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Productivity improvement of single basin inclined solar still using enamel coating and copper chips

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ABSTRACT

In the present study an attempt has been made to solve the problem of limited productivity of the conventional single slope horizontal basin solar still by improving its rate of evaporation. The conventional solar still is modified as a single slope inclined basin solar still with improved absorber surface. The absorber surface of the modified solar still is coated with black enamel paint and covered with copper chips. This resulted in augmented evaporation rate and in turn productivity of the system. The modified solar still having same footprint area as that of the conventional horizontal basin single slope solar still is fabricated and tested at Nagpur [21.14° N, 79.08° E] India. The effect of variation of feed water temperature (28°C–60°C) on the productivity of the solar still is also analysed. Theoretical modelling of both modified and conventional still is carried out and the results are compared. Experimentally the modified solar still is proved to be 9.5% more productive as compared with the conventional still. The details of modified solar still, experimental studies and the outcomes are discussed in the article.

Keywords: Solar still collector; Heat transfer enhancement; Productivity of solar still

1. Introduction

Pure water is the world's first and foremost medicine. Water available in rivers, lakes and underground reservoirs has been polluted badly in recent years due to global industrialization, fast growth in agriculture and population. Also, these water resources are not adequate to support life on the earth and may not be able to fulfill the requirement in future. Ground water containing bacteria, pollutants cannot be used for drinking. In addition, there are many coastal regions where water is abundant but the potable water is scarce. Consequently, there is a need to use sustainable energy sources for making ground water more potable, with solar energy being one of the most promising alternatives. Solar distillation systems have been used for several decades for producing drinking water from salt and contaminated water. Solar still, a simple device which can be used to convert saline, brackish water into drinking water is eco-friendly, more economical and easier to maintain. It can provide an attractive alternative solution for getting potable water in remote areas.

Several designs of solar stills have been built over the past century. Development of economical solar still with high productivity is a major challenge. Various researchers worked to improve the productivity of solar still; some of those are by, changing basin geometry [1,2], reducing heat losses in the still [3,4], augmenting heat collection by concentrator and reflectors [5,6], preheating of inlet water [7,8], maintaining optimal flow rate, achieving drop wise condensation [9,10] reducing condenser surface temperature [11–13] use of various heat storage material [14,15] absorber surface texturing [16,17], using external condensers [18,19] etc. Fig. 1 summarizes the various techniques adopted for productivity enhancement. Hansen and Narayanan [20] experimentally investigated the performance of inclined basin solar still with different wick material on different absorber plate configuration. Wire mesh stepped absorber plate configu-

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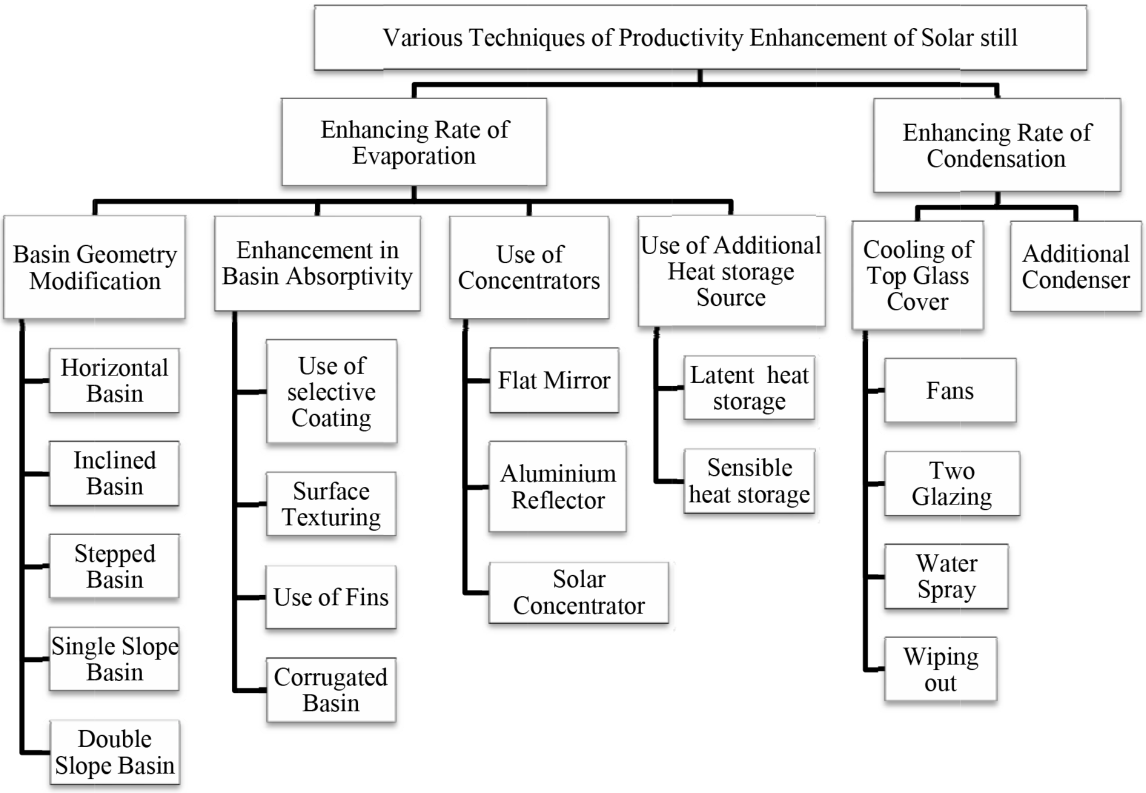

