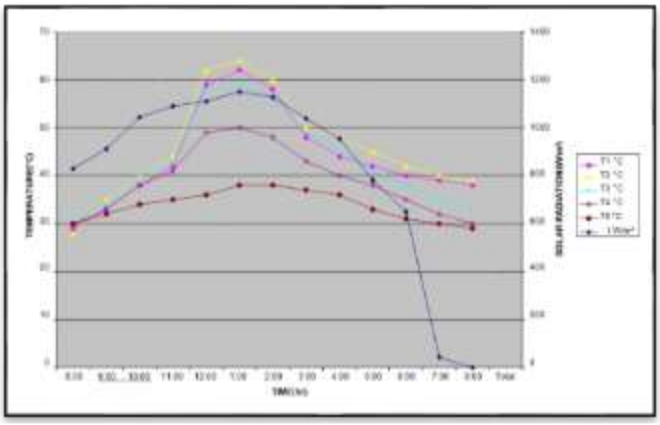

Fig. 5.1: Graph between Time Temperature and Solar radiation at 1 cm water depth

Graph between productivity Time and solar radiation at 1 cm depth of water

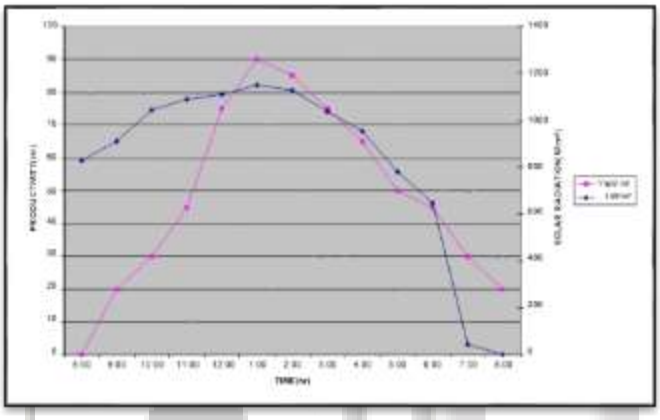

Fig. 5.2: Graph between Time Productivity and Solar radiation at 1 cm depth of water

Graph between efficiency and solar radiation with respect to time at 1 cm depth of water

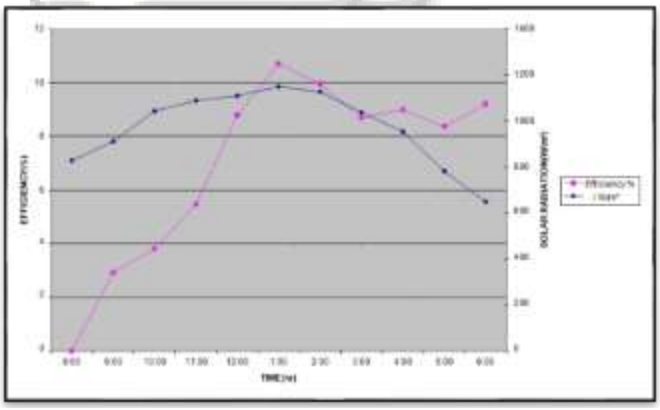

Fig. 5.3: Graph between efficiency and solar radiation with respect to time at 1 cm depth of water

Overall Productivity With Respect To Time

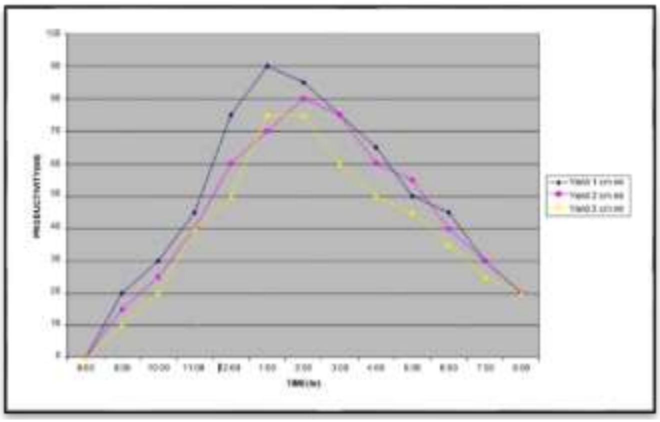

Fig. 5.4: Overall Productivity with respect to Time

The effect of depth water in modified still

Now the modified still there are some changes are done in still.

