Energy, exergy, and economic analysis of solar still using coal cylinder fins: an experimental study

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Received: 30 April 2022 / Accepted: 27 July 2022 / Published online: 6 August 2022
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Abstract
The phenomenon of drinking water scarcity has turned into the foremost issue that the world’s populace is facing today. The Algerian desert regions, including the El Oued region (southeastern Algeria), also suffer from drinking water shortages, despite the presence of huge quantities of underground salty water. Solar distillation is among the easy and cheap solutions to solve this problem because this method relies on renewable energy (solar energy) as a key factor in providing drinking water from saltwater. As solar energy is intermittent energy, energy storage is required for augmenting the yield. Coal cylinders are low cost and locally available materials that can be used as fins and energy storage materials. In this research, two solar stills such as conventional solar still with a black absorber (CSS-BA) and CSS with a black absorber and coal cylinders (CSS-BA&CC) were fabricated and tested. The CSS-BA&CC produced a potable water yield of about 4.16 kg per day while the CSS-BA could only produce 2.88 kg, which is 44.44% lower when compared to the CSS-BA&CC. The thermal efficiency was noted to be 22.04% and the exergy efficiency is 1.07% in the CSS-BA. Similarly, the thermal efficiency is 32.46% and exergy efficiency is 1.90% for the CSS-BA&CC. The experimental results proved that the potable water yield of the CSS-BA was enhanced by coal cylinders (sensible heat energy storage material -SHESM) which is a locally available low-cost material.

Keywords Distilled water · Solar still · Fins · Energy storage

Nomenclature

| Symbol | Description |
|--------|-------------|
| css-ba | conventional Solar Still with a Black Absorber |
| CSS-BA&CC | conventional solar still with a black absorber and the coal cylinders |
| TE | thermal efficiency |
| EE | exergy efficiency |
| \( T_a \) | ambient temperature |
| \( T_{bw} \) | brine water temperature |
| \( T_g \) | glass temperature |
| SS | solar still |

Introduction
In the Algerian desert regions, especially the city of El Oued, saltwater resources are available in great abundance, and their desalination requires high electrical energy and fossil energy consumption such as natural gas, which increases the production price (Prasad et al. 2021; Ng et al. 2015). Saline water desalination has become essential to produce drinkable water and fulfill the growing needs of the population for this element. Several technologies for desalination exist, including reverse osmosis (RO), membrane distillation (MD), and direct contact MD (DCMD), but they required enormous amounts of energy for their operation, such as electricity, to operate the pumps (Frantz and Seifert 2015; Azimibavil and Dehkordi 2016; Chandrika et al. 2021). Solar distillation is among the technologies, which is considered the least difficult, as it relies on sustainable energy sources. It uses solar energy to produce drinking water from...
seawater, and therefore solar distillation is best suited for water desalination (Gullinkala et al. 2010; Sathish Kumar et al. 2019; Al-harahsheh et al. 2018). But it still needs improvement to increase productivity.

