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# Brackish water desalination using black granite as heat storage medium under arid climatic conditions

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**ABSTRACT**

Solar stills are simple devices that use clean energy to produce potable water from brackish or seawater to supply drinkable water to sparsely populated and scattered communities like those in southern Algeria. In this context, the paper aims to improve the efficiency of the conventional solar still by introducing crushed black granite in the form of gravel evenly distributed over the entire surface of the still's absorber with varying amounts (five masses) as a means of heat storage medium, and then observe the mass effect under local climatic conditions on the daily cumulus of distillate. Thus, after experiments carried out at the University of Ouargla at the end of winter, the daily productivity of the black granite unit is greater in quantity and quality than that of the conventional still under the same conditions as whatever the mass of granite. The best result is obtained by: 1.25 kg, that is, 5.48 kg of granite m$^{-2}$ of absorber surface which contributed to 4.135 kg m$^{-2}$ d$^{-1}$ of distillate with an improvement in profitability of 34.09% compared to the baseline case.

*Keywords:* Solar energy; Solar still; Gravel; Granite; Heat storage; Ouargla

## 1. Introduction

Water is important for all types of life on earth. Humanity is based on fresh water supplies such as rivers, lakes, ponds and underground reservoirs for daily needs. The use of fresh water is increasing due to population growth and rapid industrialization. Much of the discharge of industrial wastes and sewage is discharged into rivers, making it difficult for fresh water to be available. The supply of fresh water in many parts of the world is gradually becoming an increasingly important topic [1]. About 20% of the world's populations live in places that do not have enough water to meet their demands or to live their lives in safe conditions [2].

Algeria is currently ranked 14th in the world among countries with water scarcity. If appropriate strategies are not considered to provide more fresh water, the situation in Algeria will worsen. By 2025, Algeria is expected to become the sixth country in the world most affected by a scarcity of fresh water [3]. One of the main solutions to solve this problem is the purification of water from available sources such as salt water, domestic and industrial wastewater and other effluents [4].

Desalination of water has been carried out in recent years using various techniques such as multi-effect distillation, membrane distillation, reverse osmosis and multi-stage desalination. All of these techniques are energy-intensive procedures and generally depend on fossil fuels. Unfortunately, the use of these desalination methods creates other problems, such as the depletion of fossil fuels, global warming and other environmental damage [5,6].

Solar stills are generally devices of simple design and used to purify brackish water [7]; this technique was used by Arab scholars to produce fresh water in 1551 [8].

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According to other techniques, it is the cheapest method of obtaining drinking water. This advantage is due to the low cost of these devices and to the clean and free energy consumed [9–11]. In 1872, a simple design of a single basin solar still was built in Las Salinas, Chile [12]. Subsequently, many researchers around the world have participated in improving the profitability of solar equipment. The biggest drawback of solar stills is their low efficiency compared to other desalination technologies [5]. Thus, several studies have been carried out to improve the efficiency of these systems [13–15]. The main cause of these low yields is due to many essential points, namely: heat losses through the design parts to the ambient air, the hot distillate evacuates the heat, the internal overheating created by the greenhouse effect, the condenser temperature increases due to the latent heat of condensation released by the vapor [10,16].

Several authors have focused on the factors that affect the performance of solar still devices. These studies indicate that various designs of solar stills affect efficiency [17].

The depth of the water is one of the main factors influencing the performance of the still. Several researchers have found that a minimal or thin layer of saline or brackish water in the absorber rapidly increases its temperature and improves the efficiency of heat and mass transfer; the investigators have studied the correlation between the depth of the water in the absorber surface and the mass transfer factor between the water and the glass cover; both have been proven and found to be dependent [18].

Kalbasi et al. [19] designed single and double effect solar stills and experimentally validated the results of their modeling. It was found that the separation of the condensing surface and the solar energy receiving surface would improve the daily productivity by 94% compared to the conventional unit. They also showed that increasing the depth of water in the basin has a negative impact on the efficiency, because as the temperature difference increases between the condensing surface and the basin, the productivity improves.

The production of distillate from a solar still is also based on the nature, thickness and inclination of the glass cover. The tilt angle should be south for locations in the northern hemisphere and north in the southern hemisphere. Usually the angle of inclination of the protective glass should be equal to the latitude of the location [1].

