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Numerical Study of a Basin Type Solar Still with a Double Glass Cover Under Winter Conditions

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ABSTRACT

A numerical analysis of a basin-type solar still with a double glass cover is done under winter circumstances of solar radiation, ambient temperature, and wind speed. Equations defining thermal balances of different components of traditional and double glass cover solar stills are used to describe the physical issue, which is then solved using the Gauss-Seidel numerical technique. The effects of solar radiation, ambient temperature, and wind speed on the daily production, internal efficiency, and overall performance of solar stills are calculated and illustrated. The findings demonstrate that a solar still with a double-glass cover is more productive and efficient than a solar still with a single glass cover.

1. Introduction

Drought and an increase in water consumption across our world, whether by individuals or industrialists, has left mankind with a serious problem: it is no longer able to satisfy their demands [1]. Faced with this challenge, many initiatives have been made in the recent past, including seawater desalination and brackish water distillation [2-4]. Solar distillation has grown in popularity in recent years [3,4]. The usage of this energy source is based on two goals: a safe energy source and rigorous environmental adherence [5,6]. Despite its high operational costs, scientific interest in this renewable, clean, and limitless energy is growing [7]. Solar stills are improving in performance and becoming more competitive than conventional distillation methods thanks to scientific study [8].

This issue has been mentioned in a number of research, as seen in Table 1. To solve the disadvantages of traditional solar distillation systems, An *et al.,* [9] proposes an improved solar distillation system that combines concentrating optical engineering and nanofluid-based spectrum splitting PV/T technology. They discovered that the spectrum properties of nanofluid had a substantial impact on the improved distillation system's performance.

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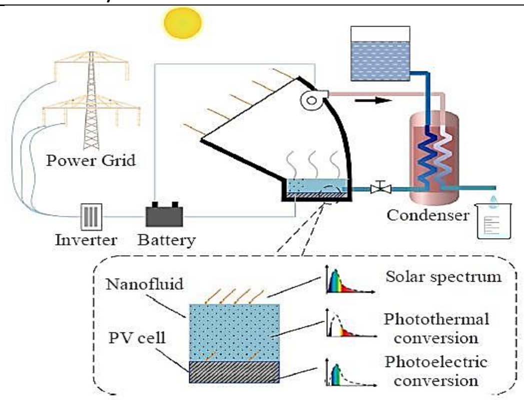
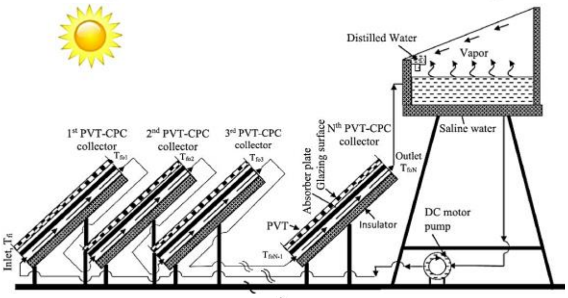
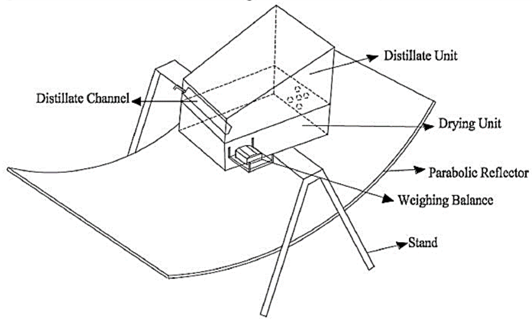
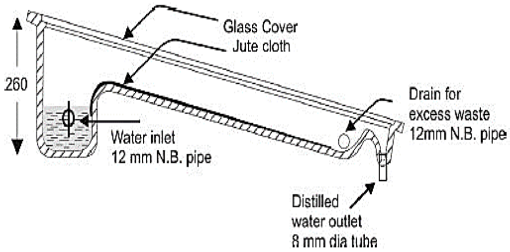
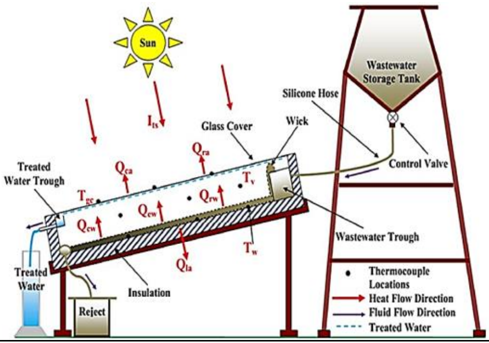
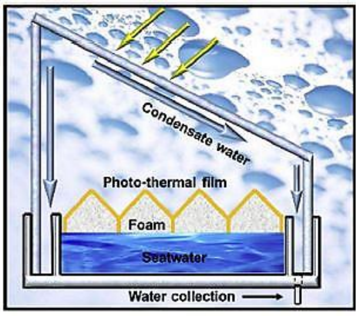
Table 1
The most current solar distillation treatment studies