Fig. 1. Techniques of productivity enhancement for conventional solar still.

ration with water coral fleece as wick had given maximum distillate output. Rajaseenivasanet and Nelson [21] analysed the effect of preheating of water using an integrated flat plate collector arrangement. The arrangement resulted in about 60% higher distillate output than the conventional solar still. To increase daily distilled water productivity of the conventional solar still Appadurai and Velmurugan [22] fabricated and tested an innovative design of solar still. Basin of the still was made with attachments like fins and coupled with a mini solar pond. 50% increase in productivity was observed. Kumar and Murugavel [23] studied the effect of agitation and an external condensation on the still. Agitation effect was given by a shaft coupled with a dc motor and an exhaust fan was used to extract the vapour from still to external condenser. The experimental result shows that the modified still enhanced the distillate productivity by 39.49% as compared to the conventional still. Use of heat storage material for off sunshine hour's distillation was made possible by Sebaii and Hazmi [24]. Paraffin wax was selected as phase change material which is kept beneath a corrugated basin. The experiment concluded with a little decrease in the daylight productivity with a considerable increase in the still overnight productivity with the use of PCM.

Productivity improvement of the solar distillation system is a topic of continuous research. A literature review on the various methods used for evaporation augmentation in the inclined basin solar still is carried out and significant recent studies are highlighted in Table 1.

The literature study reveals that there are various techniques used for improvement of the productivity of the inclined basin solar still. However, each of these techniques has its own merits and challenges.

Table 1
Studies on productivity improvement of inclined basin solar still by modifying absorber surface

S. N.	Description of work	Year and Reference
1	An inclined copper-stepped solar still was fabricated and studied under actual meteorological conditions.	2018 [25]
2	The area of the basin is minimized by the utilization of small trays in the stepped solar still.	2018 [26]
3	Flat, grooved and fin shaped absorbers surface configurations were proposed.	2017 [27]
4	Wood pulp paper wick, wicking water coral fleece fabric and polystyrene sponge as wick materials with wire mesh–stepped absorber plate were explored.	2015 [28]
5	V-corrugated absorber single-basin solar still using PCM had been explored.	2016 [29]
6	The fins are supported vertically on the basin of the still using steel wires.	2016 [30]

The present study aimed to demonstrate the cost-effective technique to augment the evaporation rate. In the current study, a simple and economical surface texturing technique is explored. The existing inclined basin solar distillation systems can be retrofitted using the present technique.

The absorber surface of the modified solar still is coated with black enamel paint and covered with copper chips. This resulted in augmented evaporation rate and in turn productivity of the system. The details of experiments are discussed in the subsequent text.

2. Experimental setup

Two identical inclined basin solar stills having same footprint area are fabricated. The conventional single slope horizontal basin solar still is used as a reference case. Whereas another solar still is modified. Fig. 1 shows the schematic of the modified basin solar still. The absorber surface of the modified solar still is inclined and coated with black enamel coating and copper chips (100 gm, 2 mm thick, 5–6 mm width). Both the solar stills have 5 mm thick toughened glass covers inclined at optimum tilt angle of 21° [31]. The water is stored in the horizontal basin of the conventional solar still. Whereas, in the modified solar still the water is made to flow over the absorber surface with a very less flow rate. To ensure the required water flow over the inclined basin, a drip irrigation water pipe is fixed at the top of the absorber surface. Fig. 1 shows the dimensions of the modified solar still. Figs. 2 and 3 show the photographs of the modified solar still.

