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Traditional solar distiller improvement by a single external refractor under the climatic conditions of the El-Oued region, Algeria

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ABSTRACT

Desalination is now successfully practiced in many countries as drinking water supply has become a growing problem in most parts of the world. Algeria, like the Maghreb countries, has generally adopted two desalination processes (membrane processes and distillation processes which require a phase change, evaporation/condensation), the latter method is subject of our study. An experimental study was made on two similar stills with a single slope, size 1 m × 1 m, the first distiller D1 is used as a control and the second distiller D2 has a simple external mirror glued to its backlog. The same experience has been done in different climates with improvement results ranging from 9% to 21%. In our case, a complete study was concerning the improvement, the efficiency, the investment and finally the error analysis of the instrumentations that have not been done before. We obtained a very interesting improvement which varied between 42% and 45%, the efficiency is 35% and the recovery period of the sum invested is recovered in 23 d, which shows that this technique is more favorable under the climatic conditions of the West Southeast region of Algeria than elsewhere.

Keywords: Desalination; Distilled water; Evaporation; Condensation; Solar radiation

1. Introduction

Algeria has the largest solar field in the Mediterranean basin and it has a large underground water reservoir in the southeastern region of Algeria (region of El-Oued). This water is infected by the fluoride so what makes this water invaluable. Earth-water treatment plants have been designed for the reuse of wastewater. A procedure followed by several countries in the world [1].

Because the water problems are inextricably linked to food production; about 70% of all freshwater used in agriculture [2], Algeria faced this problem by adopting the membrane desalination process and the phase change method which can be coupled to low-grade and renewable energy source such as wind and solar energy [3]. In the southeast region, researchers have designed a small pilot distillation station. The studies aim at improving the performance of a small solar distillation station under real isolation for underground geothermal desalination of water in arid regions in southern Algeria [4], and they are also aimed at producing drinking water in arid regions [5]. The small station had a daily capacity of more than 15 L/m^2 [6]. A study

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has been made on the performance of a wick solar distiller connected to an inclined external reflector; an improvement in pure water productivity has been reported from this study which varies between 15% and 27% [7–9]. High-capacity desalination such as multi-stage flash and reverse osmosis has become a marketable technology. On the other side, the marketplace has not inspired similar developments in low-capacity desalination technology for smaller communities, especially, solar energy-driven desalination systems due to high capital investment. But the operating and maintenance costs of these technologies are still minimum [10,11].

Lauric acid as a phase change material (PCM) was used to examine the effect of PCM mass and pond water on the daily productivity of the distillate. The study gave an increase in the daily productivity of solar distiller [12]. An experimental study on a dual-pond solar distiller shows that the addition of a vacuum tube collector increases productivity by 56% [13]. Another experimental study with a flat solar collector integrated with a conventional solar still. The result was very good and an improvement of about 60% was recorded [14]. Seasonal changes have a remarkable effect on the productivity of a conventional solar distiller; this has been proven that production in the summer season is nine times greater than during the summer season [15]. An experiment with double glazing well isolated from the four sides separated by a film of air showed a decrease in the productivity of the distilled water of 40% [16]. The cooling of the glazing of a traditional solar still is one of the solutions adopted by several researchers to improve productivity. This method consists of pouring air or water on the glazing to cool it. In this way, the temperature difference between the water and the glazing is increased. This difference favors the condensation of water vapor [17–19]. Numerical studies and mathematical models have been created to study and predict the effects of weather conditions on the productivity of a solar distiller [20–22]. The solar still with internal reflector and composite black gravel-PCM for thermal heat storage has been studied experimentally. The water enhanced by 37.55% by utilizing the composite black gravel-PCM rather than in the case of PCM only with improvement in energy and exergy efficiency about 38% and 37%, respectively [23]. The energy storage technique has been used in solar distillers to increase productivity so copper, stainless steel, mica, aluminum and a black metallic plate of Zinc they were dipped in the water basin and they gave an improvement of the pure water productivity between 19% and 45% [24–26]. Another technique is to use two refractors, one internal and the other external (up and down). This method gave a productivity increase of 125%. [27], this technique was further developed using nanofluids with high energy conversion. An experiment was carried out to see the performance of solar distillers with nanofluids based on Al_2O_3, ZnO, and SnO_2. The results show an improvement of 29.95% for Al_2O_3, 18.63% for SnO_2, and 12.67% for ZnO [28]. Different experiments have been done on a conventional solar distiller attached to an external single refractor, the results show that the improvement of the pure water productivity varies between 9% and 21% [7,29–32]. This work highlights the positive influence of an external flat refractor on the productivity of a traditional solar distiller. This simple technique involves placing a refractor in the back of a solar still. The advantage of this method is simplicity, efficiency, not expensive, and no negative effect on the environment. Its disadvantage is to adjust each time the angle of the refraction of the sun's rays on the solar still. The novelty of our work is to show that the South-East region of Algeria is a very favorable area for this technique and that we can have quite significant improvement rates compared to other research. Such work was not done before.