Author (s)	Solar style	Utilized system
An *et al.,* [9]	Basin type solar still by NSS-PVT technique	
Gupta *et al.,* [10]	PVT-CPC active solar distillation system	
Manchanda and Kumar [11]	Single basin solar distillation cum drying unit with parabolic reflector	
Tiwari and Somwanshi [12]	Single slope multiple wick solar still	
Reddy *et al.,* [13]	Tilted solar distillation unit	

<table>
<tr><td>Xu et al., [14]</td><td>Solar distillation device of origami system</td><td>
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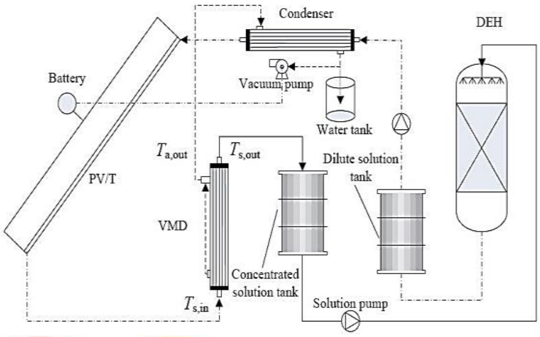
<tr><td>Zhou et al., [15]</td><td>Solar vacuum MD regeneration system</td><td>
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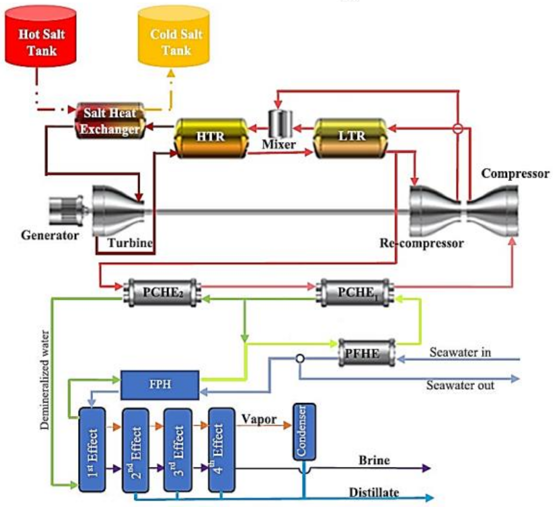
<tr><td>Sharan et al., [16]</td><td>Multi-effect distillation system</td><td>
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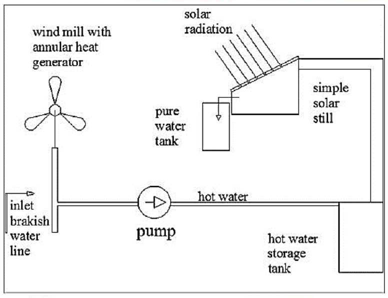
<tr><td>Moh'd et al., [17]</td><td>Hybrid solar-wind water distillation system.</td><td>
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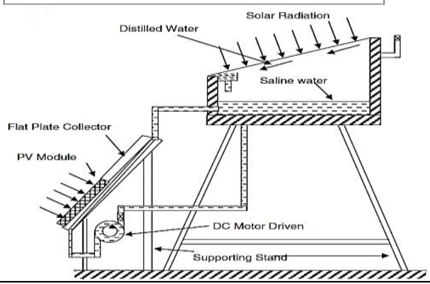
<tr><td>Tiwari et al., [18]</td><td>Active photovoltaic thermal solar distillation system</td><td>
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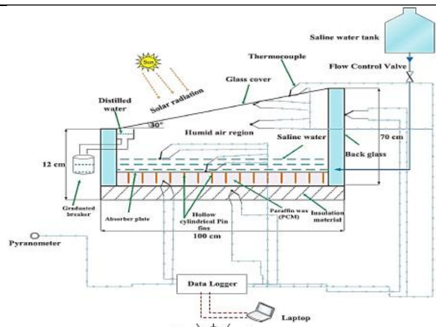
<tr><td>Yousef and Hassan [19]</td><td>Solar still incorporated with phase change materials storage unit</td><td>


