Improving the Drying Mechanism for Seaweed Through the Utilization of Closed-Drying with Modified Solar Air Heaters

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Abstract

Direct drying for seaweed is preferable for local farmers since it costs no additional processing. However, the degradation of the dried product causes economic drawbacks, which means further methods can be developed to solve the problem. In this work, improvement is made by using a closed drying method for seaweed products and combined with a solar collector as an air heater. The high evaporation increases the humidity within the drying chamber, which improves up to 17.8%. In contrast, the supplied dry air from the collector reduces the humidity within the drying chamber, which becomes lower (4.4%) than the ambient. The closed method indicates a maximum temperature of 48.6°C and 53.7°C (with collector), while the ambient temperature is only 36.8°C. It makes the closed drying receive more solar energy, resulting in more water evaporation from the product up to 87.5% compared to the direct method (70.8%). It provides a simple and low-cost approach that can maximize the harvested solar energy for the drying process. It is suitable for supporting local farmers and maintaining sustainability through renewable energy.

Keywords: aquaculture, greenhouse, modified air heater, seaweed, solar energy

1. Introduction

Energy transition has become one crucial agenda in modern society as a severe approach to mitigating the energy crisis. It results in a tremendous improvement in the utilization of alternative fuels [1], renewable energy [2], and hybridization [3]. Recent efforts have been taken to maximize the renewable sector, particularly solar energy, which also supports electricity and heat generation. The solar-electric system utilizes photovoltaic [4], while heat production can be implemented

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through solar heaters using reflection [5] and absorption [6] mechanisms. In addition, solar heat is also suitable for supporting various applications, including the drying process.

Solar drying is advantageous since it is cheap and can be harvested directly without complex equipment. It can be used in various applications, such as brick production [7] and food drying [8]. Specifically for food drying, solar dryers reduce the total energy and carbon footprint from food processing, indicating a positive contribution to energy transition [9]. The concept has been improved by the introduction of heat storage [10–12] and additional heat sources such as biomass [13], wind turbines [14], and air heaters [15]. The combination indicates that the system is attractive and is crucial in developing clean energy from the energy sector.

The typical drying model for food application is the direct drying method. The dried product is dried directly in an open environment, which is a straightforward approach without causing additional costs. A study by H. De Groote et al. analyzed the economic aspect of dried maize in Kenya, showing that the decrement in moisture content (5.8%) improves the selling cost of the product [16]. The low direct drying (DD) rate can be minimized using psycho-chemical, as reported here [17]. Different considerations were studied by G.N. Abdel-Rahman et al. for the drying process of Siwi dates, indicating the direct drying process has a higher contamination (above 90%) than the closed drying method [18]. The identic result regarding food safety was also reported by A.A. Adenitan et al., indicating closed solar drying has a lower m mycotoxin than DD [19]. Thus, closed solar drying is preferable to DD due to its lower contamination.

Closed solar drying requires air circulation to ensure moisture removal from the product. M. Kumar et al. studied groundnut drying, showing that forced convection usage leads to better drying [20]. M.C. Ndukwu et al. evaluated the sustainability of the closed drying method, demonstrating that all drying methods have excellent exergy efficiency with the highest value of 52% for drying cocoyam chips [21]. A. Afzal et al. analyzed the hybrid cabinet drying for fruits, showing that photovoltaic can be integrated for supplying electricity to a fan to ensure forced convection within the system and indicating that the final moisture of the product decreased by less than 20% [22]. The studies signify that closed drying is suitable for food drying, and adding an air heater is advantageous.

The product's dehydration is considered a complex process involving heat and mass transfer. The research here [23] demonstrates a critical aspect of solar drying, which is highly related to the mass of air flow and moisture diffusivity to ensure an effective drying process. The drying kinetics of the product require suitable heat and mass transfer, which makes further combination with an additional fan and heat source indicate a positive outcome for the process [24]. Thus, the recent trend shows a notable improvement for solar-based drying using additional heat sources [25], with the possibility of additional equipment such as heat storage [26–28]. The heat storage operates using the basic principle of heat exchanger, which requires additional working fluid [29], making the forced-air convection combination favorable for the system [30].