(Attia et al. 2021a) performed investigation on the effect of the number and length of the fins made of iron on hemispherical SS. The depth of the water was fixed at 3 cm, the height of the fins changed (1, 2, and 3 cm), and the dimension between the fins was changed to 5 and 7 cm. The results confirmed the increase of the efficiency rates in the still with the fins of the height 2-cm and 7-cm dimension between the fins. Attia et al. (2021b) studied the sand grains effect by various concentrations on the hemispherical SS. The outcomes confirmed that the distillation production when the concentration of sand grains is 30 g/L is the best and produced 7270 ml/m²/day. Omara et al. (2011) experimentally conducted comparison between three configurations (conventional, corrugated, and vertical finned CSS). The scholars showed that the daily production of vertical finned and corrugated was 40 and 21%, higher, respectively, compared to CSS. Kabeel et al. (2018) did new studies on CSS with graphite. The authors reported that CSS with graphite showed a 75.23% increase in freshwater production, compared to the CSS. Attia et al. (2021c) studied experimentally the effect of phosphate bed on SS. The experimental outcome showed that freshwater production and exergy efficiency using phosphate bed is equal to 3550 JLm²/day and 31%, respectively. However, without using a phosphate bed, these values become equal to 3040 mL/m²/day and 24.6%, respectively. Attia et al. (2020) developed a study on the effect of the aluminum balls of diameter 2 cm, distributed in the bottom of the distiller (6 × 7 balls). They concluded that the presence of aluminum balls enhanced freshwater production by 37.20%. Samuel et al. (2016) analyzed the performance of the various storage materials like ball salt storage materials and sponges in CSS. The results showed that the yield per day is 3.7 L/m² when using ball salt storage and 2.7 L/m² when the sponge is used. Nafey et al. (2021) performed studies on various black materials on CSS productivity. The observed results indicated that the yield was enhanced by 19% when using black gravel and 20% when using black rubber. Omara and Kabeel (2014) conducted a study to compare the effect of sand types (yellow and black) on solar chipping. The sand was placed as a layer at the bottom of the still and concluded that the potable water production has been enhanced by 42 and 17% when using a layer of black and yellow sand, respectively. Rajaseenivasan and Srithar (2016) conducted a study to compare the effect of fin types (circular and square) on solar chipping. The outcomes showed that the yield improved by 45.8 and 36.7% when the circular and square fins were used, respectively. Tabrizi and Sharak (2010) reported the effect of using a sand layer of thickness of 12 cm. The layer was placed at the bottom of the CSS. Compared to the conventional method, the daily production had improved by 12%. Attia et al. (2021d) published a comparative analysis between CSS and the CSS which was modified by adding 25 phosphate bags. The scientists noticed that the output of the CSS with phosphate bags at 1 and 2 cm depth of basin water was 28 and 22.5% higher, respectively, when related to the CSS. Attia et al. (2021e) experimentally placed twenty-five sandbags as energy storage materials in CSS and compared their performance with the CSS throughout the day. The outcome showed that the yield productivity is 5060 ml/m² when sandbags were used, and 3760 ml/m² by CSS. Parsa (2021) conducted the first feasibility study of using SS as a means of purifying water at the microscopic level to kill the microbes and make them fit to drink. This study comes in the wake of the COVID-19 pandemic. Sathyamurthy et al. (2021) studied the effects of adding fins to the absorber plate in a tubular model and noted an enhanced yield of 46.85% from the modified SS model. Islam et al. (2021) analyzed the optimum dimensions of a fin to produce enhanced performance. The fins of diameter 0.3 cm and 3 cm in height could produce a 41% higher yield than the conventional model. Panchal et al. (2020) experimentally examined the influence of inclined and vertical fins on freshwater productivity and observed a 26.77% enhancement in yield. Jani and Modi (2019) analyzed the performance and productivity of SS with circular and square-shaped fins. The percentage rise in yield was calculated to be 54.22% when compared to the conventional SS. Rabhi et al. (2017) achieved a 41.95% increase in freshwater yield and a 12.9% rise in efficiency when they were used condenser and pin fin absorber. Sakhivel et al. 2010 used jute cloth in CSS.

Recently, Mevada et al. (2022) used black color glass balls, black granite, and white marble stone as SHESM in CSS. CSS with rock stone bed in the basin was published by Karthick et al. (2021). Hassan and Abo-Elfadl (2021) used sand and black wool fibers as SHESM in CSS. Metal matrix structures were used as SHESM in CSS by Sathish et al. (2020). Kabeel et al. (2019) used composite material heat storage in CSS. Nagaraj et al. (2021) used Quartzite rock in CSS. Logesh et al. (2021) used an Omani rock stone bed in the CSS. The different types of fins are pin fin (Rabhi et al. 2017; Yousef et al. 2019), circular fin (El-Sebaii et al. 2015; Singh et al. 2019), Triangular fin (Abdulattee et al. 2019), square fin (Jani and Modi 2019; Rajaseenivasan and Srithar 2016), rectangular fin (Appadorai and Velmurugan 2015), and porous fin (Srivastava and Agrawal 2013). A detailed review of SS with energy storage materials published by Chauhan et al. (2021) was referred. From the detailed review, it is identified that no research work was reported in SS with coal cylinders as energy storage materials/fins. Hence in this work, we conducted experiments with the same two distillation units, the first distillation device being the CSS with a black absorber (CSS-BA) and the second distiller being the conventional solar still with a black absorber and the coal
cylinders (CSS-BA&CC). In this work, 42 identical coal cylinders with a diameter of each cylinder measuring 2-cm diameter and 0.5 cm high were used as fins. Coal cylinders are fixed at the basin which is used to improve the distillation yield. The experimentation was performing March 2021.