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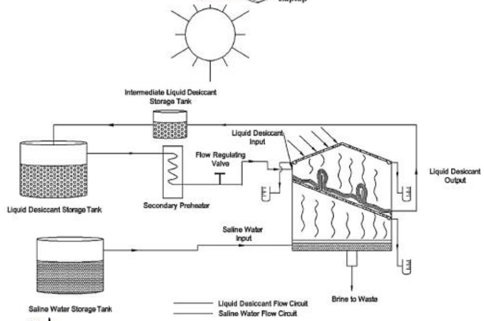
<tr><td>Shukla and Modi [20]</td><td>Liquid desiccant regenerator and water distillation system</td><td>


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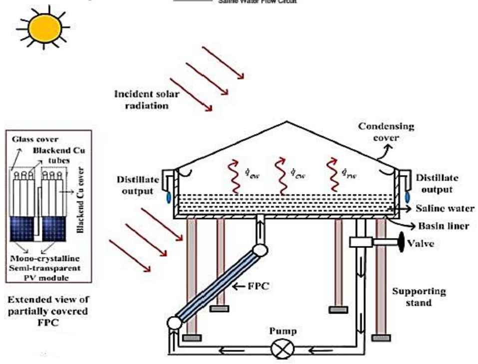
<tr><td>Dwivedi and Tiwari [21]</td><td>Active double slope solar still</td><td>


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Gupta *et al.,* [10] is working on developing an analytic properties equation for a completely identical N totally covered compound photo-thermal compound that is comparable to an integrated solar distillation system, analogous to the Hottel-Whillier-Bliss equation for a flat plate collector. The heat loss from the distillation unit basin was used to dry ginger in a drying chamber connected to the bottom of the distillation unit in Manchanda's research [11]. The tests were carried out using a parabolic reflector and a single-slope single-basin distillation and drying equipment. At lower water depths, the energy efficiency and total stress of distillation are shown to be greater. Tiwari and Somwanshi [12] provided a cost-benefit analysis of two small distillation units and a fountain tank intended to fulfill Jodhpur's 300-liter-per-day drinking water demand (India). The suggested station would be ideal for a location with plenty of brackish (impure) water, such as a river, lake, channel, or pond. A research by Reddy *et al.,* [13] proposes treating RO reject and household sewage water in a single step using an indigenously built slanted solar distillation machine. Based on experimental observations, the unit's behavior, features, treated water quality, environmental advantages, and economics have been documented. The results obtained from their study confirm solar distillation as an efficient and sustainable option for wastewater treatment.

For emergency solar water purification, Xu *et al.,* [14] create origami as photo-thermal materials based on common pen and paper. The pencil cartridge ripped into tiny sheets of graphite as a result of the drawing process, which broke the van der Waals interaction between the layers of graphite. Broadband absorption for solar energy collecting and good hydrophobic resistance to water transfer have been shown using paper fibers coupled with graphite sheets. In comparison to the flat system, the origami structure has efficiently enhanced solar energy consumption by boosting solar energy absorption area and minimizing solar reflection loss. For a liquid desiccant air conditioning system, Zhou *et al.,* [15] presented a unique solar vacuum membrane distillation regeneration. Based on the heat and mass balance, they developed a mathematical model of the VMD regeneration process and the standard thermal regeneration method. When the air temperature is less than 32 °C, the moisture content is greater than 19 g/kg, and the air flow velocity is less than 0.13 kg/s, the impact of VMD solution regeneration is superior to that of traditional heat regenerated.

