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Recent Advances in Productivity enhancement of Solar still: A review

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Abstract **Due to more increase in population and also industrial growth, peoples who living in a remote village they suffer shortage of fresh drinking water. Peoples who lives in urban as well as rural areas depends on surface water or ground water resources are mostly polluted by industrial waste. The utilization with the reverse-osmosis (RO) techniques and also other traditional techniques are so costlier method or requires a very large lands area. An economical way to converting the saline water in to the fresh water by using solar energy. Solar distiller desalination is the one and only method to converting saline water into fresh usable water with the 'evaporation and condensation. Many researchers come out and studies on the solar distiller desalination methods and this paper corresponds a review about the Nano particles utilized in solar stills to improve productivity.:**

Keywords — Phase change material, Nanoparticles, Solar still, Productivity

I. INTRODUCTION

Water have no alternative for the survival of humans. Approximately 70% of the earth covers by water, and 90% of that water is salt water and isn`t applicable for drinking purposes. Not only human water is also consuming by industrial and agricultural needs. Imbalance of demand and supply of water is due to increasing human's growth and as well as industrial grout with increasing water consumption. That is fact all most available earth water is not generally pure and not good for drinking purpose and needs treatment. The plan to make available fresh water is a continuously a major problem in many places of the earth. Sea is only feasible source for big amount of water need. But high salt contains in sea water, so we need to pure this water. There are lot of process for purifying brackish water to usable water [1] fresh water is still the big issue at many places of the earth most of in arid remote areas [2].

Water distillation is one of human's most primitive type of water refine process, and it`s popular process in all over world till the day [3] [4]. On earth with solar desalination rain water produces when solar radiation is absorbed by the sea and water evaporate. The evaporated water rises above the earth surface and is moved by the wind. When this vapour`s temperature goes down to its dewpoint temperature, condensation of water occurs, and the freshwater comes down on earth as rain. This basic process is responsible for the hydrological cycle of earth. This same phenomime is used at all type of distillation systems with utilising alternative energy resources for cooling and heating.

Desalination process use big amount of green energy to pure water from a salted water source. The fossil fuels create pollution on environment and the availability of fossil fuel is limited. In solar desalination solar distiller is a device use widely produce fresh water from brackish and saline water with use solar energy. solar still is a simple device, manufacturing is easy and less maintenance require, it is low costly but not suitable for use because productivity of still is very low. There are many solar distillation systems are designed in many years using the above principle of water desalination in different part of world. Many researchers analyzed the works out on the solar still.

Murugaval et al [5] has studied about enhancing the efficiency with single basin still with passive method. Murugaval et al. prove that the use of heat storing material, reducing water depth in basin, wick material, improve efficiency of solar still. Velmurugan and Srithar [8] Studied about the different factors which are affect output of stills. Sampathkumar et al. [6] also made a detailed study by using active solar still. Theoretical modelling and analysis with active stills were discuss. Varun and Aayush Error! Reference source not found. review about stills. Productivity of solar still depends on many parameters likewise water depth in basin [10][11][12], water and glass temperature differences [14], insulation of still [13], wind speed [15], ambient air temperature [16], and solar irradiation [17]. Thickness and angle of glass were studied by Tiwari et al. [33], Boodhan and Haraksingh et al. [34] and El–Maghlany (2015) [35]. Heat storage materials (sensible and latent) are used in the still in order to store the energy in sunshine hours and release it in evening hours to

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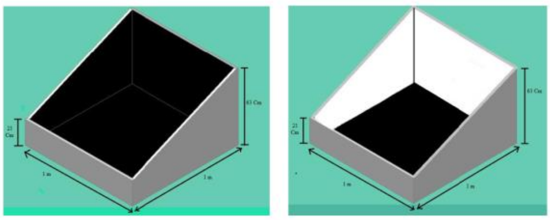
increase the productivity output. Phase change material (PCM) has been used in a solar still that stores the energy in the form of latent heat. The increased productivity has been observed at the still embedded PCM packed at the basin. Also, it has been reported that choice of PCM depends with maximum temperature of basin water.

II. NANO PARTICLES IN SOLAR STILL

Bhupendra Gupta et al. [22] investigated passive solar still by adding nanoparticles in changed still has painted sides wall with Wight color. Nanoparticles enhance thermal fluid increase the area affecting for heat transfer. CuO nanoparticle are utilized in changed still to enhance productivity and efficiency of still. Experiments are performed at two different water depth with 5cm and 10cm. Nanoparticles ware added 0.12% by weight in paint. White painted walls of still dicers the heat loss to atmosphere and will increase the productivity of changed still. Changed solar still with added nanoparticles and traditional solar still produces 3445.0 ml/m2 day and 2814.0 ml/m2 day at water depth of 5 cm whereas 3058.0 ml/m2 day and 2351.0 ml/m2 day at depth of 10 cm severally. Productivity in changed still is 22.4% with conventional still at water depth of 5 cm.



a) Perspective view of conventional still. b)Perspective view of modified still.