Most reported cases focus on the drying process of agricultural products, with minimum attention paid to aquaculture products such as seaweed. Edible seaweed is considered an important food, particularly for coastal and Asian regions with a lower carbon footprint since it uses no chemical fertilizer [31]. However, most seaweed farmer uses the DD method, especially in developed countries, due to the consideration of low-cost processing [32]. As a result, the seaweed's selling cost drops drastically due to the impact of quality degradation [33]. As a mitigation, several studies reported modification of the drying process. R.S. Pangan et al. proposed a floating dryer to minimize transportation costs using natural convection, showing that the proposed idea was suitable for decreasing operational costs while improving the dried quality of the product [34]. It shows the urgency of improving the drying method for seaweed-based products, which is essential to support the development of seaweed farming using renewable energy sources.

The present study aims to provide a fundamental basis for optimizing the drying process of seaweed. The successful implementation of closed drying for agricultural products will likely apply to seaweed. In this work, the drying process of seaweed is compared to analyze the role of closed drying using the greenhouse (GH) concept and the addition of solar heaters. The drying kinetics is analyzed to understand the impact of the collective heat energy for each configuration. Thus, an improvement in the drying process for seaweed can be applied according to the findings from this work, including a reliable solution in terms of cost and utilization of solar energy to support the sustainability of energy harvesting and food production.

2. Experimental Methods

The critical contribution of this work is to analyze the suitability of advanced seaweed drying using the GH concept. The advanced model is also equipped with a solar collector (SC). Improvement of the solar air heater is essential to maximize the output of the heated heat. Thus, we employed SC with finned (SCF) with the detailed dimension presented in Fig. 1a. The SCF employed four fins to prevent significant pressure drop and minimize the turbulence intensity of the airflow within the collector [35–37]. The fin was made of an aluminum sheet (width of 30 mm and thickness of 3 mm).

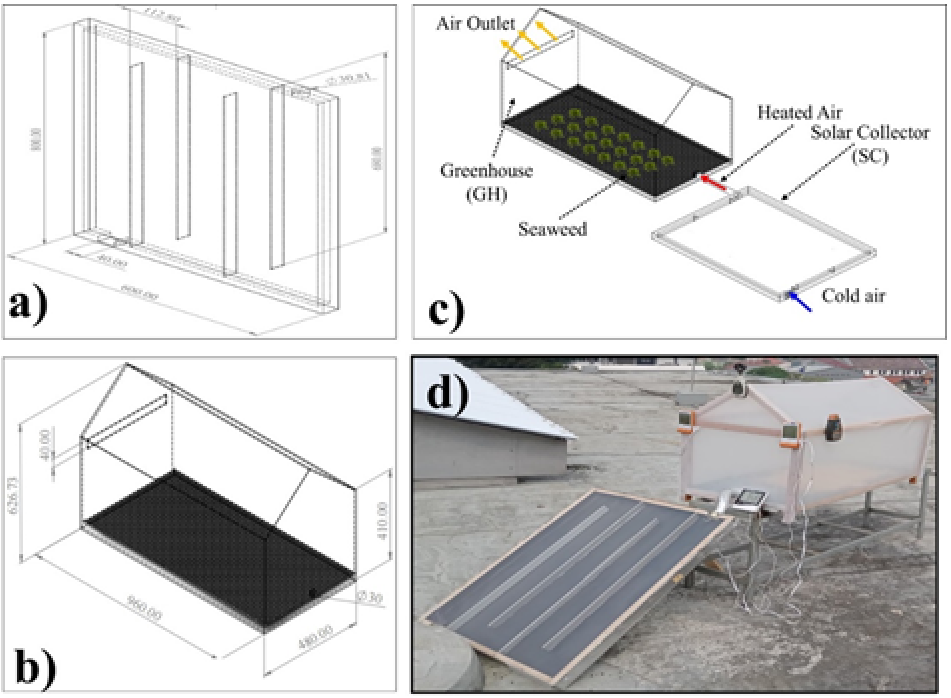

Figure 1: *Detailed dimension for SCF (a), for unit GH (b), schematic of experiment (c) and pictorial view of the process (d)*