2. Methods and experiment

The single-slope solar distiller or the distiller of Charles Wilson (its creator in Chile in 1872) but we can simply call it the conventional distiller. This distillery is a well-known device for producing distilled water under the greenhouse effect. It is based on the principle of evaporation/condensation. This system has very simple design because its components are cheap and they are available in all markets of the world. This simple device can solve the problem of drinking water in isolated areas and regions that suffers from non-potable groundwater.

2.1. Weather conditions of the experiment

Algeria is one of the sunniest countries in the world as shown in Fig. 1. The number of hours of sunshine is about 3,300 h/year. This country has a potential that promotes the exploitation of solar energy [33,34]. The experiments are carried out according to the geographical coordinates of the region of El-Oued in the south-east of Algeria, located at 33.3676° north latitude and 6.8516° longitude. The temperatures are taken every hour from 7:00 to 18:00, which is 11 h of sunshine. The meteorological conditions of the experiment are shown in Table 1.

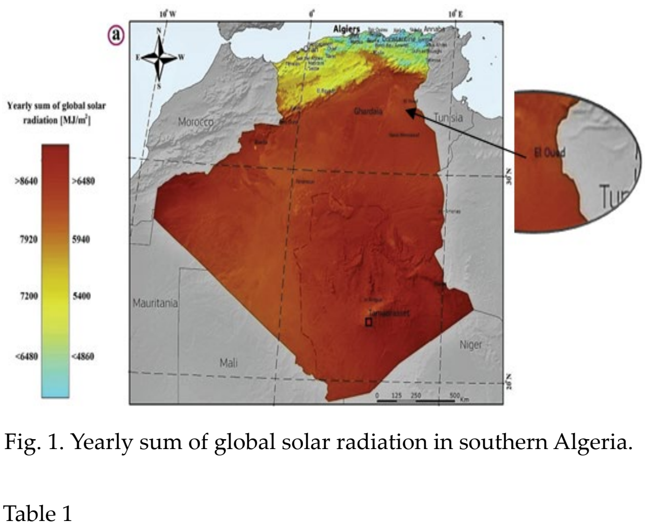

Fig. 1. Yearly sum of global solar radiation in southern Algeria.

Table 1
Experience conditions

Meteorological conditions in May 2017	
Sunrise	05:41 am
Sunset	07:19 pm
Ambient temperature	24°C–36°C
Atmospheric pressure	101,325 Pa

2.2. Principle of operation

When the sun's rays touch the surface of the water in the distiller, the black layer of the silicone (or absorber) begins to absorb the heat and the temperature of the water increases gradually according to the radiation. Get a point; water changes its liquid state to become vapor. This steam migrates towards the inner face of the inclined glazing and condenses in the form of small drops. Under the effect of gravity, the drops slide to reach the end of the collector tube located in the lower part of the glazing. All the drops will be collected in the tank under the still. The temperatures are taken automatically via an electronic card which is called Arduino card which is connected to a PC. The amount of water produced by solar distiller is measured by graduated beaker. Fig. 2 shows a sketch of our system.

3. Error analysis

Measuring instruments are directly related to errors. These errors are the percentage uncertainties that affect the accuracy of the results displayed by its instruments. The LM35 thermal sensors, the pyranometer, and the graduated beaker are measuring instruments. Table 2 shows the uncertainties of his instruments.

4. Results and discussions

The experiment was conducted in mid-May 2017 in the climate of the El-Oued region, in the south-east of Algeria. Two similar stills in dimensions with the same slope angle (20°). Distiller D1 is a reference and distiller D2 has a refractor. The refractor in question is placed behind the distiller D2 to further reflect the sunlight on the distiller D2 as shown in Fig. 3. This experiment requires special attention because each time it is necessary to ensure that the solar rays are always well reflected on the glazing of the distiller D2, an adjustment of the angle of the refractor is necessary every hour.