According to Sharan's *et al.,* [16] findings, the best storage tank design lowers distillate costs by 19 percent and raises the multi-effect distillation capacity factor from 46.4 percent to 75 percent. Cogeneration using the Brighton CSP-sCO_2 cycle was investigated at a number of coastal areas with strong solar resources. Their technical economic study revealed that the distillate generated by MED is 16 percent less expensive than the distillate produced by Yanbu's reverse osmosis technology. Moh'd *et al.,* [17] suggested and investigated a hybrid solar and wind water distillation system. Their setup includes a traditional solar-powered basin as well as a wind-powered water heater. The suggested system has the benefit of being able to work at all hours of the day and night, allowing it to produce more distilled water even on overcast days with strong winds. Their findings revealed a substantial increase in distillate output, particularly on summer nights when wind energy is high. The impact of wind turbine size on system performance has also been investigated and recorded. According to their estimations, the output may be three to four times higher than that of traditional solar distillers. Others models, such as Tiwari *et al.,* [18], Yousef and Hassan [19], Shukla and Modi [20], and Dwivedi and Tiwari [21] have lately been used in the presence of different experimental circumstances. Moreover, there are several studies that considered the heat transfer, solar energy, energy storage, etc, in channels and enclosures, and the following are just a few examples; Hassan *et al.,* [22], Johnson *et al.,* [23], Alawi and Kamar [24], Abdullah *et al.,* [25], Lubis [26], Ghalambaz *et al.,* [27,28], Hajjar *et al.,* [29], Menni *et al.,* [30-38,40], Menni and Azzi [39], Sakhri *et al.,* [41,42], Bendjamaa *et al.,* [43], Boursas *et al.,* [44], etc.

The goal of this research is to find out how double glazing affects efficiency and solar-still output. Solar greenhouses have the benefit of being easy to construct and very inexpensive. The inclusion of second window is intended to boost the greenhouse effect in the solar still. A numerical analysis of solar still with and without a double glass cover is carried out in this context. The research is based on solar still component thermal balances and an iterative Gauss-Seidel calculation technique [8,45-47]. For winter weather conditions, an ambient temperature of 12°C and a wind speed of 5 m/s, the impacts of solar radiation on daily distilled water production, overall and internal efficiency will be investigated. In this experiment, we use two solar stills, one conventional and the other with a double glass cover, both of which are practically the same in terms of glass, water and basin.

2. Methodology

2.1 Solar Stills Under Investigation

Figure 1 depicts internal and external heat transfers in conventional and double-glass cover solar-stills.

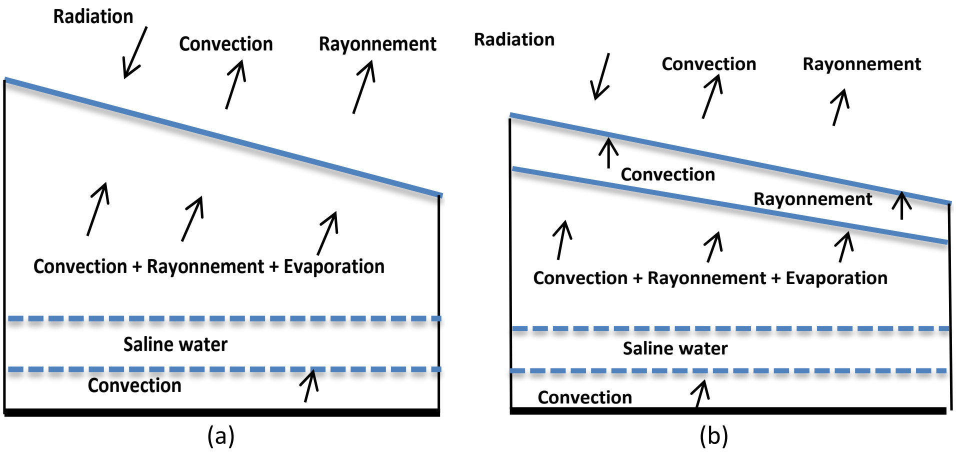

Fig. 1. Heat transfers in (a) conventional and (b) double glass cover solar stills

2.2 Assumptions

Equations defining thermal balances of various components of traditional and double glass cover solar stills are used to describe the physical issue, which is then solved using the Gauss-Seidel numerical technique.