The base of the solar collector was equipped with black PVC (polyvinyl chloride) to maximize the absorption of solar radiation. The outer wall of SCF was made of thick plywood (18 mm) and covered by an insulator to reduce the heat loss from the collector area to the environment. The diameter of the outlet port for the SCF was 30.81 mm. The GH unit (Fig. 1b) used UV-plastic, considering its low cost and excellent performance for transmitting light and solar radiation into the drying chamber. The configuration for the experimental test is shown in Fig. 1c, with a pictorial view in Fig. 1d.

The experimental evaluation was performed by comparing the DD, GH, and GH with SC. The initial assessment was performed by measuring the produced SC and SCF's relative humidity (RH) and temperature characteristics. After that, the drying process was performed using 150 grams of seaweed. The GH, SC, ambient temperature, and RH were recorded simultaneously. The final mass of the product was weighted to analyze the amount of water content that could be liberated from the dried product.

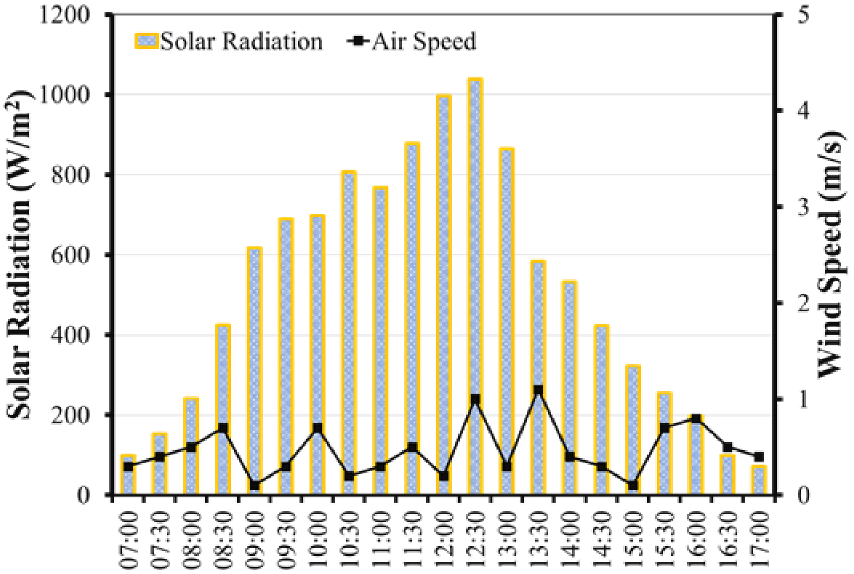

Figure 2: *Weather condition during the experimental test*

Fig. 2 shows the weather conditions during the experiment. The amount of solar radiation is considerably suitable, with a minimum value of 500 W/m^2 for the drying process. According to the profile, the optimal drying time was between 09:00 and 14:30 (local time). The typical wind characteristic is extremely low, making forced convection required for closed sun drying (GH). The weather data is used to support the drying performance.

3. RESULTS AND DISCUSSION

The functionality evaluation of the produced SC is shown in Fig. 3a. The RH decreases in the middle day due to the increment of solar radiation (Fig. 2). The lowest RH for ambient is between 47.9% - 51.2%. The collected heat from the collector significantly reduces the RH, with the lowest value being 14.1% for SCF and 18.6% for SC. It confirms the functional ability of the produced SC to supply dry air, which is essential for the drying process. In addition, the usage of help is able to improve the heating rate, which causes the air to become dryer compared to non-finned SC. It is also observed for the average temperature outlet, where SCF has the highest outlet temperature (70.7°C) compared to non-fin SC (66.6°C), as seen in Fig. 3a. The addition of fin improves the surface area of the collector and forces the air to travel at longer distance within the collector, eventually leads to a higher convective heat transfer rate of the air [38].