**Investigational methodology**

**The CSS description**

The CSS device is depicted in Fig. 1, contains a wooden basin, the basin’s length and width are 500 mm, the rear height of 14 cm, the face height of 6 cm, and 2.5 cm of a thick wall. The cover material’s thickness is 3 mm and it is made of glass. The inclination of the collector cover is 15°. The condensed water droplets are collected on the inner walls of the glass which then pass into a PCV tube and are finally transferred to the accumulation tank.

**Experimentations**

The experimental photographs of CSS with and without coal cylinders are shown in Figs 1 and 2. Two identical CSS are constructed for the experiment, the first is conventional solar still with a black absorber (CSS-BA) and the second is CSS with a black absorber and coal cylinders (CSS-BA&CC) were fabricated and tested. Initially, the absorber plates (flat absorbers) of both the stills are coated with black paint (Silicon). The first SS is the conventional model and in the second, coal cylinders were used. The number of coal cylinders attached to the absorber plate is 42 identical coal cylinders with a diameter of each cylinder measuring 2 cm diameter and 0.5 cm high were used as fins it is placed at a bottom of the basin, evenly distributed (7×6). The entire research was conducted at the El Oued University in El Oued-Algeria, and experiments are carried out in March 2021, in the climatic conditions indicated in Table 1. Table 2 shows the properties of coal.

**Analysis of experimental errors**

There is a possibility of mistakes in instruments. Due to this, it is mandatory to calculate and estimate the errors made. The solar power meter, thermocouple (K-type), and flask are used to check solar irradiation, temperature, and the amount of water collected per hour, respectively. A digital temperature indicator is used to display the measured temperature. Table 3 shows the errors in the devices used.

**Results and discussion**

**Hourly variations in solar irradiance, temperatures of ambient (Ta), brine water (Tb.w), and glass (Tg) for the CSS-BA and CSS-BA&CC**

Figures 3 and 4 display the timely changes in solar irradiance, $T_a$, $T_{b.w}$, and $T_g$ for the CSS-BA and CSS-BA&CC, respectively on 31-3-2021. Figures 5 and 6 display the timely changes in solar irradiance, $T_a$, $T_{b.w}$, and $T_g$ for the CSS-BA and CSS-BA&CC, respectively on 3-4-2021. The graphs depict that the solar irradiance rises constantly and reaches the maximum of 1005 ± 10 W/m² at 1 P.M on 31-3-2021 and 1010 ± 10 W/m² at 1 P.M on 3-4-2021. The $T_a$, $T_{b.w}$, and $T_g$ also rose similarly and obtained their peak value at 1 P.M on both 31-3-2021 and 3-4-2021. The maximum $T_a$ and average $T_a$ per day during the study were recorded to be 47 and 39.27 ± 0.1 °C, on 31-3-2021, 49 and 39.82 ± 0.1 °C, on 3-4-2021, respectively. The highest
Table 1  The climatic conditions of El Oued city

| Date          | 31/03/2021 |
|---------------|------------|
| Sunrise       | 06: 20 A.M.|
| Sunset        | 06: 51 P.M.|
| Minimum and Maximum of $T_a$ | 16–48°C |
| Average Humidity | 18 %  |
| Average Wind speed | 10 km/h |

Table 2  The properties of coal

| Properties                          | Values                  |
|-------------------------------------|-------------------------|
| Thermal conductivity (W/m K)        | 0.46                    |
| Density (g/cm$^3$)                  | 1.78                    |
| Specific Heat Capacity (J/(g. K))   | 1.26                    |
| Dimensions                         | 2-cm diameter and 0.5-cm height |
The mean value of $T_{\text{b.w}}$ per day for the CSS-BA was observed to be $66 \pm 0.1 \, ^\circ \text{C}$ on 31-3-2021 and $67 \pm 0.1 \, ^\circ \text{C}$ on 3-4-2021 while for the CSS-BA&CC was $71 \pm 0.1 \, ^\circ \text{C}$ on 31-3-2021 and $72 \pm 0.1 \, ^\circ \text{C}$ on 3-4-2021. Due to the higher thermal property of the material used within the basin, the CSS-BA&CC shows increased $T_{\text{b.w}}$.