Lovedeep Sahota et al 2016[23] has done improvement in output of double slope passive still with Al_2O_3 nanoparticles within the water for two different masses 35 kg and 80 kg. The analytical model of fluid temperature has been derived for double slope solar still. On the idea of developed model, the analysis has been conducted for the water and for water with nanoparticles with three completely different concentrations 0.04%, 0.08% and 0.12%. Result of different fractions of Al_2O_3 nanoparticles on the temperature of fluid, conduction, inside heat transfer coefficients and output of the fluid has conjointly been analyzed. For 0.12% fraction of Al_2O_3 nanoparticles, the improvement of yield for 35 kg and 80 kg base fluid has been found to be 12.2% and 8.4% respectively as compared to it of base fluid.

A.E. Kabeel et al 2013[24] increasing the productivity output of H_2O in solar still performance, the experimental attempt done to boost the solar still productivity by use of nanofluid and additionally by integration of the still basin with external condenser. The use of nanofluid is added nanosized solid particles of aluminum oxide with water. Nanofluids changes the transport properties, heat transfer characteristics and phase change properties of the water. Nanofluids are proposed to enhanced evaporation rate compare with standard water. The heat loss decreases by convection from water to glass because the condenser work as an extra effective heat and mass sink. So, the impact of drawn vapor at completely different speeds was investigated. The results show increase the distillation water yield by 53.2% yield with the solar still with external condenser. And nanofluids improves the solar still water output by concerning 116%, once the still integrated with the external condenser.

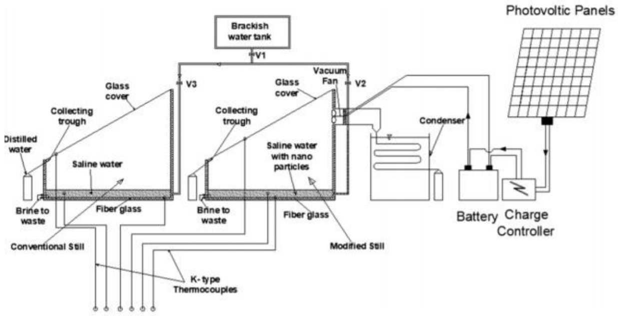


Fig. 2 Lay-out diagram of the experimental setup

S.W. Sharshir et al 2017[25] experimentally investigated to enhance the productivity of solar still. The micro flakes fractions added from 0.125% to 2%. And basin depths of nanofluid are in ranged from 0.25 to 5 cm. Whereas, the flow rate for glass cooling are ranged from 1 and 12 kg/h. The results they got shows the solar still output is increased by 44.91% and 53.95% by using copper oxide and graphite`s micro flakes, severally, compared with the traditional solar still without micro-flakes. just in case of using the water over the glass cover, as a feed water, the output yield is improved by regarding 47.80% and 57.60% using copper oxide and graphite particles, respectively while the daily efficiency of the traditional still is 30%. Moreover, the daily output of distill water, 38 % and 40 % are obtained once using oxide and graphite, severally, while no film cooling use in glass. Finally, the stills' daily output first using copper oxide and graphite micro flakes with film cooling in glass are 46.00% and 49.00% respectively.

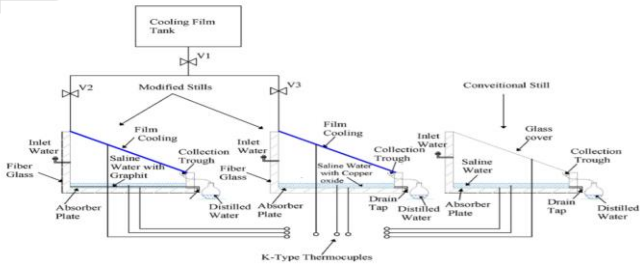


Fig. 3 Schematic diagram of experimental setup

III. PHASE CHANGE MATERIAL (PCM) IN SOLAR STILL

Ravishankar Sathyamuthy et. al 2014 [18] performed the by experiment to study the the impact of water quantity on the output of triangular type pyramid solar distillation without and with heat storage. For compare the productivity of solar still with and while not PCM a solar distiller is intended, fabricated. Experiments are performed in high temperature and humidified climate in Chennai, India. It`s

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shows that there's a rise of output of water and decrease in water quantity. There's a rise of regarding 35 in production of water with PCM and solar distiller while not PCM. Additionally, it`s found that after sunset water output from the distiller is higher than the higher water mass. The solar distiller with and while not PCM were seen to be 5.50 L/m2. day and 3.50 L/m^2 day.