Cherraye et al. [20] studied how to improve the solar still productivity through different tilt angles of glass cover. In their study, the angles were (10°, 15°, 20°, 30°, 35° and 45°). The results showed that in autumn and winter the best tilt was 30°, while in spring and summer the best tilt was 20°.

Shafii et al. [21] also studied how to enhance the yield in passive solar still without complicating its design by using an additional condensation on sidewalls. The efficiency was increased to 55.5%.

The productivity of the solar still can be improved by the use of a heat storage medium; the latter improves the absorption of solar flux and thus increases the yield both during the day when the solar irradiance is low and at night. The heat storage material stores heat during the day and provides brackish water during the evening or during the lack of solar irradiance to increase the overall performance of the solar still [22].

Several materials considerably increase the distillation period by serving as a heat storage medium which contributes to high yields such as jute cloth [23], gravel [24], stone, alluvial sand [10], cement [11], sponge [3] etc.

One of the new methods is the use of nanotechnology by introducing nanoparticles into the absorber basin to increase the heat and mass transfer capacity and therefore improve the performance of the still [25,26]. The nanoparticles added are generally fine metallic or non-metallic particles such as carbon nanotubes [27], zinc oxide (ZnO) and copper oxide (CuO) [28,29] titanium oxide ($TiO_2$) [30] and aluminum oxide $Al_2O_3$ [31].

Because of its availability and low cost, black granite crushed as gravel is one of the most suited materials for use in solar still operations. Using black granite in the basin is not new. Nafey et al. [32] conducted their experimental work using black rubber and black gravels as heat storage medium within a single sloped solar still; they found that black rubber with the size of 10 mm thickness, increased the yield by 20% and black gravel material with a size of 20–30 mm improved the output by19%.

Sakthivel and Shanmugasundaram [33] used black granite as energy storage to analyze the functioning of the solar still. They performed an experiment using different depths of gravel, for example, 12, 18, 20 and 25 mm. Daily gravel productivity has improved by approximately 17%.

Shanmugan [34] studied the impact of different energy storage substances on the efficiency of single basin solar stills with hot water supply. They used concrete stone pebbles and black granite stones as energy storage materials.

The drip procedure is used and copper tubes have been used in the solar still. The results showed that the concrete stone solar still as an energy storage material gave superior efficiency compared to stills which use other energy storage methods. It gave 8.40 L $d^{-1}$ of total distillate and 9.10 L $d^{-1}$ of hot water, even the efficiency of the still increased by 17% by using the drip procedure.

Sellami et al. [9] carried out an experimental study using layers of blackened alluvial sand as a means of heat storage; they studied the influence of the mass of sand and the size of the sand particles on the yield and the photocatalytic behavior of semiconductors present in alluvial sand. The results show that the increase in yield is inversely proportional to the size of the sand particles for a fixed mass of sand. The best result for sand particles is (0.08 mm). As the mass of sand increases, the flow rate of distilled water for a fixed particle diameter increases to an optimal value of 2.268 kg $m^{-2}$ absorber $area^{-1}$. Due to the presence of photocatalysts and their second behavior as adsorbent materials, the resulting distillate is of high quality.

Arjunan et al. [35] used different energy storage materials like black gravel, blue metal stones, pebbles and paraffin wax during the study to investigate the impact of energy storage materials on the efficiency of a simple solar still. They discovered that black granite is a more powerful material than pebbles, stone, blue metal, and paraffin wax. It provides a higher distillate yield than many materials and its improvement is 10.06% higher than that of the conventional still.

This paper aims to enhance the output of a solar still by investigating the impact of different masses of black granite (crushed as gravel) on the still efficiency in Ouargla city under local climate conditions.

## 2. Experimental setup

Solar stills are built to evaluate their performance under different conditions. Fig. 1 shows the schematic view of the experimental design used. These stills have a single basin of (57 cm × 40 cm) surface. The stills are made of galvanized metal 3 mm thick. The pool is completely covered with an insulating material 4 cm thick (polystyrene) to prevent heat loss from the pool to the outside. A sheet of wood 4 cm thick supports the basin box on the insulating material from the outside. Inside the stills, the inner surfaces of the basin bottom and side walls have been blackened to increase the absorption of solar radiation. The upper part of the basin is fitted with a 4mm thick glass cover and inclined nearly 30° from the horizon. The test units have the same dimensions as the control. The solar stills have been sealed to prevent vapor leakage from their basin to the atmosphere by insulation and with silicon at the top. The vapor condensed on the inner surface of the glass cover is collected in a channel at the bottom of the basin and to a graduated tube (1,000 mL) through a plastic tube.