The calorimetric property of the material used within the basin, the CSS-BA&CC shows increased $T_{\text{b.w}}$. The coal cylinders along with the black absorber enhanced the $T_{\text{b.w}}$ by up to $4 \pm 0.1 \, ^\circ \text{C}$. It can use the stored heat during the off-shine hours and increase the $T_{\text{b.w}}$. The $T_g$ of the CSS-BA&CC is a little greater than the CSS-BA. The highest $T_g$ for the CSS-BA was recorded to be $52 \pm 0.1 \, ^\circ \text{C}$ on 3-4-2021 while the CSS-BA&CC glass showed $53 \pm 0.1 \, ^\circ \text{C}$ on 3-4-2021. Due to modifications and the addition of coal cylinders to the CSS-BA&CC, the $T_g$ in the CSS-BA&CC was observed to be more when compared to the CSS-BA. The coal cylinders enhanced the rate of

Table 3: Accurateness and error range of measuring devices

| Instrument       | Range                | Accuracy   | Error     |
|------------------|----------------------|------------|-----------|
| Solar meter      | 0–3500 W/m²          | ±10 W/m²   | ±3.5%     |
| Calibrated flask | 0–1500 ml            | ±10 ml     | ±1.5%     |
| Thermocouple     | −100 to 600°C        | ±0.1°C     | ±1.5%     |

$T_{\text{b.w}}$ in the CSS-BA was observed to be $66 \pm 0.1 \, ^\circ \text{C}$ on 31-3-2021 and $67 \pm 0.1 \, ^\circ \text{C}$ on 3-4-2021 while for the CSS-BA&CC was $71 \pm 0.1 \, ^\circ \text{C}$ on 31-3-2021 and $72 \pm 0.1 \, ^\circ \text{C}$ on 3-4-2021. The mean value of $T_{\text{b.w}}$ per day for the CSS-BA is $54.72 \pm 0.1 \, ^\circ \text{C}$ on 31-3-2021, $55.64 \pm 0.1 \, ^\circ \text{C}$ on 3-4-2021 and the CSS-BA&CC showed $58.45 \pm 0.1 \, ^\circ \text{C}$ on 31-3-2021, $59.27 \pm 0.1 \, ^\circ \text{C}$ on 3-4-2021. Due to the higher thermal property of the material used within the basin, the CSS-BA&CC shows increased $T_{\text{b.w}}$. The coal cylinders along with the black absorber enhanced the $T_{\text{b.w}}$ by up to $4 \pm 0.1 \, ^\circ \text{C}$. It can use the stored heat during the off-shine hours and increase the $T_{\text{b.w}}$.
evaporation due to which the $T_g$ of the CSS-BA&CC is higher.