We suggest the following simplification assumptions to minimize the mathematical heaviness

i. Steady heat transfer process;
ii. Heat loss of insulation is negligible;
iii. Only the glass cover is affected by condensation;
iv. There is no temperature gradient along the water mass depth; and
v. The solar still does not have any vapor leakage.

2.3 Thermal Balance of Conventional Solar-Still

The following are the constant thermal equations for glass-cover, water and basin [48]

$$\alpha_g G + \Phi_{c-w-g} + \Phi_{r-w-g} + \Phi_{ev} - \Phi_{r-g-a} - \Phi_{c-g-a} = 0 \quad (1)$$

$$\tau_g \alpha_w G + \Phi_{c-b-w} - \Phi_{c-w-g} - \Phi_{r-w-g} - \Phi_{ev} - \Phi_{ext} = 0 \quad (2)$$

$$\tau_g \tau_w \alpha_b G - \Phi_{c-b-w} = 0 \quad (3)$$

In an explicit way, systems of equations become

$$\alpha_g G + h^c_{w-g}(T_w - T_g) + h^r_{w-g}(T_w - T_g) + h^e_{w-g}(T_w - T_g) - h^r_{g-a}(T_g - T_s) - h^c_{g-a}(T_g - T_a) = 0 \quad (4)$$

$$\tau_g \tau_w \alpha_b G - h^c_{b-w}(T_b - T_w) = 0 \quad (5)$$

$$\tau_g \alpha_w G + h^c_{b-w}(T_b - T_w) - h^c_{w-g}(T_w - T_g) - h^r_{w-g}(T_w - T_g) - h^e_{w-g}(T_w - T_g) - \left(\frac{\dot{m}Cp_w}{A_w}\right)(T_w - T_a) = 0 \quad (6)$$

2.4 Thermal Balance of Double Glass Cover Solar Still

The steady thermal equations for first and second glass covers, water and basin can be written as follows [48]

$$\alpha_g G + \Phi_{c-g2-g1} - \Phi_{c-g1-a} - \Phi_{r-g1-a} = 0 \quad (7)$$

$$\tau_g \alpha_g G + \Phi_{r-w-g2} + \Phi_{c-w-g2} + \Phi_{ev} - \Phi_{c-g1-g2} = 0 \quad (8)$$

$$\tau_g \tau_g \alpha_w G + \Phi_{c-b-w} - \Phi_{c-w-g2} - \Phi_{r-w-g2} - \Phi_{ev} - \Phi_{ext} = 0 \quad (9)$$

$$\tau_g \tau_w \alpha_b G - \Phi_{c-b-w} = 0 \quad (10)$$

In an explicit way, systems of equations become

$$\alpha_g G + h^c_{g2-g1}(T_{g2} - T_{g1}) - h^c_{g1-a}(T_{g1} - T_a) - h^r_{g1-a}(T_{g1} - T_s) = 0 \quad (11)$$

$$\tau_g \alpha_g G + h^r_{w-g2}(T_w - T_{g2}) + h^c_{w-g2}(T_w - T_{g2}) + h^e_{w-g2}(T_w - T_{g2}) - h^c_{g2-g1}(T_{g2} - T_{g1}) = 0 \quad (12)$$

$$\tau_g \tau_g \alpha_w G + h^c_{b-w}(T_b - T_w) - h^c_{w-g2}(T_w - T_{g2}) - h^r_{w-g2}(T_w - T_{g2}) - h^e_{w-g2}(T_w - T_{g2}) - \left(\frac{\dot{m}Cp_w}{A_w}\right)(T_w - T_a) = 0 \quad (13)$$

$$\tau_g \tau_g \tau_w \alpha_b G - h^c_{b-w}(T_b - T_e) = 0 \quad (14)$$

3. Results and Discussion

A comparison between this new type of solar still and a traditional solar still is planned in order to examine the effects of solar radiation (G), ambient temperature (T_a), and wind velocity (V) on daily output as well as overall (η) and internal (η_i) efficiency of a double glass cover solar still.