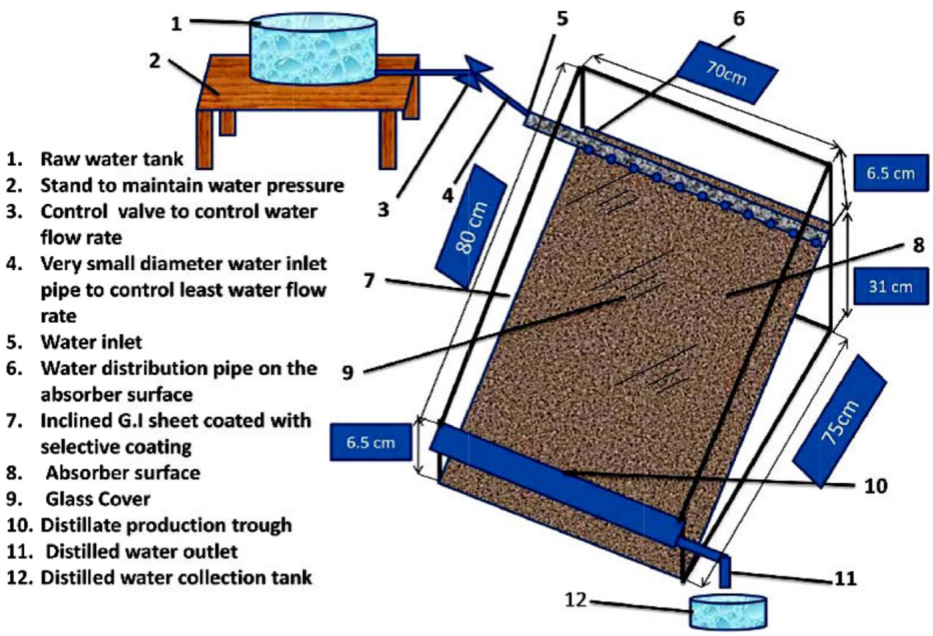

Fig. 2. Schematic of experimental setup.

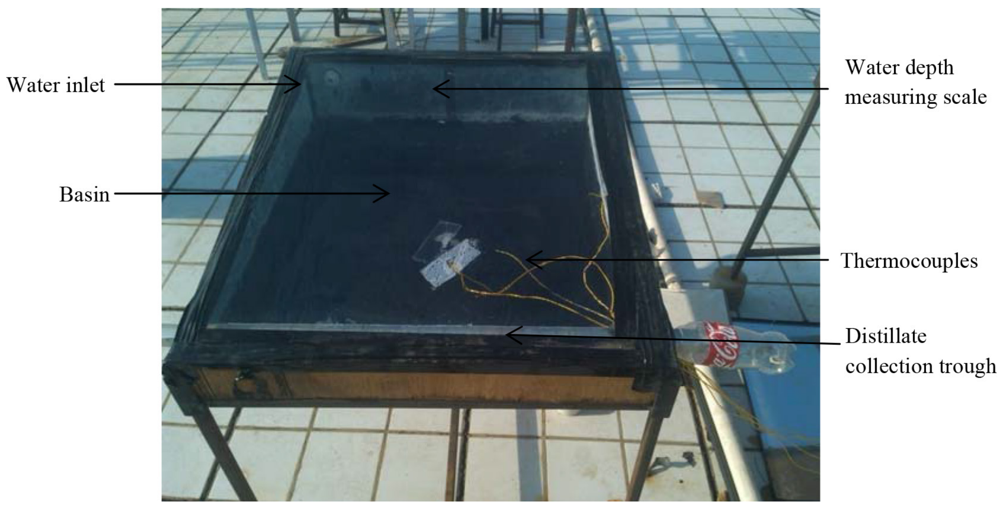

Fig. 3. Experimental setup.