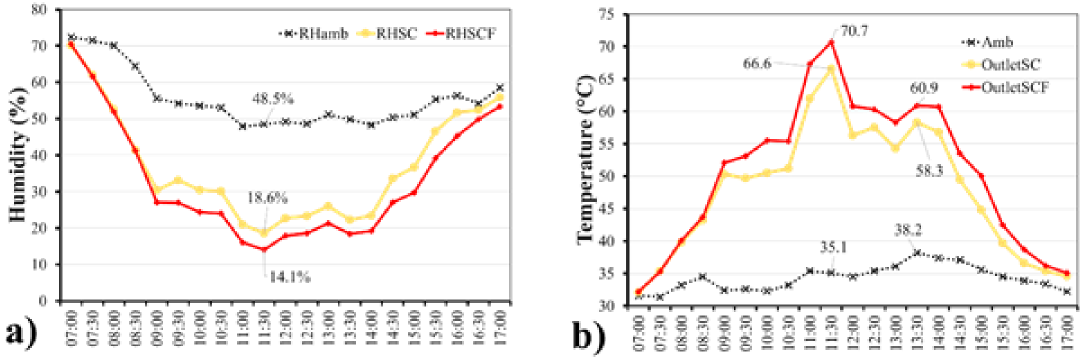

Figure 3: *Humidity (a) and temperature (b) characteristic for the tested SC*

The key advantage of using a GH dryer is a higher mass loss of dried product. It is shown in Fig. 4, where GH causes better moisture content removal from the product. In the first experiment, the mass loss for each product was relatively the same (ranging between 32.1 grams – 27.8 grams). It is the initial drying period, causing the adsorbed water at the surface of the product to evaporate [39]. The effect of the drying method is observed distinctively once the product enters the second falling rate. A higher heat accumulation affects the evaporation rate, which can be achieved by using GH. In addition, the supply heat from SCF accelerates the moisture removal from the product, resulting in the highest mass loss compared to another drying method.

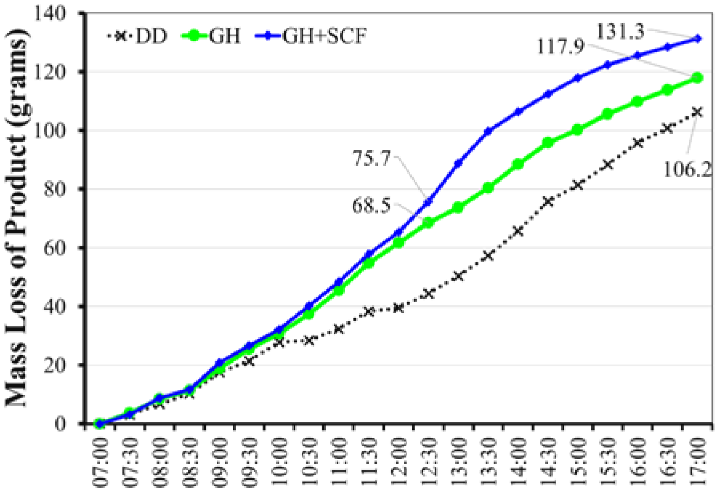

Figure 4: *Characteristic of mass loss from the dried product*

The temperature during evaluation is plotted in Fig. 5. The maximum temperature is achieved at midday, where the temperature for GH increases by 32.1% and 45.9% with SCF relative to the ambient temperature. It signifies the greenhouse effect, which accumulates heat within the drying chamber while adding SCF, which adds more energy to the GH. It also corresponds to the maximum mass loss, which improves notably for the GH model, which mainly uses SCF. Adding more heat within the system drives a higher convective heat transfer rate, leading to a better evaporation profile from the product.