**Hourly variations in the EHTC and yield**

Figure 7 and 8 show the timely changes in the EHTC value and yield production of the CSS-BA and CSS-BA&CC on 31-3-2021 and 3-4-2021, respectively. The maximum EHTC of the CSS-BA is 31.24 W/m²K on 31-3-2021, 32.62 W/m²K on 3-4-2021 and the maximum EHTC of the CSS-BA&CC is 38.46 W/m²K on 31-3-2021, 40.02 W/m²K on 3-4-2021 at 1 P.M. The average value of EHTC per day of the CSS-BA was noted to be 20.59 W/m²K on 31-3-2021, 21.32 W/m²K on 3-4-2021, and that for the CSS-BA&CC is 24.65 W/m²K on 31-3-2021, 24.65 W/m²K on 3-4-2021. The CSS-BA&CC enhances the value of EHTC by about 16.5% more than the CSS-BA. The process of evaporation in the SS is highly influenced by the material in the basin. In the CSS-BA&CC, the coal cylinders have greater thermal conductivity than the CSS-BA. So the value of EHTC of the CSS-BA&CC is observed to be greater than the CSS-BA. The highest freshwater productivity per hour from the CSS-BA is $0.52 \pm 0.01$ kg whereas the CSS-BA&CC produced about $0.78 \pm 0.01$ kg at 1 P.M. Freshwater production of $2.95 \pm 0.01$, $4.22 \pm 0.01$ kg was produced in a day from the CSS-BA, CSS-BA&CC, respectively. The CSS-BA&CC improved the freshwater productivity by 43% more than the CSS-BA. The coal cylinders placed within the basin minimize the loss of heat from the CSS-BA&CC basin. Due to greater thermal conductivity within the basin of the CSS-BA&CC, it enhances the $T_{b,w}$ EHTC, and potable water productivity.

**Fig. 7** Periodic changes in the values of EHTC and freshwater productivity from the CSS-BA and CSS-BA&CC on 31-3-2021

**Fig. 8** Periodic changes in the values of EHTC and freshwater productivity from the CSS-BA and CSS-BA&CC on 3-4-2021

**Hourly variations in the thermal efficiency and exergy efficiency of the CSS-BA and CSS-BA&CC**

Figure 9 and 10 depict the temporal variations in the thermal efficiency (TE) and exergy efficiency (EE) of the CSS-BA and CSS-BA&CC on 31-3-2021 and on 3-4-2021, respectively. During the day, the TE increases constantly and attains its highest value at 1 P.M. The highest TE value of the CSS-BA is 32.62% on 31-3-2021, 32.94% on 3-4-2021 and the CSS-BA&CC is 49.61% on 31-3-2021, 49.41% on 3-4-2021. The daily average TE of the CSS-BA is 22.04% on 31-3-2021, 21.64% on 3-4-2021 and the CSS-BA&CC is 32.46% on 31-3-2021, 32.17% on 3-4-2021. The TE and the distilled water production for the SS are related. In CSS-BA&CC, the presence of coal cylinders enhanced the
freshwater yield. So the TE of the CSS-BA&CC is 32 % greater than compared to the CSS-BA. The EE and TE of the stills have a similar graphical curve. The highest EE of the CSS-BA is 2.11 % on 31-3-2021, 2.03 % on 3-4-2021 and the CSS-BA&CC is 3.35 % on 31-3-2021, 3.47 % on 3-4-2021 which was observed during the afternoon hours. The average EE of the CSS-BA was noted to be 1.08 % on 31-3-2021, 1.1 % on 3-4-2021, and that for the CSS-BA&CC is 1.9 % on 31-3-2021, 1.89 % on 3-4-2021. The EE of the CSS-BA&CC is 41.7 to 43.68 % higher than the CSS-BA.

The cumulative freshwater yield was noted from the outcomes from the CSS-BA and CSS-BA&CC, during the day of the research (31 March 2021 and 3 April 2021 from 8 A.M to 6 P.M) is shown in Table 4 the CSS-BA model produced a daily yield of 2.88 ± 0.01 kg/m² while the CSS-BA&CC could produce 4.16 ± 0.01 kg/m² freshwater which was 44.44 % enhanced than the conventional model. The thermal efficiencies of the CSS-BA and CSS-BA&CC models were noted to be 22.04 % and 32.46 %, respectively while the exergy efficiencies were observed to be 1.07 % and 1.9 %, respectively. Due to the inclusion of coal cylinders with high thermal properties, the CSS-BA&CC showed better productivity and efficiency.

Comparison of similar studies

Table 5 shows the comparison of similar studies of the same conventional models. Several modifications were introduced in the conventional model of the solar still. To increase the performance and productivity of the solar still, several high thermal property materials were used by Kabeel et al. (2018) and reported a maximum yield of 7.73 kg, Samuel et al. (2016) used CSS integrated with sponges and reported a minimum yield of 2.7 kg. The thermal material used here is a coal cylinder bed in the basin and it has produced a yield of 4.16 ± 0.01 kg.