3.1 Solar Radiation's Impact
3.1.1 Daily production

Solar stills with single and double glass covers were tested on a daily basis (Figure 2). The findings show that the double glass cover has a beneficial impact on daily output; in fact, as solar radiation rises, the difference in daily production between conventional and double glass cover solar stills becomes significant.

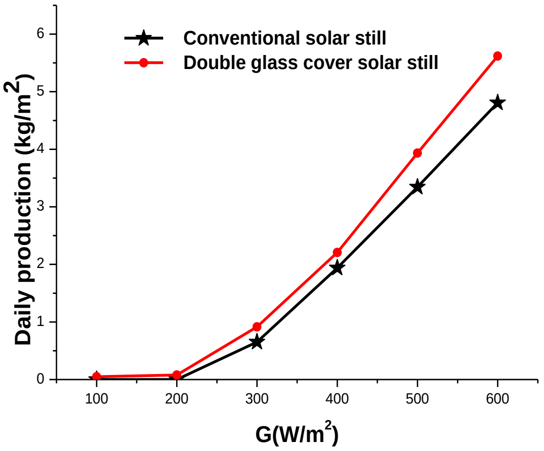

Fig. 2. Solar radiation's impact (G) on daily production, T_a = 12 °C and V = 5 m/s

3.1.2 Overall efficiency

The impact of solar radiation on overall efficiency is seen in Figure 3. Indeed, the overall efficiency of a double glass cover solar still is significantly higher than that of a conventional solar still, with a difference between the two distributions that continues to grow in favor of the double glass cover still as the radiation increases.

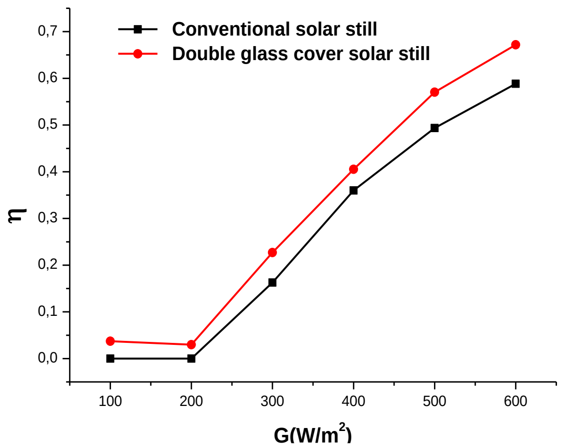

Fig. 3. Solar radiation's impact (G) on overall efficiency (η), T_a = 12 °C and V = 5 m/s

3.1.3 Internal efficiency

The influence of solar radiation on the internal efficiency of conventional and double glass cover solar stills is depicted in Figure 4. In reality, when solar radiation improves, the internal efficiency distributions of the double glazed and conventional stills both grow, with the difference between the two distributions increasing in favor of the double glazing.

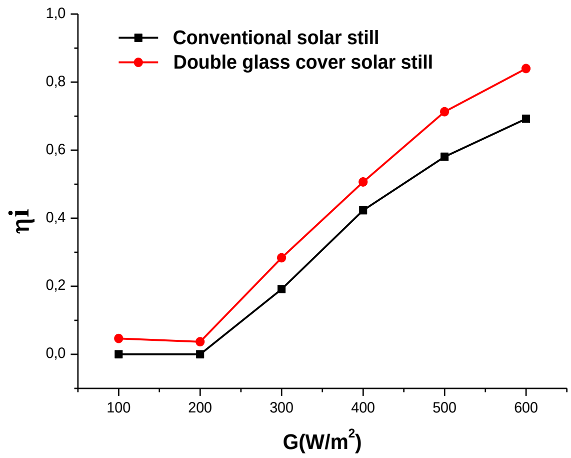

Fig. 4. Solar radiation's impact (G) on internal efficiency (η_i), T_a = 12 °C and V = 5 m/s

3.2 Ambient Temperature's Impact

3.2.1 Daily production

As shown in Figure 5, the daily production of a double glass cover solar still is significantly larger than that of a traditional solar still, with the difference between the two plots decreasing as the ambient temperature enhances.