3. Experimental method

Experimentations are carried out in the month of March at Nagpur India. Tap water available at the laboratory is used for the experiments. Water is stored in the conventional solar still in the morning. Whereas, in the modified solar still the water is made to flow over the absorber surface with a very less flow rate. During experiments the inlet water temperature varies from 28°C to 40°C. To check the effect of higher temperature of the input water on the productivity of the solar still, a separate flat plate collector is used to heat the water up to 60°C. During experiments, hot water from the flat plate collector is stored in the insulated container maintained at 60°C. The experiments are performed for the entire month of March from 9 am to 6 pm daily. The radiation intensities are measured using a well calibrated Class–I pyranometer (Kipp and Zonen). Temperatures of the cover plates, basin, absorber surface, water inlet, water stored in the basin and ambient air have been measured using calibrated thermocouples and attached data logger. The experiments were performed for the entire month. The average values of the entire month have been considered for the subsequent calculations so that the effect of instrumental error if any can be neglected.

4. Performance analysis

The performance of the modified solar still is analyzed in two ways. The performance of the system is predicted using theoretical analyses. The hourly distillate output of the solar still is estimated from the knowledge of different temperatures and thermo physical properties of water. Further, the experiments are performed to analyse the system performance during field application. The modified solar still was meant to be used with the ordinary tap water available at the location, Nagpur (India). In this study, for the location of the experiments the tap water temperature generally varies in the range of 28°C to 40°C. Therefore, to check the effect of input water temperature on the productivity of the solar still, the two general temperatures 28°C and 40°C are chosen. Both these studies are discussed in the subsequent text.

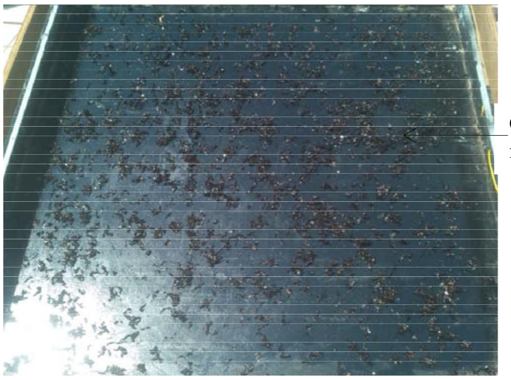

Fig. 4. Inclined solar still coated with enamel paint and copper chips.

4.1. Theoretical evaluation

The hourly distillate output of the solar still is estimated by the theoretical analysis. The convective heat losses and the evaporative loss coefficients are calculated using standard correlations as discussed below [Eqs. (1)–(7)] [32,33].

Latent heat of evaporation can be given as

$$L = 3.1615\times10^{6}\times\left[1-7.6160\times10^{-4}T\right] \quad (1)$$

Rate of convective heat transfer from water surface to the glass cover by convection in the upward direction through humid fluid can be given as

$$q_{cw} = h_{cw}\left(T_W - T_g\right) \quad (2)$$

Corresponding convective loss coefficient h_{cw} is

$$h_{cw} = 0.884\left[T_w - T_g + \frac{(P_w - P_g)(T_w + 273)}{268.9\times10^{3} - P_w}\right]^{0.33} \quad (3)$$

Values P_w and P_g are calculated as

$$P(T) = \exp\left[25.317 - \frac{5144}{T+273}\right] \quad (4)$$

Rate of evaporative heat transfer from water surface to glass cover per unit area is

$$q_{ew} = h_{ew}\left(T_w - T_g\right) \quad (5)$$

Evaporative loss coefficient from the Eq. (5) is

$$h_{ew} = 16.273\times10^{-3}h_{cw}\left(\frac{P_w - P_g}{T_W - T_g}\right) \quad (6)$$

The hourly distillate output per m^2 area from still is given by

$$m_{ew} = \frac{q_{ew}}{L}\times3600 \quad (7)$$

Figs. 5, 6 and 7 represent the theoretical distillate output for both conventional and modified solar still.

In the conventional solar still the water is stored in the basin whereas; in the modified still the water is flowing. When the radiation intensity reduces after 1300 hrs the stored water temperature in the conventional solar still

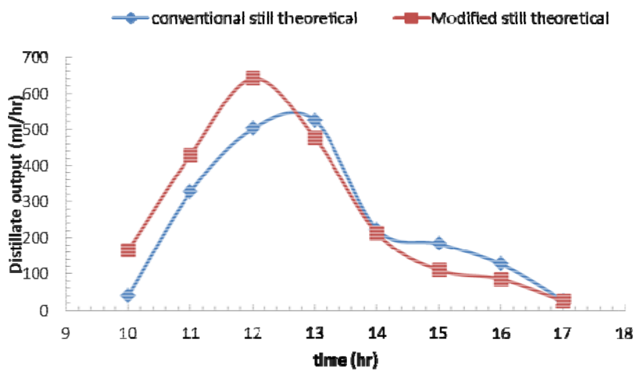

Fig. 5. Theoretical estimation of productivity of conventional and modified solar still having 28°C inlet water temperature.