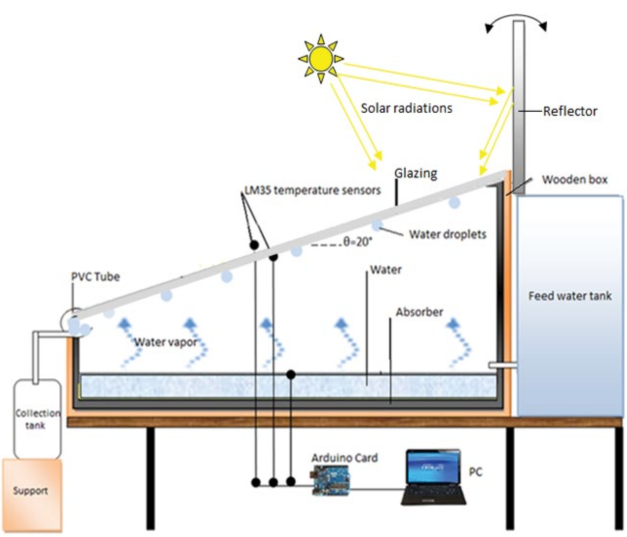

Fig. 2. Croquet of the solar still with a refractor.

4.1. Evolution of solar radiation and ambient temperature

Fig. 4 illustrates the evolution of solar radiation in W/m² and the ambient temperature in °C for 1 d. It is noted that the radiation obtained is between 300 W/m² at 7:00 and 100 W/m² at 18:00 and it reaches a peak around noon and it begins to

Table 2
Errors for various measuring

Device	Accuracy	Range	Error
Pyranometer	±1 W/m²	0–5,000 W/m²	0.153%
Temperature sensors LM35	±1°C	–40°C–110°C	2.173%
Calibrated cup	±5 ml	0–2,000 ml	1.502%
Errors in daily productivity	±5 ml	0–2,000 ml	0.103%

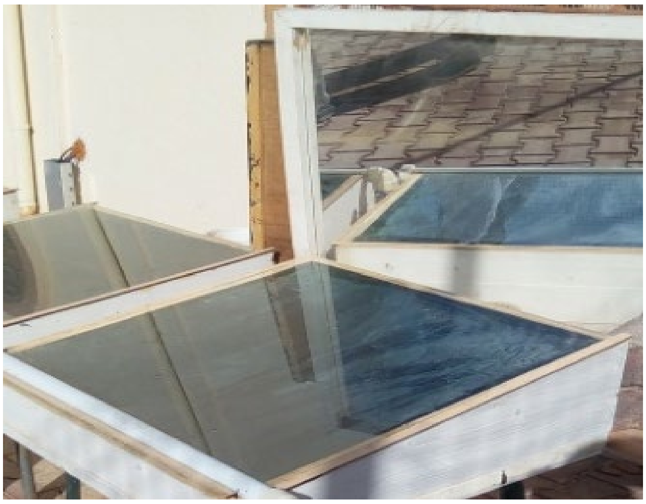

Fig. 3. Distiller D2 with a refractor.

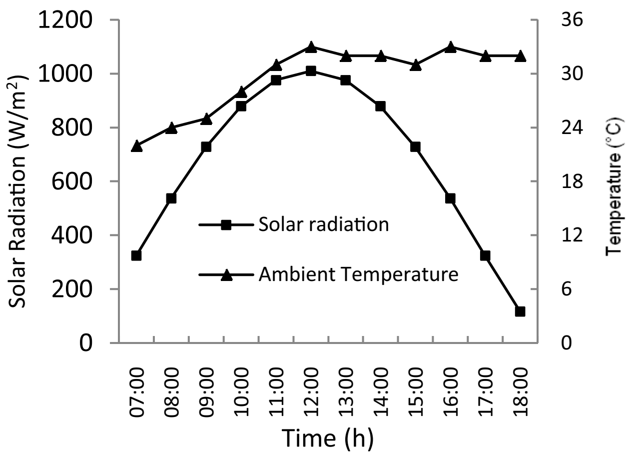

Fig. 4. Hourly evolution of solar radiation and ambient temperature time.

decrease afternoon. The evolution of the ambient temperature varies during the experiment between 22°C to 35°C and it is maximum towards midday. From Fig. 4, the change in ambient temperature afternoon was constant until the end of the experiment, although solar radiation started to decrease.