A.E. Kabeel et al 2016 [19] performed the experiment to enhance the working of solar distiller that can increse productivity of freshwater. So as to enhance the output of a solar still, a phase transition material (PCM) was added as a heat medium. They designed two solar stills, made and tested within the experimental study to check the output from the solar desalinization system. One is solar distiller with the PCM and another is standard solar still. From the experimental result, the everyday fresh water output for solar distiller with PCM is beyond that of standard solar still. The daily fresh productivity some reached 7.54 L/m2 day for solar distiller with PCM, while its worth is recorded 4.51 L/m2 day for the traditional solar distiller. The results show that the everyday freshwater productivity for solar distiller with PCM is 67.18% more that of the traditional solar still. Also, the solar distiller with PCM is effective in everyday freshwater productivity with 67%-68.8% enhancement compared to a traditional solar still within the amount from June to July 2015 underneath the ambient conditions of Tanta town (Egypt).

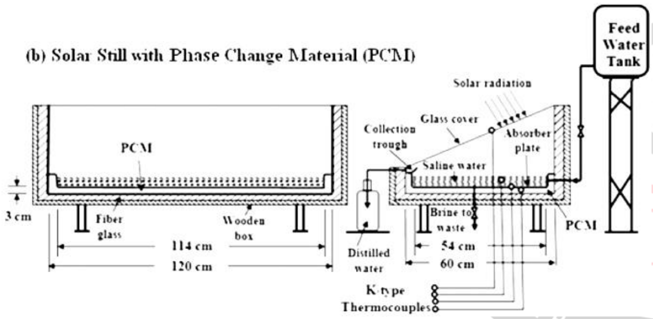

Fig. 4 Schematic diagram of the experimental work.

Mohamed et. al 2018[20] studied the efficiency of single slope distiller in addition to phase transition material like heat storage unit and it`s of specifically results with output of distiller showing , totally different cases are thought, Case 1: solar still while not phase transition material (conventional solar still), Case 2: solar still coupled only with phase transition material connected to the still base, Case 3: solar distiller with hollow cylindrical pin fins embedded within the phase transition material, case 4: solar distiller with phase transition material and wire wool fibres within the distiller basin and case 5: solar still with only steel fibres within still basin. The performance of the solar still for the 5 cases is through an experiment evaluated and compared to every other below the identical climate conditions of latest Borg town, Egypt. The results disclosed that the use of phase transition material not give positively results in the daytime freshwater output with a major encasement within the overall freshwater yield of distiller. Moreover, use of wire fibres within the basin with a phase transition material based mostly solar distiller (case 4) increase the entire daytime freshwater output by 140% with a drop by the overnight productivity by 80%, compared to case two. From all tested cases the case five achieves the best accumulated everyday freshwater productivity (approximately 25 some improvement within the everyday productivity compared to case 1) and thermal efficiency with minimum value.

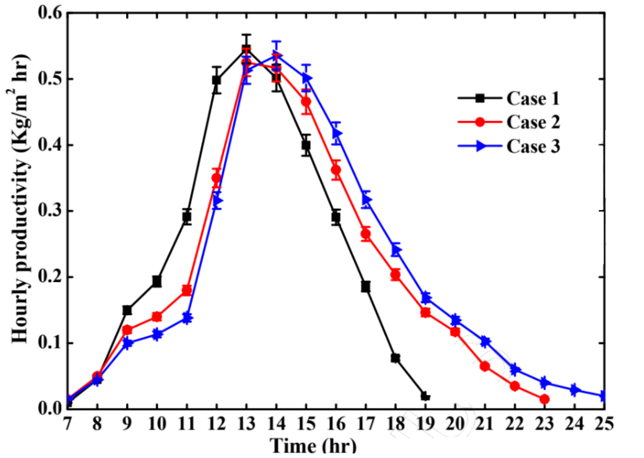

Fig. 5 The rate of hourly freshwater productivity along the day for the three cases 1, 2 and 3