The water level in the conventional basin is generally fixed between 0.5 and 2 cm [11]. In our case, the brackish water level is set around 1.5 cm. Further distiller specifications are displayed in Table 1.

## 3. Experimental procedure

The experiments were carried out at the Process Engineering Laboratory (PEL) in Ouargla University: (31.95°N latitude, 5.40°E longitude). Ouargla city which is located in southern Algeria is situated at 141 m above sea level. It has a solar energy of about 2260 kWh $m^{-2}$ $y^{-1}$ and 3,400 h of sunshine per year [3,9].

To conduct an experimental study regarding the enhancement of the yield, five masses of black granite (5 mm size) crushed as gravel (500 g, 750 g, 1 kg, 1.25 kg and 1.5 kg) were placed so as to cover homogeneously the entire surface of the absorber (Fig. 2).

The gravel's properties make it an important medium for heat storage. Black granite has a heat capacity equal to 0.676 kJ $kg^{-1}$ $K^{-1}$, its thermal conductivity is 0.75 $Wm^{-1}$ $K^{-1}$ and its solar absorbance coefficient is 0.85 [33].

To validate measurements, the latter were repeated during three subsequent days for each unit; the average values were taken and then presented as graphical data.

## 4. Measuring instruments

During the tests, different parameters were measured to evaluate the performance of the system. The temperatures at different points (glass cover temperature, basin water temperature and absorber plate temperature) were measured by K-type thermocouples. Solar radiation was measured using a Solar-meter (Mac-solar). An anemometer (Testo 416) was used to measure wind speed. The quantity of freshwater output was measured by a graduate tube (1,000 mL). The accuracy, range and errors of the measuring tools are presented in Table 2.

## 5. Results and discussion

The experimental research was conducted in March because the weather was sometimes clear during this month in our region nevertheless; from time to time there are a passage of small clouds and a sudden breath of fresh wind which maybe cause a drop of solar irradiance and/or ambient temperature (Figs. 3 and 4).

Fig. 3 displays the variation of solar irradiance (G) vs. local time for three chosen days in this month. As seen in the figure, four points from eleven of solar irradiance are higher than 800 W $m^{-2}$ on March 11th, and eight points on March 14th and nine points on March 20th exceed this value. The minimum value of 635 W $m^{-2}$ is recorded at 08:00 A.M. (March 11th) and 295 W $m^{-2}$ at the end of tests for the same day. The maximum value of 1,067 W $m^{-2}$ was recorded at 11:00 and 13:00 for the day of March 20th. We can say that Ouargla is a perfect place for solar devices [9].

Typical measurement of ambient temperature vs. local time for three chosen days in March is presented in Fig. 4. It is obviously shown that the temperature increases during the morning to reach its maximum value of 33°C at 12:00 A.M.; this variation is due to the variation of the solar irradiance. It can be simply found that the temperature stays high after 16:00 h, which favors distillation even after

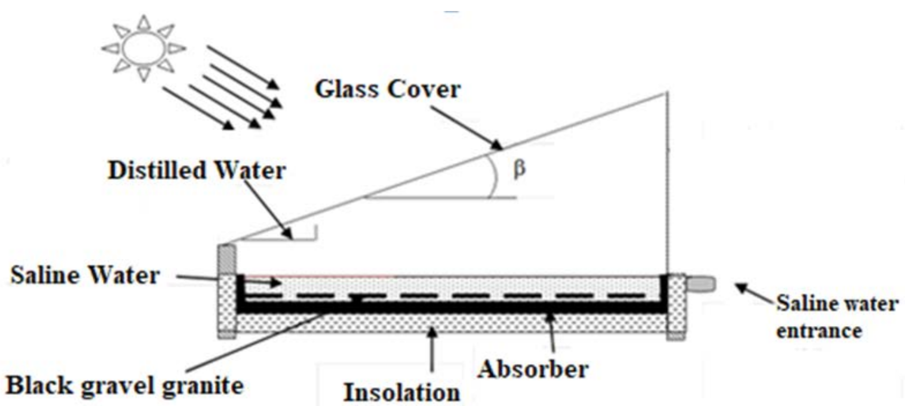


Fig. 1. Schematic diagram of the test desalination unit.