Temperature distribution within the GH is simulated numerically and plotted in Fig. 6. The

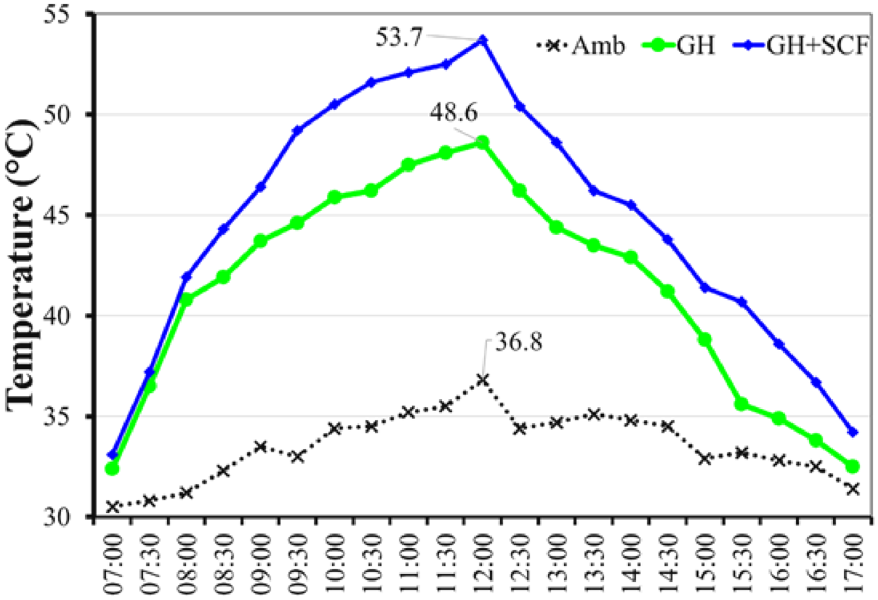

Figure 5: *Temperature comparison during drying process*

inlet temperature for each model was set according to the average ambient temperature (30°C) and maximum inlet temperature from SCF (90°C). In addition, the inlet temperature was also set at 60°C, which is the melting temperature of various organic materials for heat storage [40]. Each profile indicates a steady heat distribution in the middle region of the drying chamber, while the highest temperature is localized in the top region. The temperature decreases before leaving the drying chamber, showing the heat transfer between the dry air and the product. It makes the drying process occur steadily, resulting in a better drying process. Moreover, the product is located close to the inlet, which maximizes the heat uptake.

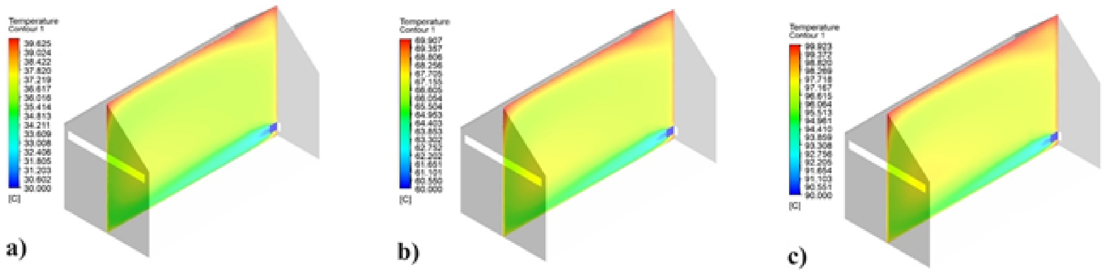

Figure 6: *Temperature distribution at inlet 30°C (a), 60°C (b) and 90°C (c)*

The air distribution is shown in Fig. 7a, showing a suitable stream profile within the drying chamber. It is essential to accelerate the drying process since evaporation leads to a higher moisture content within the drying chamber (Fig. 7b), making the released water molecules denser inside the GH. It can be seen that GH has the highest RH, which corresponds to a higher water release from the product. Providing dryer air through the SFC helps to reduce the RH within the GH, resulting in better moisture release from the product. The supplied dry, hot air from SCF contributes positively to accelerating the drying process.