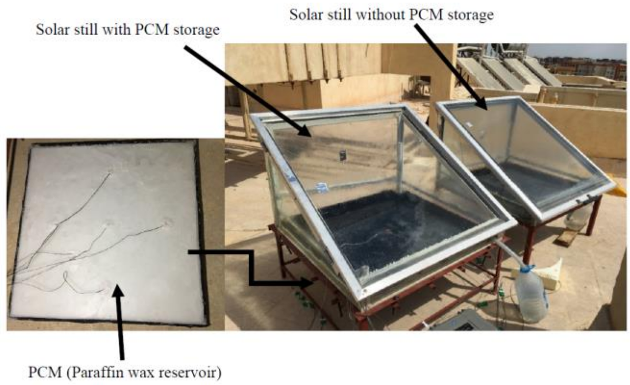

Fig. 6 A photographic of the experimental setup of the solar still with PCM

A.E. Kabeel et. al 2017[21] studied with a changed pyramid solar distiller with v-corrugated absorbers plate and PCM and without PCM is created and fancied below the identical in ambient atmosphere at Tanta town, Egypt. The output of the modified pyramid distiller within the v-corrugated basin plate with PCM and without PCM consensual distiller, to explain the improvement within the output with the changed pyramid distiller compare with PCM.

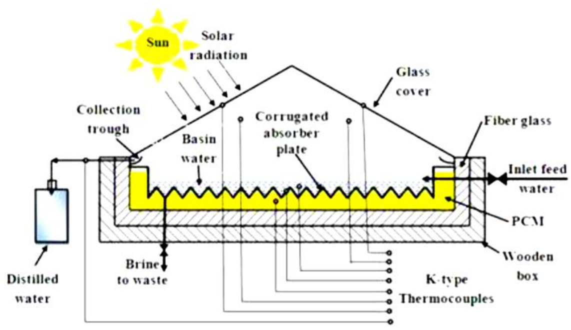

Fig. 7 Modified pyramid still with PCM

From the experimental data the output distillation through changed pyramid distiller with PCM is more than standard

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pyramid still. The accumulated distillation yield reached close to 6.6 L/m^2d^1 for modified pyramid still with PCM whereas its worth was 3.5L/m^2d^1 for standard pyramid still. The v-corrugated plate use in basin as absorbers plate on the PCM in basin improve the output distillation productivity of a changed pyramid still with PCM at 87.40% compared with traditional pyramid distiller. And also, the changed pyramid distiller embedded PCM is batter at daily efficiency up to 86.41% - 88% enhancement compared with traditional pyramid distiller.

IV. PHASE CHANGE PHASE CHANGE MATERIAL AND NANOPARTICLE

To overcome limitations of the conventional solar systems with a low efficiency, this systems using the nanoparticles with the base fluid as a heat transfer media has been proposed by HK Gupta et al 2013. Mixing of nanoparticles in the base improves the optical and thermo physical properties of the base liquids[35][36][37]

The output of solar distiller with NPCM has been investigated by S. Shanmugan et. al 2018 [26] they gain the yield with wick materials and in basin of solar distiller with PCM and also Nanoparticle as FWCW is 7.46 kg m^{-2} day^{-1} & 4.12 kg m^{-2} day^{-1}, severally.

In this study, S.W. Sharshir et al 2017[27] modified the standard solar still. The outside performance of changed solar distillers was studied to check its potential for real life application. The modifications embrace victimisation flake black lead nanoparticles (FGN), natural action material (PCM), and film cooling. within the addition of the 3 previous modifications, the productivity was increased as high as 73.8% compared therewith of the standard still.

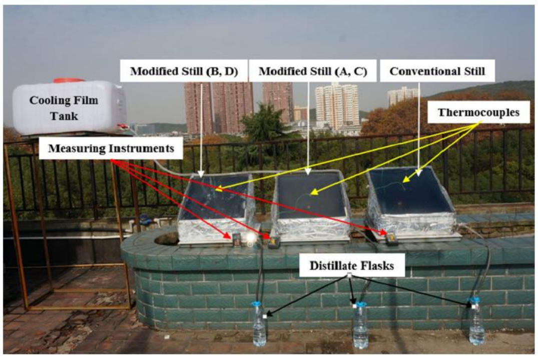

Fig. 8 Photograph of the experimental setup.

The simple mixture technique for using FGN in solar distillers was proved to be more effective. The improvement in output of the distiller with FGN [type (A)], FGN with PCM [type (B)] FGN and also film cooling [type(C)], FGN, PCM and with film cooling [type (D)] are 50.28 %, 65.00 %, 56.15 %, 73.80 %, severally.