Table 1
Specifications of a single slope solar still used in this research

| Specification | Description | Dimension |
|---|---|---|
| Glass covers | Window glass | 4 mm thickness |
| Frame | Wood | 4 cm thickness |
| Basin | Galvanized metal | 3 mm thickness |
| Insulation | Polystyrene | 4 cm thickness |
| Material | Black gravel | 5 mm size |

Table 2
Accuracy, measurement range and error limit for different measurement devices

| Instrument | Accuracy | Range | % Error |
|---|---|---|---|
| Anemometer | +0.1 m $s^{-1}$ | 0–40 m $s^{-1}$ | 1.5% |
| Thermometer | +0.01°C | 0°C–300°C | 1% |
| Thermocouple | +0.1°C | 0°C–100°C | 1% |
| Solar meter | +1 W $m^{-2}$ | 0–1,500 W $m^{-2}$ | <3% ± 1% |
| Graduate tube | +10 mL | 0–1,000 mL | 1% |

Fig. 2. Photograph view of unit's absorber.

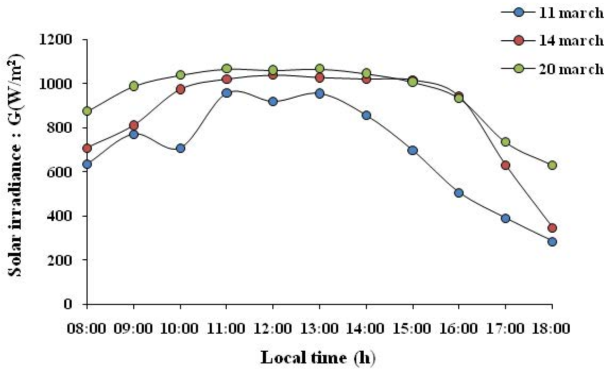


Fig. 3. Solar irradiance vs. local time.

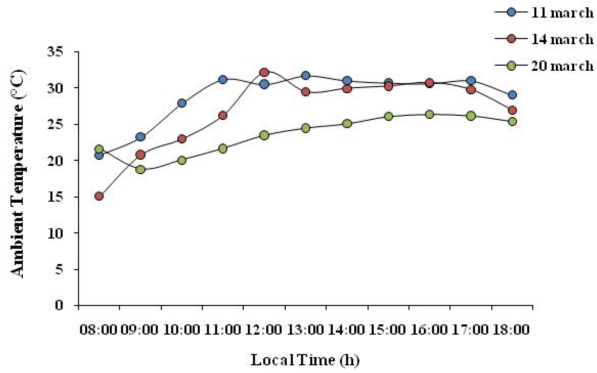


Fig. 4. Ambient temperature vs. local time.

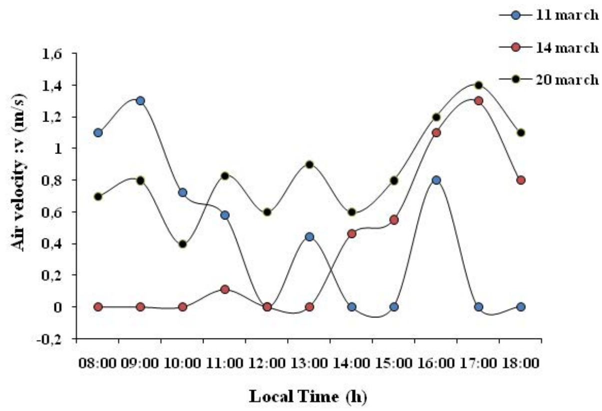


Fig. 5. Wind speed vs. local time.

17.00 h because of thermal inertia and/or the heat storage materials such as black granite in the present study.

Fig. 5 displays the variation of the wind speed vs. local time for the three chosen days. It is clearly seen that the wind speed varies between 0 and 1.4 m $s^{-1}$ during the experiment period. Generally, the low value of wind velocity has not a great effect on the distillation performance. Sudden gusts of breath have been observed at the beginning (March 11 and 20th) and the end (March 11, 14 and 20th) of experiments which explains certain drops in solar irradiance or ambient temperature during these days Fig. 5.