Economic analysis

Table 6 shows the calculation to find the number of days required to recover the net cost of CSS-BA&CC and CSS-BA. The common costs between the CSS-BA and CSS-BA&CC involve the apparatus cost (8000 DZD) and the maintenance cost (50 DZD). The CSS-BA&CC uses coal cylinders (10 DZD) for enhancing its performance. The market rate for 1 L freshwater is 60 DZD. The CSS-BA produces a yield of 2.88 kg/m² which costs about 207.6 DZD while the CSS-BA&CC with daily productivity of 4.16 kg/m² costs about 242.4 DZD. The payback period for the CSS-BA was calculated to be 39 days while for the CSS-BA&CC, it was 33 days.

Equations for the calculation payback period

\begin{align}
TC &= TCM + MC \quad (1a) \\
TC &= TCM + MS + CCP \quad (1b) \\
DWPC &= PAW + CDWM \quad (2) \\
PP &= \frac{TC}{DWPC} \quad (3)
\end{align}

Equation (1.a) is for CSS-BA  
Equation (1.b) is for CSS-BA&CC

TC total cost of manufacture.
CCP coal cylinders of the price.
MC maintenance cost.
TC  total cost.

PAW  the produced amount of water during the day.

CDWM  the cost per liter of distilled water on the market.

DWPC  the daily water production cost.

PP  payback period.

Conclusions

From the current study of two CSS (CSS with a black absorber and CSS with the coal cylinders), the effect of coal cylinders on the productivity of solar distillate is studied and the following conclusions have been made:

- Coal cylinders increase the surface area of the basin on the one hand. On the other hand, they act as energy storage materials, which further heat the basin water. Coal cylinders are also low cost and locally available. Therefore, the use of coal cylinders as fins improves the yield of distillation.

- In CSS with a black absorber and the coal cylinders, the difference in $T_{b,w}$ and $T_g$ is $15°C$ and without coal cylinders, it is $10°C$.

- Coal cylinders led to a rise in $T_{b,w}$ due to which the production of distilled water from CSS-BA&CC was greater than CSS-BA.

- The CSS-BA&CC produced a potable water yield of about $4.2$ kg per day while the CSS-BA could only produce $2.95$ kg, which is $43.3%$ lower when compared to the CSS-BA&CC.

- The TE was noted to be $22.04%$ and the EE is $1.07%$ in the CSS-BA in a day. Similarly, the TE is $32.46%$ and EE is $1.90%$ of the CSS-BA&CC per day.

- The potable water yield of the CSS-BA was enhanced by coal cylinders which is a locally available low-cost material.

Appendix 1

The EHTC from $T_{b,w}$ to $T_g$ is found by,

$$h_{c,w-g} = 16.273 \times 10^{-3} \times h_{c,w-g} \left( \frac{P_w - P_g}{T_w - T_g} \right)$$

(4)

Convective HTC from $T_{b,w}$ to $T_g$ is found by,

$$h_c = 0.884 \left( (T_w - T_g) + \frac{(P_w - P_g)(T_w + 273.15)}{(268.9 \times 10^{-3} - P_w)} \right)^{1/3} /$$

(5)

| Authors               | SS with improvements | Location | Yield (L/day) | Increase (%) |
|-----------------------|----------------------|----------|---------------|--------------|
| Omara et al. (2011)   | CSS with fins        | Egypt    | 4.1           | 21.00        |
| Kabeel et al. (2018)  | CSS with graphite    | Egypt    | 7.73          | 75.23        |
| Attia et al. (2021)   | Effect of phosphate bed on CSS | Algeria | 3.55          | 31.00        |
| Attia et al. (2020)   | CSS integrated with aluminum balls | Algeria | 6.25          | 37.20        |
| Samuel et al. (2016)  | CSS integrated with sponges | India    | 2.7           | 22.27        |
| Nafey et al. (2001)   | CSS using different black materials | Egypt    | 4.5           | 20           |
| Present study         | CSS with black absorber and coal cylinders | Algeria | 4.2           | 43.3         |