The basin size 1m x 0.5m x 0.1m has been fabricated with transparent glass of 8 mm thickness. Top cover of the basin is closed with transparent glass of 4 mm thickness at angle 30° inclination from both sides.

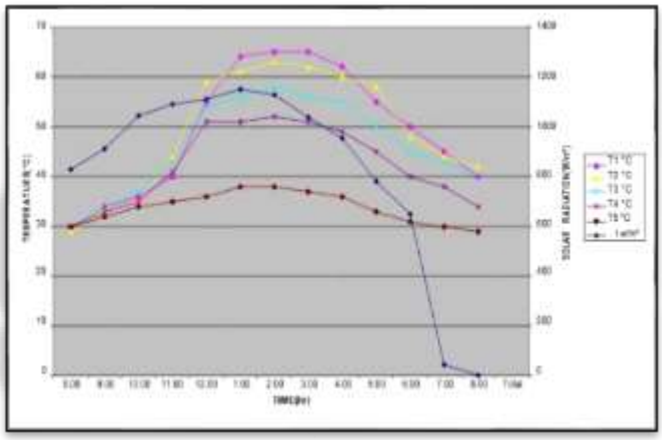

Fig. 5.5: Graph between time and temperature at 1 cm depth of water in modified still

Graph between productivity time and solar radiation at 1 cm depth of water

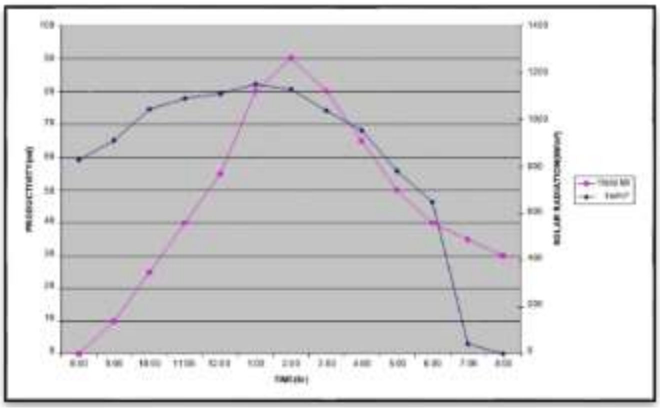

Fig. 5.6: Graph between Productivity Time and Solar radiation at 1 cm depth of water

Graph between efficiency and solar radiation with respect to time at 1 cm depth of water

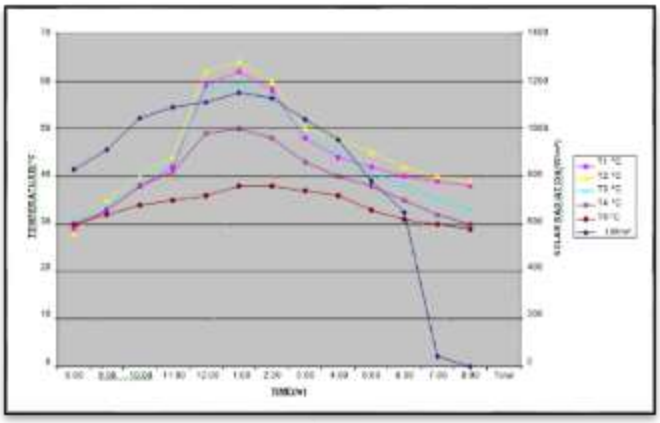

Fig. 5.7: Graph between efficiency and solar radiation with respect to time at 1 cm depth of water