Fig. 6 shows the hourly yield for each unit vs. local time. The graphs indicate that the hourly output is significantly related to the solar irradiance. This figure illustrates that, the hourly output increases from zero in 08:00 to the maximum values between 12:30–14:00 and then they decrease until the end of the day. The hourly production of the solar still with black gravel is higher than that of the witness, because that the granite plays the role of heat storage medium by providing brackish water with energy; in addition, it also plays the second role of an adsorbent material which we'll see later. It should be noted that the drops recorded sometimes in solar irradiance have a negative influence on hourly production.

In summary, Fig. 6 illustrates that the best amount of black gravel granite is around or slightly less than 1.25 kg, but this mass is the most suitable because it covers exactly the entire surface of the absorber in a single layer which allows us to estimate the surface density of black granite to (5.48 kg granite $m^{-2}$ of absorber area).

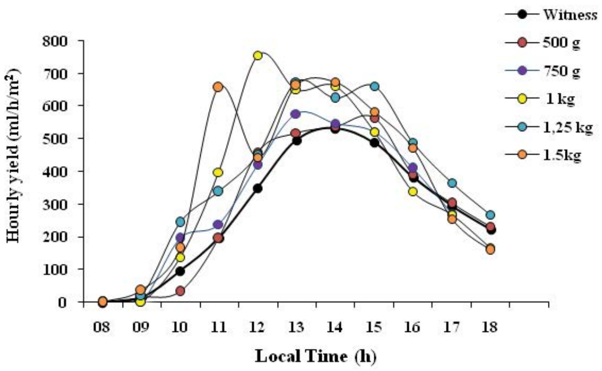


Fig. 6. Effect of the black gravel granite on the hourly yield for each unit.

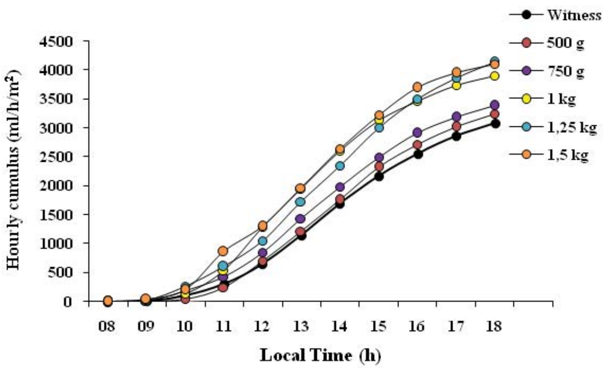


Fig. 7. Effect of black gravel's mass on the hourly cumulus of each unit.

The hourly output usually does not offer a good judgment about the still yield; the assumptions are also confirmed by the daily accumulated output; Fig. 7 will confirm our remarks. As shown, all units with the granite produce more than witness unit however their different enhancement. The units with gravel of: 500 g, 750 g, 1.0 kg, 1.25 kg, 1.5 kg and the witness has the respective outputs of: 3,251.01; 3,386.67; 3,901.58; 4,134.77; 4,108.83 and 3,083.52 mL m$^{-2}$.

By calculating the gain in the output, the proportion of the increase in the output for units with black gravel was respectively: 5.43%, 9.83%, 26.53%, 34.09% and 33.25%; so, the best unit is that with 1.25 kg of gravel.

Fig. 8 illustrates the result of the gain's variation in distilled water vs. the mass of heat storage medium for the studied cases. As seen, the curve reaches its maximum near ($m$ = 1.25 kg) of black granite; the daily yield is 4.135 kg m$^2$ with an enhancement of 34.09% compared to the baseline case. So, the heat storage mass of 1.25 kg of gravel, that is, (5.48 kg of gravel m$^{-2}$ of absorber area) is almost the optimal value which can be chosen.

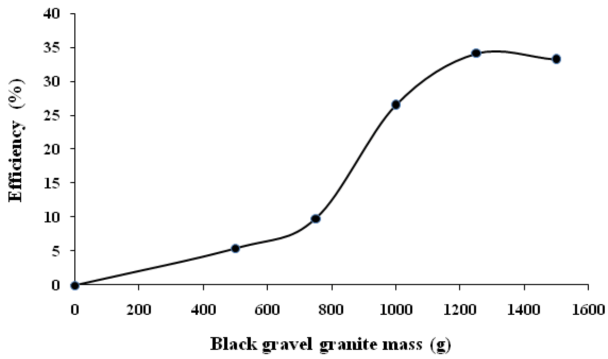


Fig. 8. Enhancement rate vs. the black granite gravel mass.