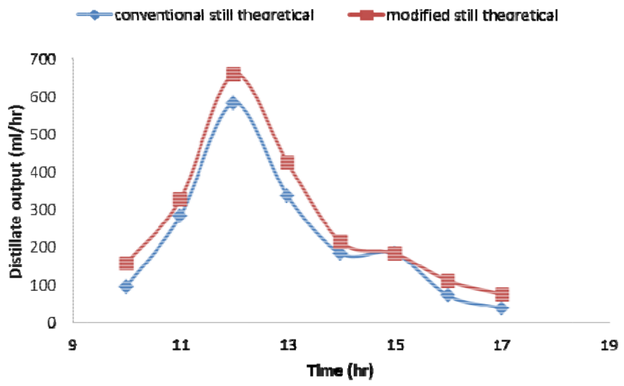

Fig. 6. Theoretical estimation of productivity of conventional and modified solar still at 40°C inlet water temperature.

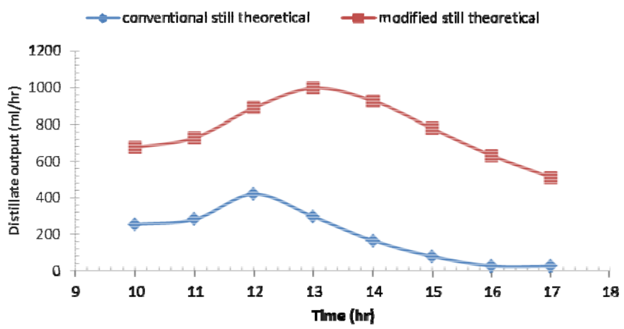

Fig. 7. Theoretical estimation of productivity of conventional and modified solar still at 60°C inlet water temperature.

remains fairly sufficient to condense. On the other hand, after 1300 h the temperature of the absorber surface of the modified solar still reduces which in turn reduces evaporation rate of water. Thus, the rate of condensation is reduced after 1 PM in the modified solar still. However, for the entire day, the total condensate output of the modified arrangement is higher as compared to conventional system.

From Figs. 5–7 it can be seen that the productivity of the modified solar still for the entire day is higher than the conventional horizontal basin solar still. Also, the productivity increases with increase in the inlet water temperature. The distillate output of the modified solar still is maximum for 60°C inlet water temperature.

4.2. Experimental evaluation

To verify the theoretical claims, the experiments are performed. The conventional horizontal basin solar still is considered as a reference. The performance of the modified solar still is compared with the conventional solar still for different inlet water temperatures. Figs. 8, 9 and 10 represent the experimental distillate output for both conventional and modified solar stills.

From Figs. 8–10 it can be seen that the productivity of the modified solar still for the entire day is higher than the conventional horizontal basin solar still. Also, the productivity increases with increase in the inlet water temperature. The distillate output of the modified solar still is maximum for 60°C inlet water temperature.

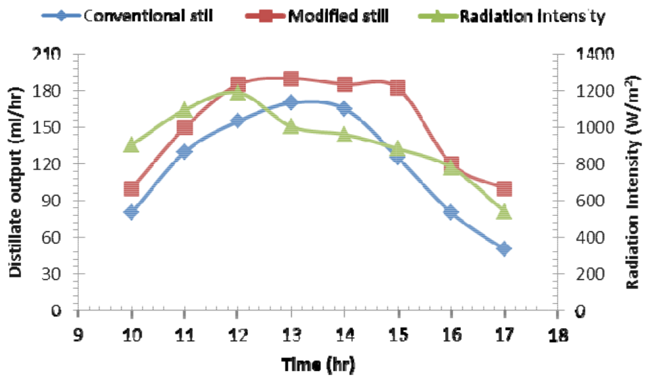

Fig. 8. Comparison of productivity of conventional and modified still at 28°C inlet water temperature.

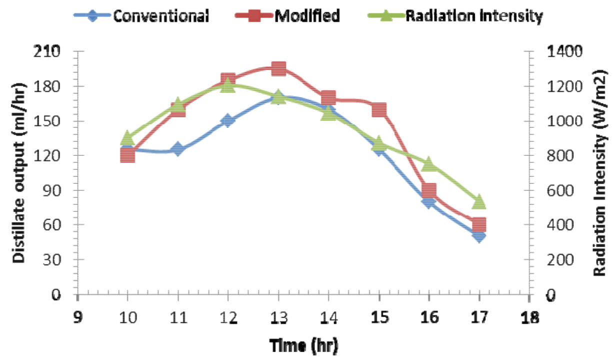

Fig. 9. Comparison of productivity of conventional and modified still at 40°C inlet water temperature.