Overall productivity with respect to time

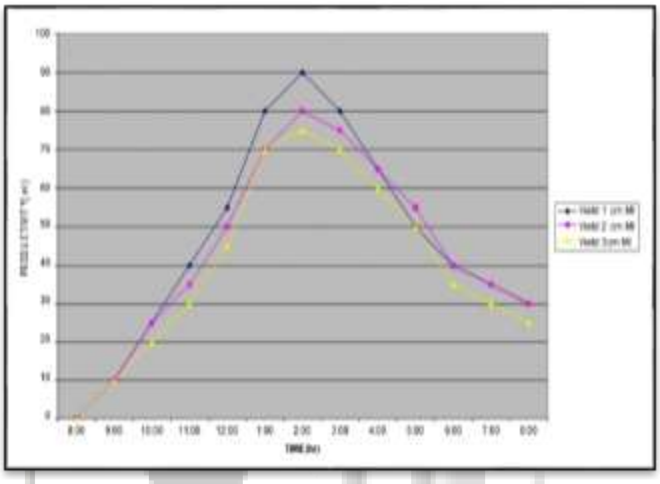

Fig. 5.8: Overall Productivity with respect to Time

V. CONCLUSION

This project consists of two double slope single basin passive solar stills water is used in both stills i.e. a conventional still and non-conventional. Observations have been noted during the experiments and from the analysis of results which came and graphs were plotted with respect to respective parameters are as follows.

- In terms of yield, maximum conversion of water is obtained from Horizontally Double Sloped solar still with 780ml of pure water at 1 cm depth of saline water, which is in comparison 34.48%
- The efficiencies get maximum by 10.37% when non-conventional solar still is used with only saline water at 2 PM. on using conventional still with saline water at 1cm it gives 9.17% at 1 PM.
- In terms of efficiency, it is observed that the overall maximum efficiency is obtained by Horizontally Double Sloped solar still is 10.37% which is 13.08% higher than the yield of conventional still using water
- So, it can be concluded that the Horizontally Double Sloped solar still is more optimized still for the production of pure water by using single basin double slope passive solar still.

VI. FUTURE SCOPE

There is always an opportunity to more explore a one technique from one level to other level. The more exploration is required to optimize the existing technique and to make it more efficient. In this project, future opportunities to make it more authentic and optimized are as follows,

- For this project, to get the exact results of the experiment and to validate the experimental results, thermal analysis with help of computational fluid dynamics can be done.
- By taking reference of these readings obtained by using different material, the new materials can also be used and investigated the performance of still.
- In this project, only conventional design of still is used with some storage material. In future, the more comparison can be obtained by using different designs with same materials
- At present, the storage materials are used individually in each still but, for more exploration mix of two or more material can be used to investigate the efficiency and productivity and comparison could be done.

REFERENCES

[1] Zakaria haddad, Abla and Ahmed Rahmani "Improving the basin type solar still performance using a vertical rotating wick" Desalination 418 (2017) 71-78.
[2] Kamel Rabhi, Rached Nciri, Faozi Nasri, Chaouki Ali and Habib Ben Bacha "Experimental performance analysis of a single basin single slope solarstill with pin absorber and condenser" Desalination 416 (2017) 86-93.
[3] Hitesh Panchal and Indra Mohan "Various methods applied to solar still for enhancement of distillate output" Desalination 415 (2017) 76-89/
[4] Barsharat Jamil and Naiem Akhtar "Effect of specific height on the performance ofa single slope solar still: An experimental study" Desalination 414 (2017) 73-88.
[5] Ravi Shankar Sathyamurty, P.K. Nagarajan and B. Madhu" A Review of integrating solar collectors to solar still" Renewable and Sustainable Energy Reviews 77 (2017) 1069-1097.
[6] Nisrin Abdelal and Yazan Taamneh "Enhancementof pyramid solar still productivity using absorber plates made of carbon fiber/CNT – modified epoxy composites" Desalination 419 (2017) 117-124.
[7] M.H. Sellami, T. Belkins and M.L. Aliouar "Improvement of solar still performance by covering absorber with blackened layers of sponge" Groundwater forSustainable Development 5 (2017) 111- 117.
[8] Lovedeep Sahota and G.N. Tiwari "Ëffect of nanofluids on the performance of passive double slope solar still: A comparative study using characterstic curve" Desalination 388 920160 9-21.
[9] P. Vishwanath Kumar, Anil Kumar, Om Prakash and Ajay Kumar Kaviti "Solar still system design: A review", Renewable and sustainable energy resources.
[10] Ali F. Muftah, M.A. Alghoul n, Ahmad Fudholi, M.M. Abdul Majeed and K. Sopian "Factorsaffecting basin type solar still productivity: A detailed review""'Renewable and Sustainable Energy Reviews.
[11] K.R. Ranjan1, S.C. Koushik1 and N.L. Panwar1 "Energy and exergy analysis of passive solar distillation systems",