## 6. Water analysis report

To evaluate their quality, brackish and distilled waters by the witness and that obtained by gravel's units have been analyzed for some of their important physical parameters specifically: pH, total dissolved solids (TDS), salinity and electrical conductivity using the appropriate equipment previously cited. The mean values of these analyses are presented in Table 3.

It can be easily observed that distilled water produced by conventional unit (without gravel) is better than brackish water from a quality point of view; however, the distillate obtained using black granite is the best by referring to the salinity, conductivity and TDS; so, the black granite plays also the role of water's purifying or otherwise an adsorbent material.

Table 4 gives an overview between the yield enhancement of this study and some other solar stills recently carried out by several other researchers in the world (Nafey et al. [32]; Sakthivel and Shanmugasundaram [33]; Shanmugan [34], Arjunan et al. [35], Panchal et al. [36], Ali Ouar et al. [16], Nasri et al. [37] and Muthu Saravanan et al. [38]). The results shown in the following table indicate that the present work and its results are acceptable compared with those of other studies.

## 7. Distilled water cost price

To assess the cost price of the distillate, we will follow the same method and the same equations used previously

Table 3
Physical parameters of brackish and distilled water

| Water quality | pH | TDS (mg L$^{-1}$) | Salinity (%) | Conductivity (µs cm$^{-1}$) |
|---|---|---|---|---|
| Brackish water | 7.98 | 2,025 | 2.14 | 4,047 |
| Distilled water with black granite | 6.04 | 5.81 | 0.05 | 2.05 |
| Distilled water by witness unit | 6.78 | 6.11 | 0.07 | 2.38 |

Table 4
Comparison between the present study and those obtained by other researchers

| Author and year | Materials used | Location | Daily production (kg m$^{-2}$) | Yield improvement (%) |
|---|---|---|---|---|
| Nafey et al. [32] | Black rubber – black gravels | Suez, Egypt | 3.5 | 20%–19% |
| Sakthivel and Shanmugasundaram [33] | Black gravel | Tamil Nadu, India | 3.9 | 17 |
| Shanmugan [34] | Concrete stone, pebbles and black granite stones | Tamil Nadu, India | 6.90, 6.40 and 5.95 | 17 |
| Arjunan et al. [35] | Black granite, blue metal stones, pebbles and paraffin wax | Tamil Nadu, India | 2.6 | 10.06 |
| Panchal et al. [36] | Sand stone | Gujarat, India | 3.58 | 28.71 |
| Ali Ouar et al. [16] | Bitumen | Ouargla, Algeria | 4.64 | 25.35 |
| Nasri et al. [37] | Gravel | Adrar, Algeria | 5 | 32.20 |
| Muthu Saravanan et al. [38] | Kanche marbles | Tamil Nadu, India | 4.094 | 16.32 |
| Present study 2020 | Black granite | Ouargla, Algeria | 4.135 | 34.09 |

Table 5
Comparison between the distillate cost price of the present study and that of other works taken as example

| Author | Material used as heat storage medium | Distillate cost price (DZD kg$^{-1}$) 1 US $ = 150 DZD | Year |
|---|---|---|---|
| Sellami et al. [11] | Portland cement | 0.88 | 2016 |
| Sellami et al. [10] | Mixture of portland cement and alluvial sand | 0.48 | 2016 |
| Sellami et al. [3] | Sponge layers | 0.45 | 2017 |
| Ali Ouar et al. [16] | Absorbent material (bitumen, charcoal and black ink) | 0.76 | 2017 |
| Nasri et al. [37] | Gravel | 0.72 | 2019 |
| Present study | Black granite gravel | 0.69 | 2020 |

in our old works [3,10,11,16], taking in addition another example from the Algerian Sahara [37] to compare the result of this study with those obtained with identical and/or similar materials and the same principle (heat storage); and then see if the process is economical or not. The results are summarized in Table 5, knowing that: 1 US $ = 150 Algerian Dinars (DZD).