Table 5  Comparison of similar studies

| Authors               | Location | Yield (L/day) | Increase (%) |
|-----------------------|----------|---------------|--------------|
| Omara et al. (2011)   | Egypt    | 4.1           | 21.00        |
| Kabeel et al. (2018)  | Egypt    | 7.73          | 75.23        |
| Attia et al. (2021)   | Algeria  | 3.55          | 31.00        |
| Attia et al. (2020)   | Algeria  | 6.25          | 37.20        |
| Samuel et al. (2016)  | India    | 2.7           | 22.27        |
| Nafey et al. (2001)   | Egypt    | 4.5           | 20           |
| Present study         | Algeria  | 4.2           | 43.3         |

Table 6  Comparison of the cost of manufacturing CSS-BA and CSS-BA&CC. 1$ = 132.78 DZD, 1€ = 156.03 DZD

|                        | CSS-BA | CSS-BA&CC |
|------------------------|--------|-----------|
| Physical cost          | 8000 DZD | 8000 DZD |
| The price of coal cylinders | – | 10 |
| Maintenance cost       | 50 DZD  | 50 DZD    |
| Total cost             | 8050 DZD | 8060 DZD |
| The amount of yield produced, (kg/m²/day) | 2.95 | 4.2 |
| Cost of one liter of distilled water on the market | 60 DZD | 60 DZD |
| Price of daily water production | 207.6 DZD | 242.4 DZD |
| Payback period (days)  | 39 Day | 33 Day    |
Partial vapor pressure on the $T_{b,w}$ is found by,

$$P_w = \exp \left( 25.317 - \frac{5144}{273 + T_w} \right)$$

(6)

Partial vapor pressure on the $T_g$ is finding $b$,

$$P_g = \exp \left( 25.317 - \frac{5144}{273 + T_g} \right)$$

(7)

The TE of the CSS-BA and CSS-BA&CC is found using Eq. (8)

$$\eta = \frac{\sum m_w L}{\sum I(t) A_x \times 3600} \times 100$$

(8)

The EE of the CSS-BA and CSS-BA&CC is given by,

$$\eta_{energy\;efficiency} = \frac{E_{out}}{E_{in}} \times 100$$

(9)

The hourly exergy output and input of the CSS-BA and CSS-BA&CC are calculated by,

$$E_{out} = E_{evaporation} = \frac{m_e}{3600} \times A_w \times h_{fg} \times \left( 1 - \frac{T_a}{T_w} \right)$$

(10)

$$E_{in} = E_{sun} = A_w \times I(t) \times \left[ 1 - \frac{4}{3} \left( \frac{T_a}{T_{sun}} \right) + \frac{1}{3} \left( \frac{T_a}{T_{sun}} \right)^4 \right]$$

(11)

Appendix 2

Uncertainty analysis

The overall level of uncertainty experienced during the studies is dependent on any potential instrument error. Table 3 lists the level of uncertainty related to the experimental instruments. The height of water collected in the calibrated flask determines how accurately distilled water will be produced. In mathematics, it is written as,

$$R_m = \sqrt{\left( \frac{\partial m}{\partial h} R_h \right)^2}$$

(12)

The degree of uncertainty in estimating the daily efficacy of the CSS-BA and CSS-BA&CC relies on solar radiation and water collection rates. It is written as,

$$R_\eta = \sqrt{\left( \frac{\partial \eta}{\partial m} R_m \right)^2 + \left( \frac{\partial \eta}{\partial I(t)} R_{I(t)} \right)^2}$$

(13)

Temperature, solar intensity, and distillate water calculations all have estimated errors of 1.5, 3.5, and 1.5%, respectively. Similar to this, Eq. (13) is used to determine the uncertainty error for daily efficiency, and it is observed to be 2.1%.

Author contribution Savithiri Vembu: conceptualization, writing - original draft preparation.

Mohammed El Hadi Attia: Methodology, resources.

Mohanasundaram Thangamuthu: review and editing.

Gunasekar Thangamuthu: review and editing.

Data availability Not Applicable

Declarations

Ethical approval Not Applicable.

Consent to participate Not applicable.

Consent to publish Not applicable.

Competing interests The authors declare no competing interests.

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