4.2. Evolution of the temperatures in the two distillers

Fig. 5 shows the evolution of all the temperatures of the two distillers D1 and D2 during the duration of the experiment. We can see that all the temperatures start to increase from 7:00 to 12:00 in a progressive way. From 12:00 to 15:00 all temperatures are maximum as solar radiation is also at a maximum. After 15:00 h, all the temperatures of the solar distiller components started to decrease as the solar radiation begins to weaken. The use of an external refractor increases the temperature of the distiller D2 water tank. This water temperature is higher compared to the water temperature of the distiller D1 which the maximum temperature of the latter varies between 55°C and 70°C. This difference in temperature gives an advantage to the distiller D2 to produce a quantity of pure water more interesting than a distiller D1 (without a refractor).

4.3. Accumulated distillate

Fig. 6 shows the evolution of the accumulated pure water of the two distillers D1 and D2 with time. Both graphs start from zero milliliters, as time passes, the amount of water produced by the two stills accumulates slowly. At 18:00 the amount produced from the distiller with the refractor is 4,840.4 ml/m^2 d and the amount produced by the simple distiller without refractor is 3,408.4 ml/m^2 d. In other words, the distiller D2 produces 1.42 times more than the distiller D1 (without refractor). The accumulation curves clearly show the influence of the external refractor on the pure water productivity of a solar distiller D2 (with refractor).

4.4. Daily productivity variation

Fig. 7 shows the variation in daily productivity for D1 and D2 distillers throughout the day. The productivity of the two distillations increased from zero to a peak of 405.8 ml/m^2 d for the D1 still and 664 ml/m^2 d for the D2 distiller. After 13:00 the productivity begins to decrease slowly to reach its minimum value at 18:00. The total amount of pure water produced by the distiller D1 is 3,408.4 ml/m^2 d and that produced by the distiller D2 is 4,840.4 ml/m^2 d during the same period. The difference between the two quantities produced represents an improvement in production of 1,432 ml/m^2 d. This difference is due to a single difference between the two distillers; it's just the commercial refractor.

4.5. Thermal efficiency

The time variation of the thermal efficiency of the distiller D1 and the distiller D2 is calculated based on the method in [35] and illustrated in Fig. 8. The hourly thermal efficiency of the distiller D1 reaches its maximum value of

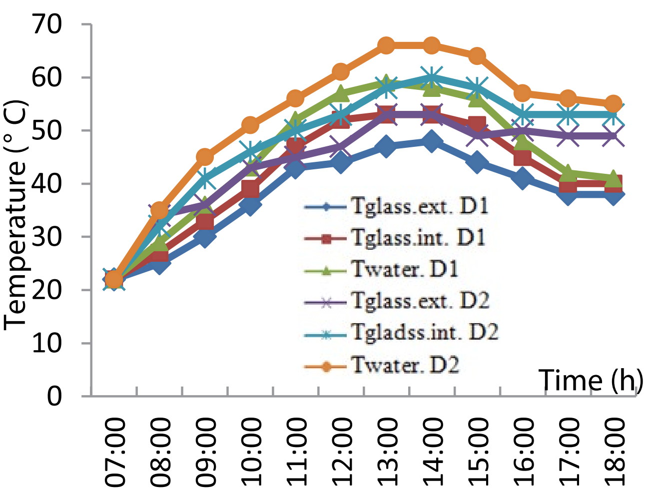

Fig. 5. Evolution of the inner glazing temperature of the distillers.

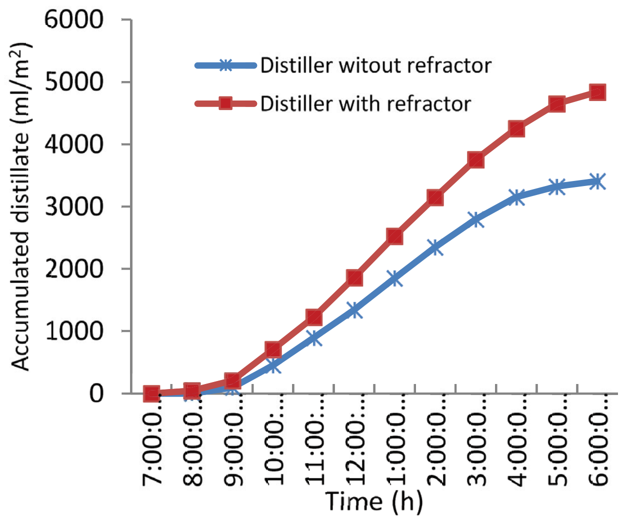

Fig. 6. Evolution of the accumulated pure water.