## 8. Conclusion

This work is a contribution to solving the problem of the shortage of drinking water encountered in southern Algeria. Our experiments aim to increase the efficiency of conventional stills installed in these areas by adding black granite crushed as gravel in the still absorber. The experiments carried out at Ouargla University during the end of winter based on an economic study, reveal that:

- The Saharan region in Algeria is sunny most of the year; so, it is an ideal place for all kinds of solar activities.
- It is clear that the granite crushed as gravel is a widely available and costly material which can enhance the yield of solar still when it is added as heat storage medium.
- Adding black granite with the mass of 500 g, 750 g, 1 kg, 1.25 kg and 1.5 kg improves the still output by 5.43%, 9.83%, 26.53%, 34.09% and 33.25% respectively compared to the baseline case.
- The best result is obtained with 1.25 kg of granite resulting in a daily production of 4.135 kg m$^{-2}$ of distillate with 34.09% improvement compared to the baseline case.
- In addition, the analysis of some physical parameters of distilled and brackish water shows that the water quality is markedly improved after distillation in the presence of granite, which explains that the latter plays also the role of an adsorbent material because of its color and its chemical composition reducing therefore, the concentration of many organic compounds present in water such as phenols.

## References

[1] H.N. Panchal, Use of thermal energy storage materials for enhancement in distillate output of solar still: a review, Renewable Sustainable Energy Rev., 61 (2016) 86–96.
[2] A.E. Kabeel, E.M.S. El-Said, Water production for irrigation and drinking needs in remote arid communities using

closed-system greenhouse: a review, Eng. Sci. Technol. Int. J., 18 (2015) 294–301.

[3] M.H. Sellami, T. Belkis, M.L. Aliouar, S.D. Meddour, H. Bouguettaia, K. Loudiyi, Improvement of solar still performance by covering absorber with blackened layers of sponge, Groundwater Sustainable Dev., 5 (2017) 111–117.

[4] K. Srithar, T. Rajaseenivasan, N. Karthik, M. Periyannan, M. Gowtham, Stand alone triple basin solar desalination system with cover cooling and parabolic dish concentrator, Renewable Energy, 90 (2016) 157–165.

[5] M. Faegh, M.B. Shafii, Experimental investigation of a solar still equipped with an external heat storage system using phase change materials and heat pipes, Desalination, 409 (2017) 128–135.

[6] M.S. Yousef, H. Hassan, An experimental work on the performance of single slope solar still incorporated with latent heat storage system in hot climate conditions, J. Cleaner Prod., 209 (2019) 1396–1410.

[7] M. Edalatpour, K. Aryana, A. Kianifar, G.N. Tiwari, O. Mahian, S. Wongwises, Solar stills: a review of the latest developments in numerical simulations, Sol. Energy, 135 (2016) 897–922.

[8] H. Panchal, I. Mohan, Various methods applied to solar still for enhancement of distillate output, Desalination, 415 (2017) 76–89.

[9] M.H. Sellami, H. Bouguettaia, D. Bechki, M. Zeroual, S. Kachi, S. Boughali, B. Bouchekima, H. Mahcene, Effect of absorber coating on the performance of a solar still in the region of Ouargla (Algeria), Desal. Water Treat., 51 (2013) 6490–6497.

[10] 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.

[11] M.H. Sellami, R. Touahir, S. Guemari, K. Loudiyi, Use of Portland cement as heat storage medium in solar desalination, Desalination, 398 (2016) 180–188.

[12] O. Ansari, M. Asbik, A. Bah, A. Arbaoui, A. Khmou, Desalination of the brackish water using a passive solar still with a heat energy storage system, Desalination, 324 (2013) 10–20.

[13] S.A. Kalogirou, Seawater desalination using renewable energy sources, Prog. Energy Combust. Sci., 31 (2005) 242–281.

[14] A.G.M. Ibrahim, S.E. Elshamarka, Performance study of a modified basin type solar still, Sol. Energy, 118 (2015) 397–409.

[15] C. Elango, N. Gunasekaran, K. Sampathkumar, Thermal models of solar still—a comprehensive review, Renewable Sustainable Energy Rev., 47 (2015) 856–911.

[16] M.L. Ali Ouar, M.H. Sellami, S.E. Meddour, R. Touahir, S. Guemari, K. Loudiyi, Experimental yield analysis of groundwater solar desalination system using absorbent materials, Groundwater Sustainable Dev., 5 (2017) 261–267.

[17] A. Bilal, B. Jamil, N. Ul Haque, A. Ansari, Investigating the effect of pumice stones sensible heat storage on the performance of a solar still, Groundwater Sustainable Dev., 9 (2019) 100228, doi: 10.1016/j.gsd.2019.100228.