Hemin Thakkar, et al 2015[28] investigate performance on solar distiller Integrated with Nano Particles with and while not use of paraffin as a phase transition material

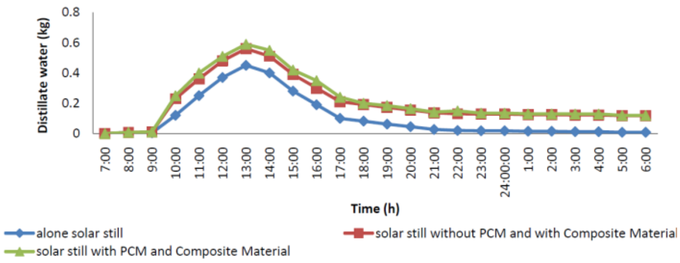

Fig. 9 hourly distillate output of solar stills

For this analysis of performance, 3 identical one square meter space solar stills have used. 1st solar distiller integrated with Nano particles and PCM, another with only Nano-composites and third one is while not Nano-composites and PCM. For the preparation of Nano particles aluminum oxide is employed and coated on the surface of the absorbent plate. It's found that, solar distiller embedded with Nano particles 92% more productive found against traditional solar distiller and only Nano-composites integrated solar still is 106 % more productive compared with traditional solar still.

Gupta et al. (2017) [29] created traditional and improved solar distillers having the identical dimensions. The modified still in Fig.8 is with cooling film in glass and CuO nanomaterials. Results reveal that the improved still turn out 4000 ml/m^2 per day of fresh water, whereas its productivity has achieved 34 % to the traditional manufacturer.

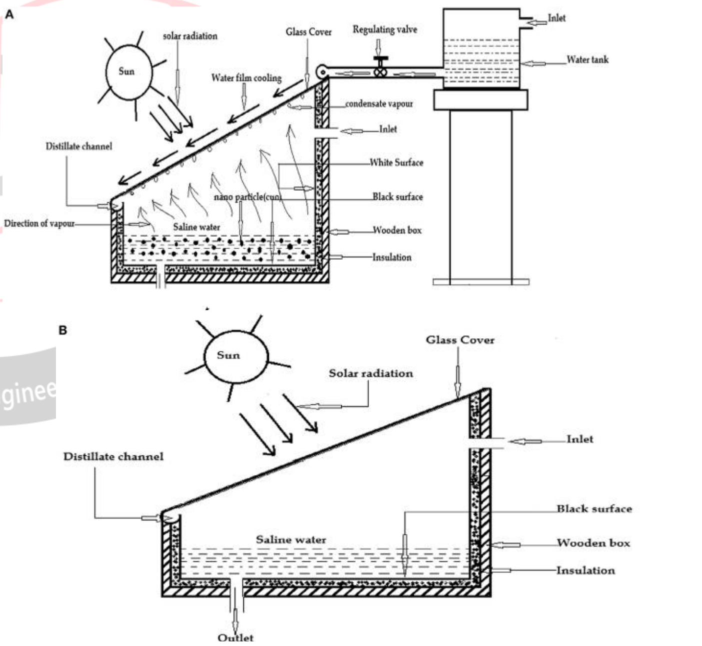

Fig.10

(a) Enhanced solar still (b) Traditional solar distiller.

V. PHASE CHANGE MATERIAL WITH NANO PARTICLES

Nanoparticles were mixed in paraffin wax (as a phase change material) to increase the thermal conductivity and hance the productivity compared with base material.

A. Phase change material and Al_2O_3 nanoparticles

A comparative study has been done by Miqdam Tariq Chaichan et al 2018[30] the blending of nanoparticles with the wax changes the thermophysical properties of the used wax. The thermophysical properties as density, viscosity, and thermal conduction showed increasing values in

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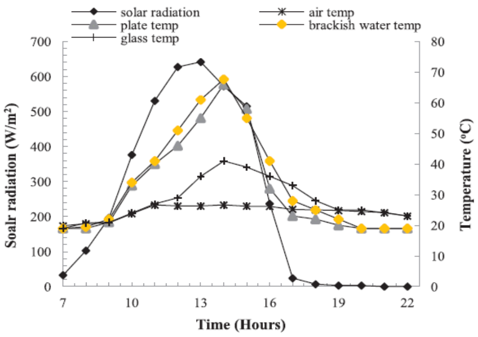
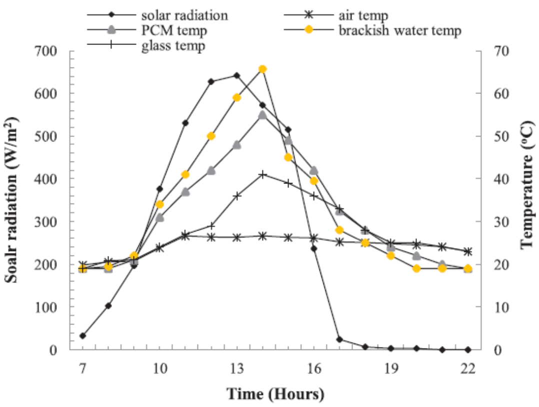
distinction to the particular heat wherever it reduced comparatively. 3 distillers were created to check the impact of addition these nanoparticles to solar still. The primary of that was with none modification and therefore the second had paraffin wax as further material. within the third distiller, a mixture of paraffin with a Nano particles aluminum oxide unfold on that was improve thermal conduction. The improvement of nanoparticles with wax accrued considerably the speed of heat transfer, leading to higher output of the solar still. paraffin wax in still increase daily freshwater output to 10.38 % while the enhancement of Nano particles aluminum oxide to paraffin with improved still deliver up to 60.53 % compared to the simple still output because of everyday distillation when the sunset. Graphs shows the temperature variation of the distillers' variable elements compared to the air temperature and solar intensity.