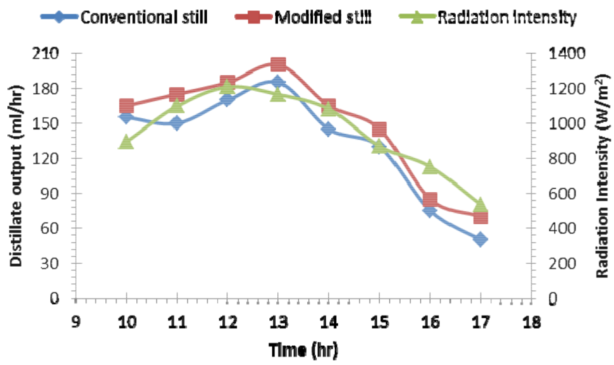

Fig. 10. Comparison of productivity of conventional and modified still at 60°C inlet water temperature.

Figs. 11–13 show the effect of copper chips and enamel coating on the performance of the solar still for different water inlet temperatures.

3. Discussions and conclusion

In the present study an attempt has been made to solve the problem of limited productivity of the conventional single slope horizontal basin solar still by improving its rate of evaporation. The conventional solar still is modified as a single slope inclined basin solar still with improved absorber

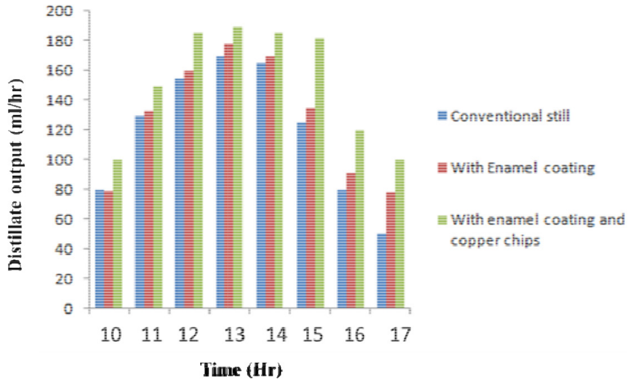

Fig. 11. Effect of copper chips and enamel chips on productivity (28°C water inlet temperature).

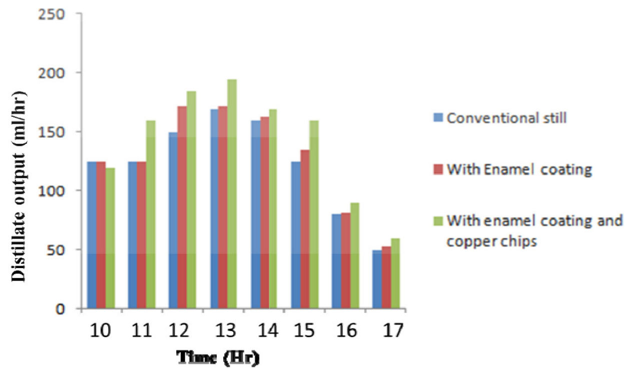

Fig. 12. Effect of copper chips and enamel chips on productivity (40°C water inlet temperature).

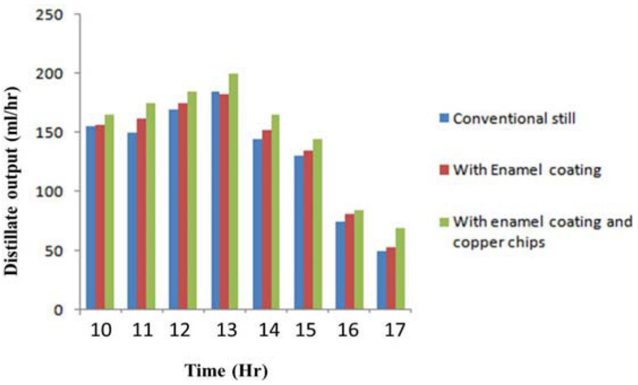

Fig. 13. Effect of copper chips and enamel chips on productivity (60°C water inlet temperature).

surface. The absorber surface of the modified solar still is coated with black enamel paint and covered with copper chips. This resulted in augmented evaporation rate and in turn productivity of the system. The modified solar still having same footprint area as that of the conventional horizontal basin single slope solar still is fabricated and tested at Nagpur [21.14° N, 79.08° E] India. The effect of variation of feed water temperature (28–60°C) on the productivity of the solar still is also analysed.

