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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.

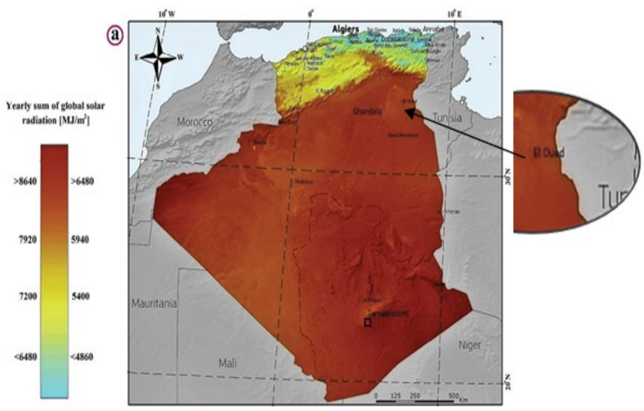

Fig. 1. Yearly sum of global solar radiation in southern Algeria.

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

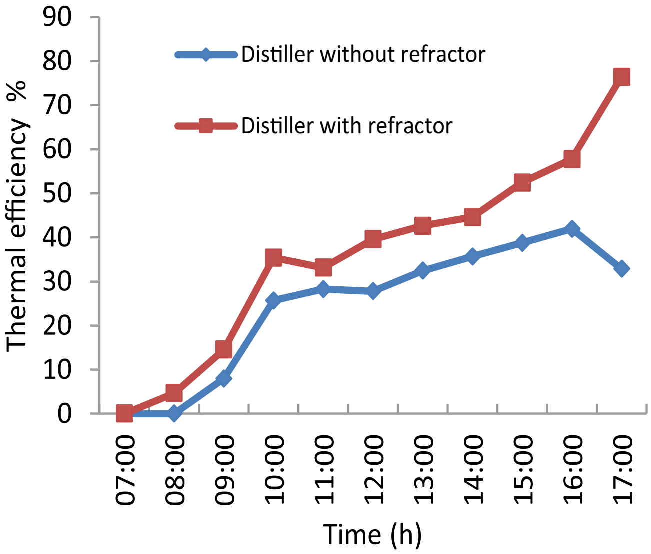

Fig. 8. Thermal efficiency.

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	D1: 1.86	
	D2: 484.0	D2: 2.87	
Maintenance cost	50	0.37	
Net profit	D1: 260.8	Dc: 2.48	
	D2: 434.0	Ds: 1.75	
Recovery period (d)			D1: 38 d
			D2: 23 d

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