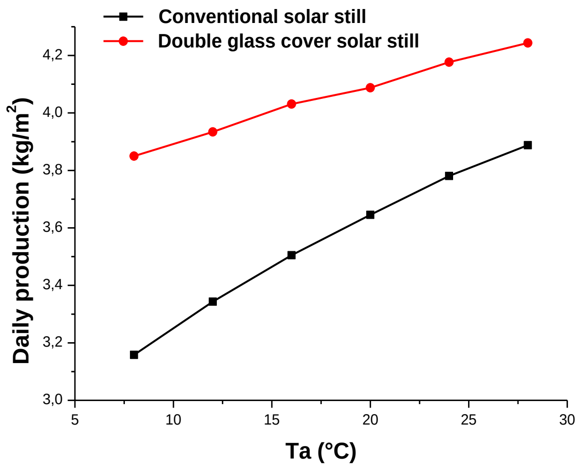

Fig. 5. Ambient temperature's impact (T_a) on daily production in distilled water, G = 500 W/m^2 and V = 5m/s

3.2.2 Overall efficiency

The double glass cover solar still has a considerably greater overall efficiency than a traditional solar still, as seen in Figure 6 The overall efficiency of the improved system fluctuates slowly when compared to traditional system, and the difference between the two distributions decreases as the ambient temperature improves.

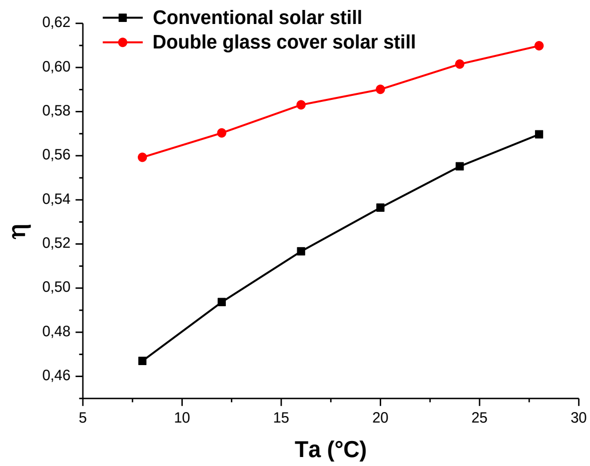

Fig. 6. Ambient temperature's impact (T_a) on overall efficiency (η), G = 500 W/m^2 and V = 5m/s

3.2.3 Internal efficiency

Figure 7 shows how the two stills behave in the situation of internal efficiency, which is comparable to the case of overall efficiency. It's worth noting that the internal efficiency values of the two stills are significantly greater than the overall efficiency, which is consistent with the mathematical formulae for the sun distillation phenomena.

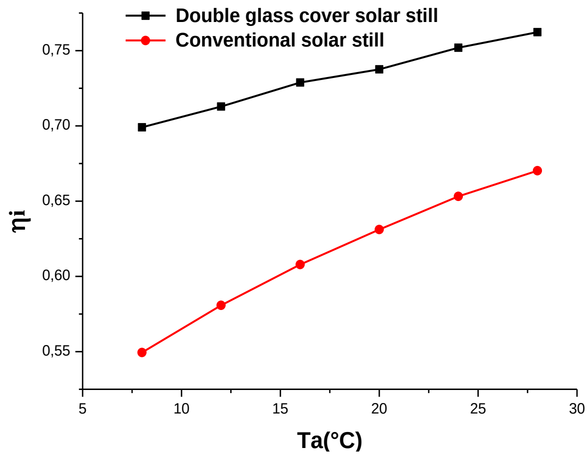

Fig. 7. Ambient temperature's impact (T_a) on internal efficiency (η_i), G = 500 W/m^2 and V = 5m/s

3.3 Solar Radiation's Impact on Temperatures
3.3.1 In conventional solar still

Figure 8 demonstrates that the basin (absorber) and water temperatures are identical. This may be explained by the fact that the basin's thermal insulation is excellent (2nd assumption); it only heats the bulk of water, resulting in their temperatures being well confused. However, it is evident that the temperature differential between the masse of water and the temperature of the glass cover grows as solar radiation enhances.