In the study, it has been observed that the black enamel coating improves the rate of absorption of the sunlight. The copper chips on the absorber surface of the modified solar still cause the obstructions to the flowing water over the absorber surface. This resulted into overall increase in the rate of evaporation of the water and in turn the productivity of the solar still. Theoretical modelling of both modified and conventional still is carried out and the results are compared. Experimentally, the modified solar still is proved to be 9.5% more productive as compared with the conventional still.

Further, it has been observed that the productivity of the solar still increases with increase in the inlet water temperature. In the current study a separate solar water heater is used to heat the inlet water. The same system can also be modified to make use of other energy sources for preheating of water like industrial waste heat and biomass.

The passive heat transfer augmentation technique of surface texturing using the raw copper chips is very economical. The performance of the existing solar still can be improved by this retrofitting. Further, it is recommended to check the performance of the solar still using different texturing materials with different density and texture patterns, different selective surface coating materials with various coating thickness. It is also suggested to investigate the durability of coating materials and surface texturing technique used in this study for longer exposure to sunlight.

Symbols

h_{cw} — Convective loss coefficient (W/m^2·°C)
h_{ew} — Evaporative heat transfer coefficient from water surface to glass cover (W/m^2·°C)
L — Latent heat of vaporization (J/kg·k)
m_{ew} — Distillate output (ml/h)
P_g — Partial vapor pressure at glass temperature (N/m^2)
P_w — Partial vapor pressure at water temperature (N/m^2)
q_{cw} — Convective heat transfer from water surface to the glass cover (W)
q_{ew} — Evaporative heat transfer from water surface to glass cover (W)
T — Operating temperature (°C)
T_g — Glass temperature (°C)
T_w — Water temperature (°C)

References

[1] M.S.S. Abujazar, S. Fatihah, E.R. Lotfy, A.E. Kabeel, S. Sharil, Performance evaluation of inclined copper–stepped solar still in a wet tropical climate, Desalination, 425 (2017) 94–103 (2018).
[2] M.S.S. Abujazar, S. Fatihah, A.R. Rakmi, M.Z. Shahrom, The effects of design parameters on productivity performance of a solar still for seawater desalination: A review, Desalination, 385 (2016) 178–193.
[3] B.A.K. Abu–Hijleh, Effect of water emissivity on solar still efficiency, Int. J. Sustain. Energy, 23(1–2) (2003) 13–19.
[4] A. Layek, Exergetic analysis of basin type solar still, Eng. Sci. Technol. Int. J., 21 (2018) 99–106.
[5] Z.M. Omara, A.E. Kabeel, A.S. Abdullah, A review of solar still performance with reflectors, Renew. Sustain. Energy Rev., 68 (2016) 638–649.

[6] M.A. Al–Nimr, M.E. Dahdolan, Modeling of a novel concentrated PV/T distillation system enhanced with a porous evaporator and an internal condenser, Sol. Energy, 120 (2015) 593–602.

[7] A.M. Al–Shabibi, M. Tahat, Thermal performance of a single slope solar water still with enhanced solar heating system, Int. Conf. Renew. Energies Power Qual., 1(13) (2015) 25–34.

[8] B.B. Singh, R. Dubey, A.K. Rai, Performance study of a solar still with, 8(2) (2017) 289–294.

[9] R. Bhardwaj, M.V. Ten Kortenaar, R.F. Mudde, Maximized production of water by increasing area of condensation surface for solar distillation, Appl. Energy, 154 (2015) 480–490.

[10] R. Bhardwaj, M.V. ten Kortenaar, R.F. Mudde, Influence of condensation surface on solar distillation, Desalination, 326 (2013) 37–45.

[11] S.W. Sharshir, G. Peng, L. Wu, N. Yang, F.A. Essa, A.H. Elsheik, S.I.T. Mohamed, A.E. Kabeel, Enhancing the solar still performance using nanofluids and glass cover cooling: Experimental study, Appl. Therm. Eng., 113 (2017) 684–693.

[12] Z.M. Omara, A.S. Abdullah, A.E. Kabeel, F.A. Essa, The cooling techniques of the solar stills' glass covers – A review, Renew. Sustain. Energy Rev., 78 (2017) 176–193.