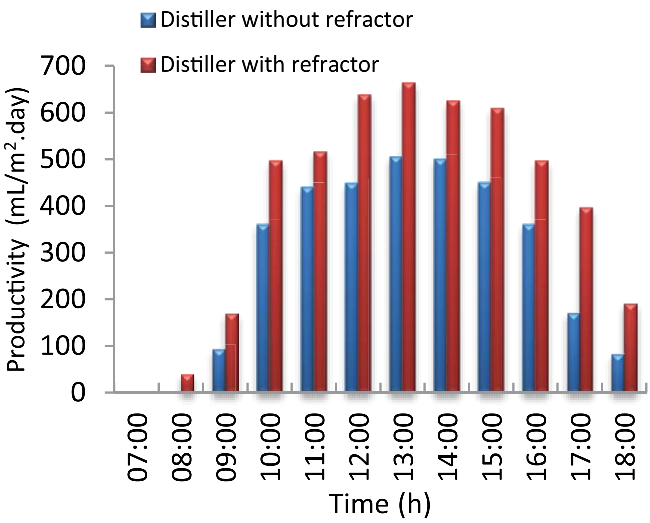

Fig. 7. Variation in productivity of the distillers.

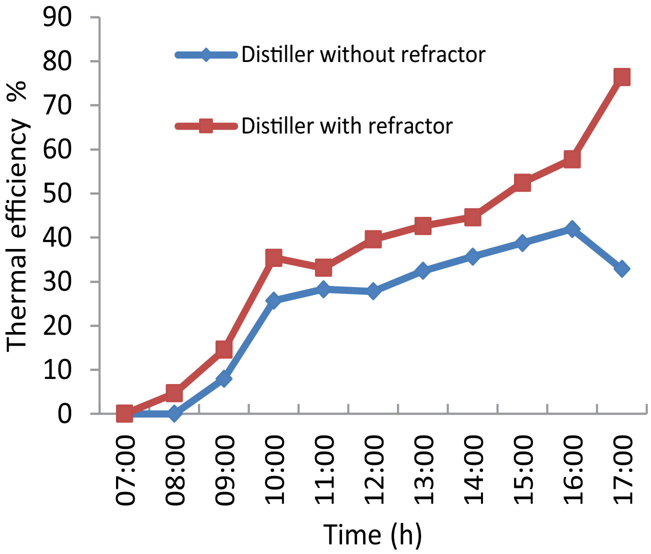

Fig. 8. Thermal efficiency.

41.93% at 16:00 and the distiller D2 is 73.43%at 17:00. The average daily thermal efficiency of the distiller D1 without a refractor is 24.66% and that of the distiller D2 with a refractor is 36.74%. The thermal efficiency of the distiller D2 is higher than that of the distiller D1. This difference is due to the refractor.

5. Economic evaluation

In Algeria, 1 L of distilled water costs about 100 DA, which remains a very high price compared to 1 L of mineral water (16.66 Da). The use of a simple conventional still solar distiller can produce at least 3,894 L/d. A symbolic price of 50 DA per day has been set for maintenance. Based on the method in [36,37] the economic evaluation of the resent systems is performed. Table 3 shows the manufacturing and maintenance prices and the price of a liter of distilled water at the market. Based on its prices, we can recover the amount invested in his project for 38 d for the conventional recipient, without a refractor and 23 d for the distiller with a refractor.

6. Conclusions

Two similar distillers exposed to the sun under the same metrological conditions, the distiller D2 has only one difference compared to the distiller reference D1 is that the distiller D2 has a plane refractor that reflects additional solar radiation on the water and it heats the water. The difference in temperature between the water and the inner glazing is a very important factor in the distillation. The difference in average temperature between the inner glazing and the water of the distiller D2 basin is 63°C and that of the distiller D1 is 38°C. Therefore, the distiller which has the greatest difference in average temperature (in our case the distiller D2), will have high productivity.