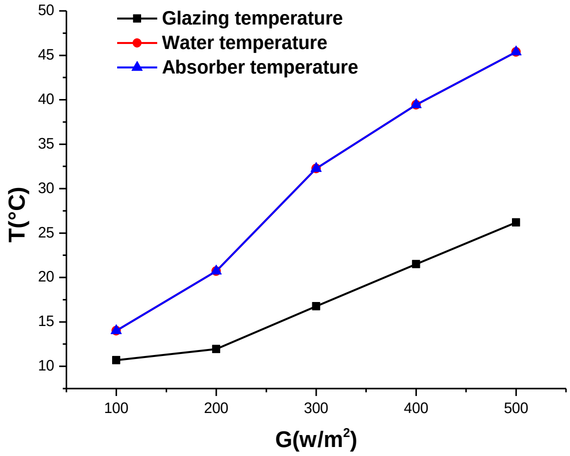

Fig. 8. Effect of solar radiation (G) on temperatures (T) in conventional solar still, T_a = 12°C and V = 5 m/s

3.3.2 In double glass cover solar still

Figure 9 depicts the distribution of water and basin temperatures as a function of incident solar radiation. Furthermore, as a result of solar radiation, the temperature difference between the interior glass cover and the water continues to rise. It's also noting that the temperature of the basin rises with solar radiation, and the temperature distribution of exterior glass cover is perfectly identical to that of a traditional solar still.

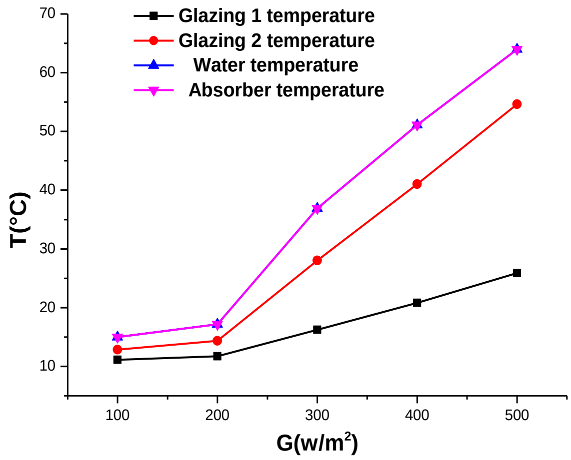

Fig. 9. Effect of solar radiation (G) on temperatures (T) in double glass cover solar still, T_a = 12°C and V = 5 m/s

4. Conclusions

The effects of solar radiation, ambient temperature and wind velocity on the performance of conventional and double glass cover solar stills are investigated numerically. The study focused on the equilibrium equations of various components of stills, with the Gauss-Seidel approach being used to calculate the solution numerically. The findings obtained have indicated that the double glass cover solar still is superior in terms of daily production, overall and internal efficiency than the traditional solar still under so-called winter circumstances when the distribution phenomena become virtually impossible.

Future studies in the scope of solar distillation can be carried out by presenting a comparison of different types of solar distillates such as: single-acting distillation, single slope still, double slope still, spherical still, cylinder still, conical still, multi-stage hair film distiller, multi-story still, etc. In addition to solar radiation, ocean temperature, and wind velocity, there are other factors such as operating conditions and geographic location affect the productivity of the solar distillation. It can check the extent of insulation of the internal and external surfaces of the distiller, thickness of the brine strip, the physical properties of the walls, the slope of the glass on the horizontal surface, the height of the brine level in the distiller, the distance that divides the free surface into two collectors, the characteristics of the components of the solar still, etc.

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