[13] A.Z. Al–Garni, Productivity enhancement of single slope solar still using immersion-type water heater and external cooling fan during summer, Desal. Water Treat., 52(34–36) (2014) 6295–6303.

[14] M. Al–Harahsheh, M. Abu–Arabi, H. Mousa, Z. Alzghoul, Solar desalination using solar still enhanced by external solar collector and PCM, Appl. Therm. Eng., 128 (2018) 1030–1040.

[15] M.H. Sellami, S. Guemari, R. Touahir, K. Loudiyi, Solar distillation using a blackened mixture of Portland cement and alluvial sand as a heat storage medium, Desalination, 394 (2016) 155–161.

[16] P.K. Srivastava, S.K. Agrawal, Experimental and theoretical analysis of single sloped basin type solar still consisting of multiple low thermal inertia floating porous absorbers, Desalination, 311 (2013) 198–205.

[17] S. Rashidi, N. Rahbar, M.S. Valipour, J.A. Esfahani, Enhancement of solar still by reticular porous media: Experimental investigation with exergy and economic analysis, Appl. Therm. Eng., 130 (2018) 1341–1348.

[18] P. Monowe, M. Masale, N. Nijegorodov, V. Vasilenko, A portable single-basin solar still with an external reflecting booster and an outside condenser, Desalination, 280 (2011) 332–338.

[19] A.E. Kabeel, Z.M. Omara, F.A. Essa, Enhancement of modified solar still integrated with external condenser using nanofluids: An experimental approach, Energy Convers. Manag., 78 (2014) 493–498.

[20] R.S. Hansen, C.S. Narayanan, K.K. Murugavel, Performance analysis on inclined solar still with different new wick materials and wire mesh, Desalination, 358 (2015) 1–8.

[21] T. Rajaseenivasan, P.N. Raja, K. Srithar, An experimental investigation on a solar still with an integrated flat plate collector, Desalination, 347 (2014) 131–137.

[22] M. Appadurai, V. Velmurugan, Performance analysis of fin type solar still integrated with fin type mini solar pond, Sustain. Energy Technol. Assess., 9 (2015) 30–36.

[23] R.A. Kumar, G. Esakkimuthu, K.K. Murugavel, Performance enhancement of a single basin single slope solar still using agitation effect and external condenser, Desalination, 399 (2016) 198–202.

[24] A.A. El–Sebaii, A.A. Al–Ghamdi, F.S. Al–Hazmi, A.S. Faidah, Thermal performance of a single basin solar still with PCM as a storage medium, Appl. Energy, 86(7–8) (2009) 1187–1195.

[25] M.S.S. Abujazar, S. Fatihah, E.R. Lotfy, A.E. Kabeel, S. Sharil, Performance evaluation of inclined copper–stepped solar still in a wet tropical climate, Desalination, 425 (2018) 94–103.

[26] A.F. Muftah, K. Sopian, M.A. Alghoul, Performance of basin type stepped solar still enhanced with superior design concepts, Desalination, 435 (2018) 198–209.

[27] R.S. Hansen, K.K. Murugavel, Enhancement of integrated solar still using different new absorber configurations: An experimental approach, Desalination, 422 (2017) 59–67.

[28] R.S. Hansen, C.S. Narayanan, K.K. Murugavel, Performance analysis on inclined solar still with different new wick materials and wire mesh, Desalination, 358 (2015) 1–8.

[29] S.M. Shalaby, E. El–Bialy, A.A. El–Sebaii, An experimental investigation of a v–corrugated absorber single–basin solar still using PCM, Desalination, 398 (2016) 247–255.

[30] W.M. Alaian, E.A. Elnegiry, A.M. Hamed, Experimental investigation on the performance of solar still augmented with pin–finned wick, Desalination, 379 (2016) 10–15.

[31] S.P. Sukhatme, J.K. Nayak, Solar energy principles of thermal collection and storage, 3rd ed., Tata McGraw–Hill Education, New Delhi 1996.

[32] N. Rahbar, J.A. Esfahani, Productivity estimation of a single–slope solar still: Theoretical and numerical analysis, Energy, 49 (2013) 289–297.

[33] A. Alaudeen, A.S. Abu Thahir, K. Vasanth, A.M.I. Tom, K. Srithar, Experimental and theoretical analysis of solar still with glass basin, Desal. Water Treat., 54(6) (2015) 1489–1498.