A- Distiller 1



B- Distiller 2

Fig. 11 A three months daily average temperatures variation with time for the tested distillers

B. Phase change material and CuO nanoparticles

Dsilva winfred et at 2017[31] study with solar still is made-up one by one with phase transition material (PCM) and phase change material with nanoparticles (NPCM) and analysed each by experimentation and in theory. It found that the solar distiller with PCM give output 1.96 kg/0.5m^2 where the solar distiller with NPCM give output 2.64 kg/0.5m^2. There was 35 % enhancement in productivity discovered in solar distiller with NPCM as compare with solar distiller with PCM. 0.3 w/w% of copper oxide nanoparticles are inseminated in paraffin one by one to create NPCM.

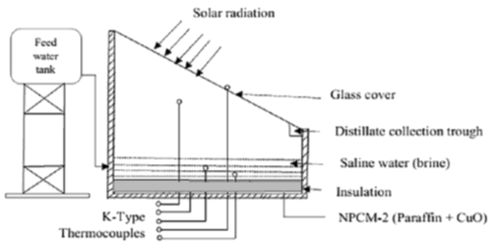


Fig. 12 Solar still with CuO nanoparticles enhanced phase change material

As per fig 12 it's shows that the hourly productivity of solar still with NPCM is above that of the solar still with PCM. It's found that originally (up to 12:00 PM), there was only a minor distinction within the productivity of two stills, because the time takings, discharging of PCM and NPCM happens, the still with NPCM produces a lot of condensation hourly because it melting and solidifying rate was more than that of PCM.

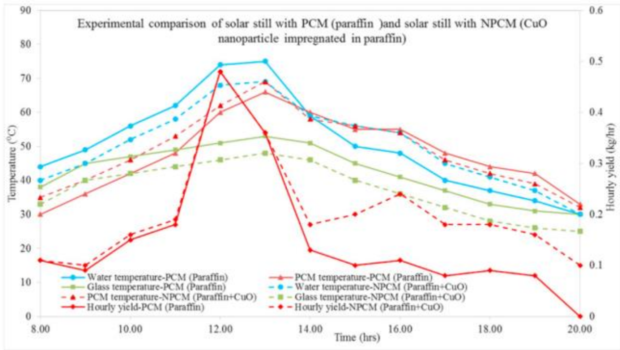


Fig. 13 Experimental comparison of solar distiller with PCM and solar distiller with NPCM(CuO)

C. Phase change material and TiO2 nanoparticles

The performance of solar still with NPCM has been investigated by Dsilva Winfred [32], four solar still has been made-up with PCM, NPCM-1(CuO), NPCM-2(TiO$_2$), NPCM-3(GO), the addition of nanoparticles increases the melting and solidification temperature of the pcm.

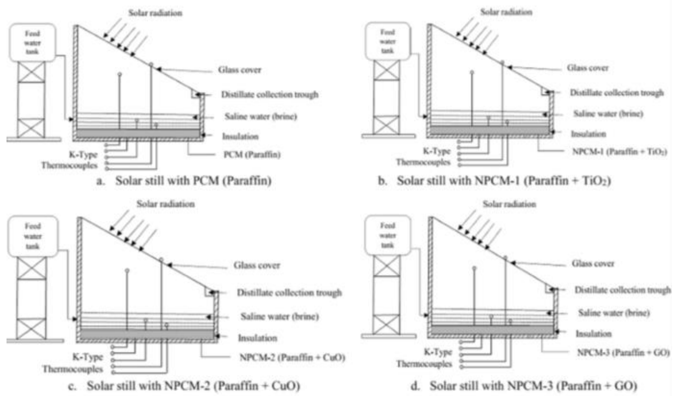


Fig. 14 Overall comparison chart

Addition of TiO$_2$ increase the thermal conduction of pcm by 25%. Productivity of solar still accrued by 26% as compared to pcm without nanoparticles and 39.3% as compared to traditional solar still.