International Journal of Low-Carbon Technologies 2016, 11, 211–221.
[12] A.K. Sethi & V.K. Dwivedi (2012) ‘Evaluation of internal heat transfer coefficient of Double Slope Active Solar Still under forced circulation mode, International Journal of Engineering Research & Technology (IJERT), Vol. 1 Issue 8, 1-5.
[13] M.R. Rajamanickam, A. Ragupathy “Influence of Water Depth on Internal Heat and Mass Transfer in a Double Slope Solar Still”, Energy Procedia 14 (2012) 1701 – 1708.
[14] Rahul Dev, H.N. Singh, G.N. Tiwari. ―Characteristic equation of double slope passive solar still‖. Desalination 267:261–266, 2011.
[15] Kalidasa Murugavel, K., Sivakumar, S. Riaz Ahamed, J., Chockalingam, Kn. K. S. K., and Srithar, K., “Single basin double slope solar still with minimum basin depth and energy storing materials”, Applied energy, Vol.87, pp.514-523, 2010.
[16] Pro Abhishek Kumar and Shubham Dwivedi, “An Experimental Approach to Increase Efficiency of Modified Solar Still and Comparison between Conventional, Modified and Modified Solar Still using Iron as Heat Storage Medium”, IJSRD, Vol. 7, Issue 09, 2020
[17] T. Arunkumar, R. Velraj, D.C. Denkenberger, Ravishankar Sathyamurthy, K. Vinoth Kumar, Amimul Ahsan, Productivity enhancements of compound parabolic concentrator tubular solar stills, Renew. Energy 88 (2016) 391–400, http://dx.doi.org/10.1016/j.renene.2015.11.051.
[18] Mohamed A. Eltawil, Z.M. Omara, Enhancing the solar still performance using solar photovoltaic, flat plate collector and hot air, Desalination 349 (2014) 1–9, http://dx.doi.org/10.1016/j.desal.2014.06.021.
[19] A. El-Bahi, D. Inan, A solar still with minimum inclination, coupled to an outside condenser, Desalination 123 (1999) 79–83, http://dx.doi.org/10.1016/S0011- 9164(99)00061-2.
[20] Mohamed Mustapha Belhadj, Hamza Bouguettaia, Yacine Marif, Moussa Zerrouki, Numerical study of a double-slope solar still coupled with capillary film condenser in south Algeria, Energy Convers. Manag. 94 (2015) 245–252, http://dx.doi.org/10.1016/j.enconman.2015.01.069.
[21] Ahmed Rahmani, Abdelouahab Boutriaa, Amar Hadef, An experimental approach to improve the basin type solar still using an integrated natural circulation loop, Energy Convers. Manag. 93 (2015) 298–308, http://dx.doi.org/10.1016/j. enconman.2015.01.026.
[22] Chang-Dae Park, Byung-Ju Lim, Kyung-Yul Chung, Sung-Soo Lee, Young-Man Kim, Experimental evaluation of hybrid solar still using waste heat, Desalination 379 (2016) 1–9, http://dx.doi.org/10.1016/j.desal.2015.10.004.
[23] G.N. Tiwari, J.K. Yadav, D.B. Singh, I.M. Al-Helal, Ahmed Mahmod Abdel-Ghany, Exergoeconomic and enviroeconomic analyses of partially covered photovoltaic flat plate collector active solar distillation system, Desalination 367 (2015) 186–196, http://dx.doi.org/10.1016/j.desal.2015.04.010.
[24] S.W. Sharshir, Guilong Peng, Nuo Yang, Mohamed A. Eltawil, Mohamed Kamal Ahmed Ali, A.E. Kabeel, A hybrid desalination system using humidification dehumidification and solar stills integrated with evacuated solar water heater, Energy Convers. Manag. 124 (2016) 287–296, http://dx.doi.org/10.1016/j. enconman.2016.07.028.
[25] K. Murase, Y. Yamagishi, K. Tano, Development of a hybrid solar distillator of a basin type distillator and a membrane distillator, Desalin. Water Treat. 9 (1–3) (2009) 96–104, http://dx.doi.org/10.5004/dwt.2009.757.
[26] S.A. El-Agouz, Experimental investigation of stepped solar still with continuous water circulation, Energy Convers. Manag. 86 (2014) 186–193, http://dx.doi.org/10.1016/j.enconman.2014.05.021.