- The productivity of the distiller D1 is 3.4084 L/m^2 d and for the distiller D2 is 4.8404 L/m^2 d. It can be concluded that this single difference (flat reflector) has improved the productivity of freshwater in a conventional solar distiller of 1.42 times. Such a rate of improvement is very important, which means that our region is in favor of this technique.
- The thermal efficiency of the distiller D2 is higher than that of the distiller D1 of 11.81%. This difference is due to the refractor.
- The amount invested in the distiller with the tractors is recovered in 23 d but for the other distiller without refractor, it is recovered in 38 d.

Table 3
Fabrication cost of improved solar still

	Algerian Dinar DA	Euro, 1 € = 136.03 DA (August 2018)	
Total cost of fabrication to consider	10,000	73.51	
Wood	5,000		
Workforce	2,000		
Glass	500		
Silicone	1,000		
Piping work	1,500		
Cost per liter of distilled water	100	0.73	
Solar distiller productivity (L/m^2/d)			D1: 3.4084 L/m^2/d D2: 4.8404 L/m^2/d
Cost of water produced per day	D1: 340.8 D2: 484.0	D1: 1.86 D2: 2.87	
Maintenance cost	50	0.37	
Net profit	D1: 260.8 D2: 434.0	Dc: 2.48 Ds: 1.75	
Recovery period (d)			D1: 38 d D2: 23 d

References

[1] A. Mallik, Md. A. Arefin, Clean water: design of an efficient and feasible water treatment plant for rural South-Bengal, J. Mech. Eng. Res Develop., 41(2018) 156–167.

[2] A.E. Kabeel, EM.S. El-Said, Water production for irrigation and drinking needs in remote arid communities using closed-system greenhouse: A review, Eng. Sci. Technol., 18 (2) (2015) 294–301.

[3] A.E. Kabeel, M. Abdelgaied and E.M.S. El-Said, Study of a solar-driven membrane distillation system: evaporative cooling effect on performance enhancement, Renew. Energy 106 (2017) 192–200.

[4] B. Bouchekima, Solar desalination plant for small size use in remote arid areas of South Algeria for the production of drinking water, Desalination, 156 (2003) 353–354.

[5] B. Bouchekima, A small solar desalination plant for the production of drinking water in remote arid areas of southern Algeria, Desalination, 159 (2003) 197–204.

[6] B. Bouchekima, A solar desalination plant for domestic water needs in arid areas of South Algeria, Desalination, 153 (2003) 65–69.

[7] H. Tanaka, Y Nakatake, Increase in distillate productivity by inclining the flat plate external reflector of a tilted-wick solar still in winter, Sol Energy, 83 (2009) 785–9.

[8] R. Balan, J. Chandrasekaran, S. Shanmugan, B. Janarthanan and S. Kumar, Reviews on passive solar distillation, Desal. Water Treat., 28 (2011) 217–238.

[9] Z.M. Omara, A.E. Kabeel, A.S. Abdullah and F.A. Essa, Experimental investigation of corrugated absorber solar still with wick and reflectors, Desalination, 381 (2016) 111–6.

[10] A.E. Kabeel and E.M.S. El-Said, Development strategies and solar thermal energy utilization for water desalination systems in remote regions: a review, Desal. Water Treat., 1 (2013) 1–18.

[11] A.E. Kabeel and E.M.S. El-Said, Technological aspects of advancement in low capacity solar thermal desalination units, Int. J. Sustain. Energy, 32 (5) (2013) 315–332.

[12] A.F. Al-Hamadani, S.K.Shukla, Water Distillation Using Solar Energy System with Lauric Acid as Storage Medium, 1 (2011) 1–8.

[13] H.N. Panchal, Enhancement of distillate output of double basin solar still with vacuum tubes, J. King Saud Univ. Eng. Sci. 2013,

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

[15] A. Khechekhouche, A. Boukhari, Z. Driss, N. Benhissen, Seasonal effect on solar distillation in the El-Oued region of south-east Algeria, Int. J.Energetica, 2 (2017) 42–45

[16] A. Khechekhouche, B. Boubaker, M. Manokar, R.Sathyamurthy, A.E.Kabeel. Exploitation of an insulated air chamber as a glazed cover of a conventional solar still.Heat Transfer - Asian Res., 48 (2019) 1563–1574.

[17] B. Gupta, R. Sharma, P. Shankar, P. Baredar, Performance enhancement of modified solar still using water sprinkler: An experimental approach, Perspect. Sci., 8 (2016) 191–194.