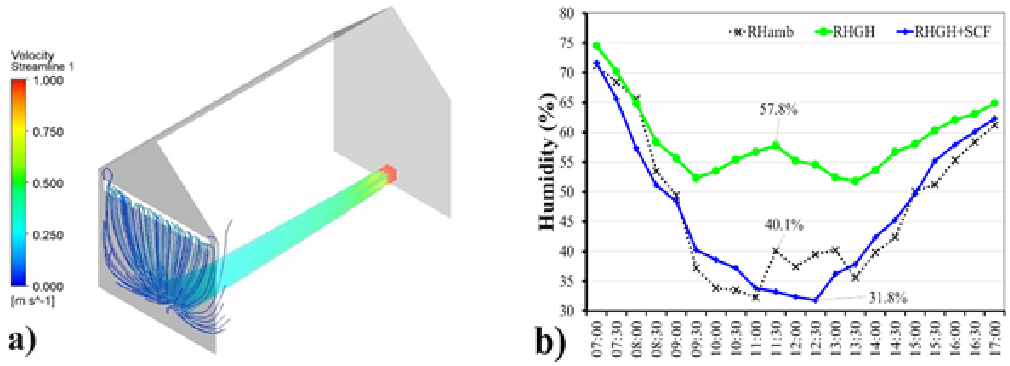

Figure 7: *Characteristic of air distribution (a) and RH during the drying process*

The rating drying is plotted in Fig. 8, showing the detailed drying performance for each method. The initial rating has a similar profile, confirming the first failing rate of the product. The impact of a slow drying rate is observed for the DD process, resulting in an average increment of only 5%/hour. It is caused by uncontrolled temperature and humidity since the process occurs as a direct method. The slow drying rate leads to a significant decrement in the second failing rate, which is observed as an insufficient process to release the water content from the product. As a final result, the maximum mass loss is only 70.8% of the initial mass (Fig. 4).

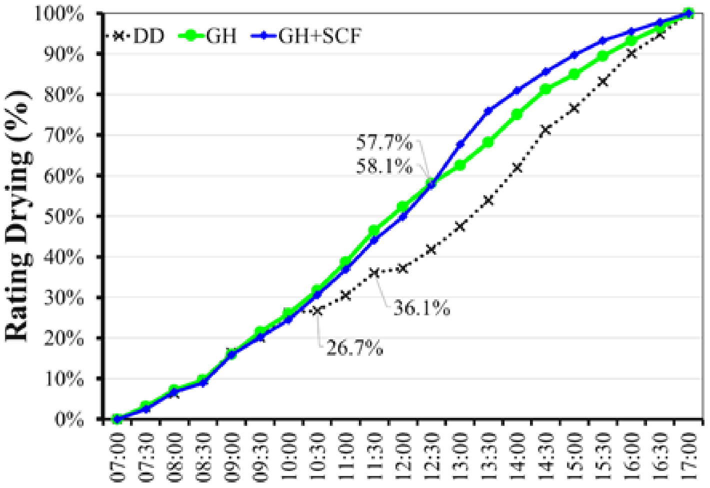

Figure 8: *The rating drying comparison for each drying scenario*

The excellent drying performance for GH is achieved since it distributes heat effectively with a suitable mass transfer from the fan. It causes the moisture content to be liberated effectively, resulting in a higher humidity within the drying chamber and a higher total moisture content (78.6%). The drying process can be accelerated with the help of SCF, leading to the highest mass loss of product, up to 87.5%. Thus, the finding indicates that significant improvement in solar energy harvesting can be taken for the drying process using suitable heat and mass distribution and an additional supply of dry-hot air from SFC.

4. Conclusion

The evaluation of seaweed drying performance was assessed and analyzed. According to the result, closed drying performs better in maximizing the evaporation process of the seaweed. The usage of GH increases the drying rate up to 11.02%, while the addition of SCF has the highest increment (23.6%). The temperature within the drying chamber elevates around 32.1% and 45.9% for GH and GH with SCF. The proposed model improves seaweed products' drying performance with minimum equipment modification.

The finding indicates a substantial improvement in drying aquaculture products. Future improvements can be made by integrating the system with photovoltaics and solar air heater mechanisms. Moreover, the integration with heat storage promotes a continuous drying operation. It reduces the total duration of the drying process, adding more positive outcomes to harvesting solar power for the aquaculture sector.

Declaration of interest: The authors declare no conflicts of interest.

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