[18] R. Tripathi, G.N. Tiwari, Performance evaluation of a solar still by using the concept of solar fractionation, 169 (2004) 69–80.

[19] R. Kalbasi, A.A. Alemrajabi, M. Afrand, Thermal modeling and analysis of single and double effect solar stills: an experimental validation, Appl. Therm. Eng., 129 (2018) 1455–1465.

[20] R. Cherraye, B. Bouchekima, D. Bechki, H. Bouguettaia, A. Khechekhouche, The effect of tilt angle on solar still productivity at different seasons in arid conditions (South Algeria), Int. J. Ambient Energy, 41 (2020) 1–7.

[21] M.B. Shafii, A. Favakeh, M. Faegh, H. Sadrhosseini, Experimental investigation of a novel passive solar still with additional condensation on sidewalls, Desal. Water Treat., 89 (2017) 29–35.

[22] P. Patel, R. Kumar, Comparative performance evaluation of modified passive solar still using sensible heat storage material and increased frontal height, Procedia Technol., 23 (2016) 431–438.

[23] M. Sakthivel, S. Shanmugasundaram, T. Alwarsamy, An experimental study on a regenerative solar still with energy storage medium — Jute cloth, Desalination, 264 (2010) 24–31.

[24] S.M. Deshpande, J. Deepak, N. Patel, Enhancement of Solar still with Internal, External Reflector and Black Granite Gravel, Conference: International Conference on Futuristic Trends in Engineering, Science, Pharmacy and Management, Vadodara, India, 2016.

[25] B. Gupta, A. Kumar, P.V. Baredar, Experimental investigation on modified solar still using nanoparticles and water sprinkler attachment, Front. Mater., 4 (2017) 1–7, doi: 10.3389/fmats.2017.00023.

[26] A. Elfasakhany, Performance assessment and productivity of a simple-type solar still integrated with nanocomposite energy storage system, Appl. Energy, 183 (2016) 399–407.

[27] M.K. Gnanadason, P.S. Kumar, G. Jemilda, S.S. Jasper, Effect of nanofluids in a modified vacuum single basin solar still, Int. J. Sci. Eng. Res., 3 (2012) 1–7.

[28] M. Sindal, N. Singh, A. Sharma, Solar desalination using zinc oxide as photocatalyst, J. Chem. Biol. Phys. Sci., 3 (2013) 958–962.

[29] M. Sindal, N. Singh, A. Sharma, Use of cupric oxide as photocatalyst in solar desalination, Int. J. Green Herbal Chem., 2 (2013) 203–207.

[30] B. Panitapu, V. Koneru, S. Lalitha, S. Sagi, A. Parik, Solar distillation using nano-material, Int. J. Sci. Eng. Technol., 587 (2014) 583–587.

[31] 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. Manage., 78 (2014) 493–498.

[32] A.S. Nafey, M. Abdelkader, A. Abdelmotalip, A.A. Mabrouk, Solar still productivity enhancement, Energy Convers. Manage., 42 (2001) 1401–1408.

[33] M. Sakthivel, S. Shanmugasundaram, Effect of energy storage medium (black granite gravel) on the performance of a solar still, Int. J. Energy Res., 32 (2008) 68–82.

[34] S. Shanmugan, Experimental investigation of various energy absorbing materials on performance of single slope single basin solar still with hot water provision, Int. J. Innovative Res. Sci. Eng. Technol., 2 (2013) 7760–7767.

[35] T.V. Arjunan, H.S. Aybar, P. Sadagopan, B.S. Chandran, S. Neelakrishnan, N. Nedunchezhian, The effect of energy storage materials on the performance of a simple solar, Energy Sources Part A, 36 (2014) 131–141.

[36] H. Panchal, P. Patel, N. Patel, H. Thakkar, Performance analysis of solar still with different energy-absorbing materials, Int. J. Ambient Energy, 38 (2017) 224–228.

[37] B. Nasri, A. Benatiallah, S. Kalloum, D. Benatiallah, Improvement of glass solar still performance using locally available materials in the southern region of Algeria, Groundwater Sustainable Dev., 9 (2019) 100258, doi: 10.1016/j.gsd.2019.100213.

[38] N. Muthu Saravanan, S. Rajakumar, A.A.M. Moshi, Experimental investigation on the performance enhancement of single basin double slope solar still using kanchey marbles as sensible heat storage materials, Mater. Today Proc., 39 (2021) 1600–1604.