[18] Y. El-Samadony, A.E.Kabeel, Theoretical estimation of the optimum glass cover water film cooling parameters combinations of a stepped solar still, Energy, 68 (2014) 744–750.

[19] A.A.K. Al-Waeli, K.H.M. Al-Asadi, Enhancing the productivity of a single slope solar water distiller by cooling the transparent cover, Scholars Bulletin, 2018.

[20] R. Gugulothu, N. S. Somanchi, K. V. K. Reddy, D. Gantha, A review on solar water distillation using sensible and latent heat, Procedia Earth Planet. Sci., 11 (2015) 354–360.

[21] C.D. Park, B.J. Lim, Y.D. Noh, S.S. Lee, K.Y. Chung, Parametric performance test of distiller utilizing solar and waste heat, Desal. Water Treat., 55 (2015) 3303–3309.

[22] H. Al-Hinai, M.S. Al-Nassri, B.A. Jubran, Effect of climatic, design and operational parameters onthe yield of a simple solar still, Energy Convers. Manage., 43 (2002) 1639–1650.

[23] A.E. Kabeel, G.B. Abdelaziz and E.M.S. El-Said, Experimental investigation of a solar still with composite material heat storage: Energy, exergy and economic analysis, J. Cleaner Prod., 231 (2019) 21- 34.

[24] H.N. Panchal, N. Patel, ANSYS CFD and experimental comparison of various parameters of a solar still, Int. J.Amb. Energy, 39 (2018) 551–557.

[25] A.Khechekhouche, B. Benhaoua, A. E. Kabeel, M. H. Attia, W. M. El-Maghlany, Improvement of solar distiller productivity by a black metallic plate of zinc as a thermal storage material, J. Testing Eval., 49 (2019) in press.

[26] N. Smakdji, A. Kaabi, B. Lips, Optimization and modeling of a solar still with heat storage, Desal. Water Treat., 52 (2014) 1761–1769.

[27] A.E. Kabeel, S.A. El-Agouz, T. Arunkumar, R.Sathyamurthy, Enhancing the performance of single slope solar still using jute cloth knitted with sand heat energy storage. 20th International Water Technology Conference, IWTC20. 2017.

[28] Z.M. Omara., A.E Kabeel, M.M. Younes. Enhancing the stepped solar still performance using external reflectors, Energy Convers. Manage. 78 (2014), 876–881.

[29] Elango T, Kannan A, KalidasaMurugavel K. Performance study on single basin single slope solar still with different water nanofluids. Desalination,360 (2015) 45–51.

[30] Z.M. Omaraa, A.E. Kabeel, A.S. Abdullah. A review of solar still performance with reflectors. Renew. Sustain. Energy Rev., 68 (2017) 638–649

[31] H. Tanaka, Y. Nakatake, Improvement of the tilted wick solar still by using a flat plate reflector. Desalination,216 (2007) 139–46.

[32] H. Tanaka, Tilted wick solar still with external flat plate reflector: optimum inclination of still and reflector, Desalination, 249 (2009) 411–5.

[33] L. Achour, M.Bouharkat, O. Assas, O. Behar, Hybrid model for estimating monthly global solar radiation for the Southern of Algeria: Case study: Tamanrasset, Algeria. Energy 135 (2017) 526–539.

[34] M. Nia, M. Chegaar, M.F. Benatallah, M. Aillerie, Contribution to the Quantification of Solar Radiation in Algeria, Terra Green 13 International Conference 2013-Advancements in Renewable Energy and Clean Environment. Energyprocedia 2013.

[35] S.M. Elshamy and E.M.S. El-Said, Comparative study based on thermal, exergetic and economic analyses of a tubular solar still with semi-circular corrugated absorber, J. Cleaner Prod. 195 (2018) 328–339.

[36] A.E. Kabeel, T.M. Abouelmaaty and EM.S. El-Said, Economic analysis of a small-scale hybrid air humidification and dehumidification-water flashing evaporation (HDH-SSF) desalination plant, Energy 53 (2013) 306–311.

[37] A.F. Mohamed, A.A. Hegazi, G.I. Sultan and E.M.S. El-Said, Enhancement of a solar still performance by inclusion the basalt stones as a porous sensible absorber: experimental study and thermo-economic analysis, Solar Energy Mater. Solar Cells, 200 (2019) 109958.