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D. *Phase change material and GO nanoparticles*

The performance of solar still with NPCM has been investigated by Dsilva Winfred [32], Addition of GO will increase the thermal conduction of pcm by 101%. Productivity of solar still is increase by 18% as to traditional solar still. while NPCM3 contains a highest conductivity, it's an occasional productivity thanks to its pour latent heat thus it's not potential candidate to be used in solar still.

Author	Nano-particles	Productivity increment	Solar still area	Weight fraction
Dsilva Winfred [31]	CuO	*35.05 %	0.5 m^2	0.3 %
Miqdam Tariq[30]	Al_2O_3	60 %	1 m^2	0.5%
Dsilva Winfred [32]	TiO_3 CuO GO	39.3 % 43.2 % 18 %	0.5 m^2	0.3%

TABLE I

*compare to solar still with pcm.

VI. CONCLUSION

The addition of nanoparticles decreases the melting and solidification temperature of phase transition material (PCM) and additionally improve the thermal conduction. High conduction increases the melting time of pcm and additional latent heat offers more heat throughout the solidification.

PCM can represent a supply of heat for the basin water to keep the temperature distinction with the outer glass. For this purpose, it's suggested to merge the PCM within the solar still to provide the heat to water once after sunset. The experimental data prove that the daily distill water output for the solar still with PCM is more than that of the standard solar still.

Use of nanoparticles in phase transition materials has higher potential as against the utilization of virgin phase change material in solar still applications Productivity of solar still inflated with addition of nanoparticles within the PCM with different nanoparticles as Al2O3 TiO3, CuO and GO is 60, 39.3, 43.2,18% respectively. Even though GO has the highest thermal conductivity, it has less output because of its less latent heat. With GO nanoparticles solar distiller shows poor annual productivity. Hence it`s not recommend for solar distiller applications.

REFERENCES

[1] Sukhamte SP. Solar energy: principle of thermal collection and storage. New Delhi: Tata-McGrawth-Hill; 1987.

[2] Tiwari GN. Solar energy: fundamentals, design, modeling and application. New York/New Delhi: CRC Press/Narosa Publishing House; 2003

[3] Kalogirou SA. Seawater desalination using renewable energy sources. Prog Energy Combust Sci 2005;31:242–81.

[4] Bund schuh, Bund schuh J, Mahmoodi H, Goose MFA. Renewable energy-driven desalination technologies: a comprehensive review on challenges and potential applications of integrated systems. Desalination 2015; 356:94–114

[5] Olango, T., Margrave, K., 2015. The effect of the water depth on the productivity for single and double basin double slope glass solar stills. Desalination 359, 82–91.

[6] K. Sampath Kumar, P. Senthil Kumar, Utilization of solar water heater in a single basin solar still — an experimental study, Desalination 297 (2012) 8–19.

[7] Kaushal Aayush, Varun. Solar Stills: a review. Renewable and Sustainable Energy Reviews 2010 ;14 (1): 446–53

[8] V. Velmurugan, M. Gopalakrishnan, R. Raghu, K. Srithar, Single basin solar still with fin for enhancing productivity, J. Energy Convers. Manage. 49 (2008) 2602–2608.

[9] S.A. El-Agouz, Y.A.F. El-Samadony, A.E. Kabeel, Performance evaluation of a continuous flow inclined solar still desalination system, Energy Convers.Manag. 101 (2015) 606–615.

[10] Rajamanickam MR, Ragupathy A. Influence of water depth on internal heat and mass transfer in a double slope solar still. Energy Procedia 2012; 14:1701–8.

[11] Suneja S, Tiwari GN. Effect of water depth on the performance of an inverted absorber double basin solar still. Energy Convers Manag 1999; 40:1885–97.

[12] Murugavel KK, Sivakumar S, Ahamed JR, Chockalingam KKSK, Srithar K. Single basin double slope solar still with minimum basin depth and energy storing materials. Appl Energy 2010; 87:514–23.

[13] Arunkumar T, Kabeel AE, Raj K, Denkenberger D, Sathyamurthy R, Ragupathy P, et al. Productivity enhancement of solar still by using porous absorber with bubble-wrap insulation. J Clean Prod 2018; 195:1149–61.

[14] Kabeel AE, El-Agouz SA. Review of researches and developments on solar stills. Desalination 2011; 276:1–12

[15] El-Sebaii AA. Effect of wind speed on some designs of solar stills. Energy Convers Manag 2000; 41:523–38.

[16] Jubran BA. Effect of climatic, design and operational parameters on the yield of a simple solar still. Energy Convers Manag 2002; 43:1639–50.

[17] Trieb F, Müller-Steinhagen H, Kern J, Scharfe J, Kabariti M, Al Taher A. Technologies for large scale seawater dsesalination using concentrated solar radiation. Desalination 2009; 235:33–43

[18] S. Ravishankara, P.K. Nagarajan, D. Vijayakumar, M.K. Jawahar, Phase change material on augmentation

 DOI : 10.18231/2454-9150.2019.0335

of fresh water production using pyramid solar still, Int. J. Renew. Energy Dev. 2 (3) (2013) 1–15.

[19] A.E. Kabeel, Mohamed Abdelgaied Improving the performance of solar still by using PCM as a thermal storage medium under Egyptian conditions Desalination 383 (2016) 22–28

[20] Mohamed S. Yousef, Hamdy Hassan, an experimental work on the performance of single slope solar still incorporated with latent heat storage system in hot climate conditions, Journal of Cleaner Production (2018), doi: 10.1016/j.jclepro.2018.11.120

[21] A.E. Kabeel, Mohamed A. Teamah, Mohamed Abdelgaied, Gmal B. Abdel Aziz, Modified pyramid solar still with v-corrugated absorber plate and PCM as a thermal storagemedium, (2017), doi: 10.1016/j.jclepro.2017.05.195

[22] Bhupendra Gupta, Prem Shankar, Raghvendra Sharma, Prashant Bareda, Performance enhancement using Nano particles in modified Passive solar still, Procedia Technol. 25 (2016) 1209–1216.

[23] Sahota Lovedeep, Tiwari GN. Effect of Al2O3 nanoparticles on the performance of passive double slope solar still. Sol Energy 2016; 130:260–72.

[24] Kabeel AE, Omara ZM, Essa FA. Enhancement of modified solar still integrated with external condenser using nanofluids: an experimental approach. Energy Convers Manage 2014; 78:493–8.

[25] Sharshir, S.W., Peng, G., Wu, L., Yang, N., Essa, F.A., Elsheikhd, A.H., Showgi, I.T.M., Kabeel, A.E., 2017a. Enhancing the solar still performance using nanofluids and glass cover cooling: experimental study. Appl. Therm. Eng. 113, 684–693.

[26] S. Shanmugan, S. Palani, B. Janarthanan, Productivity enhancement of solar still by PCM and Nanoparticles miscellaneous basin absorbing materials, Desalination, Volume 433,2018, Pages 186-198

[27] S.W. Sharshir, Guilong Peng, Lirong Wu, F.A. Essa, A.E. Kabeel, Nuo Yang, The effects of flake graphite nanoparticles, phase change material, and film cooling on the solar still performance. Applied Energy 191 (2017) 358–366

[28] Hemin Thakkar, Dr. Hitesh Panchal, Performance Investigation on Solar Still with PCM and Nano-Composites: Experimental Investigation, 2nd International Conference on Multidisciplinary Research & Practice 2018, 334-339

[29] Gupta, B., Kumar, A., Baredar, P.V., 2017. Experimental investigation on modified solar still using nanoparticles and water sprinkler attachment. Front Mater 4, 23.

[30] Miqdam Tariq Chaichan, Hussein A. Kazem, Single slope solar distillator productivity improvement using phase change material and Al2O3 nanoparticle. Solar Energy 164 (2018) 370–381

[31] Dsilva Winfred Rufuss, D., Iniyan, S., Davies, P.A., 2017a. Nanoparticles Enhanced Phase Change Material (NPCM) as Heat Storage in Solar Still Application for Productivity Enhancement. Energy Procedia 141, 45–49.

[32] D. Dsilva Winfred Rufuss, L. Suganthi, S. Iniyan, P.A. Davies, Effects of nanoparticle-enhanced phase change material (NPCM) on solar still productivity, Journal of Cleaner Production (2018),

[32] Tiwari, G.N., Thomas, J.M., Khan, E., 1994. Optimisation of glass cover inclination for maximum yield in a solar still. Heat Recov. Syst. CHP 14 (4), 447–455

[33] Boodhan, M.K., Haraksingh, I., 2015. An investigation into the effect on the productivity of cascade–type solar distillation systems with varying cover thicknesses and still

[34] El–Maghlany, W.M., 2015. An approach to optimization of double slope solar still geometry for maximum collected solar energy. Alex Eng J 54, 82 828.

[35]HK Gupta, GD Agrawal, J Mathur An overview of Nanofluids: A new media towards green environment International Journal of environmental sciences 3 (1), 433-440

[36]HK Gupta, GD Agrawal, J Mathur Experimental study of water based Al2O3 nanofluid flow in direct absorption solar collector Macromolecular Symposia 357 (1), 30-37

[37]HK Gupta, GD Agrawal, J Mathur Experimental Evaluation of Using Nanofluid in Direct Absorption Solar Collector Energy Technology & Ecological Concerns: A Contemporary Approach, 150-154

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