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Enhancing the Performance of an Active Greenhouse Dryer by Using Copper Oxide and Zinc Oxide Nano-Enhanced Absorber Coating

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ENHANCING THE PERFORMANCE OF AN ACTIVE GREENHOUSE DRYER BY USING COPPER OXIDE AND ZINC OXIDE NANO-ENHANCED ABSORBER COATING

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SUMMARY

In this work, the effect of applying nano-enhanced absorber coating on the absorber bottom plate of an active greenhouse dryer has been investigated experimentally. In the first step of the study, three different greenhouse dryer geometries including an uneven-span, parabolic and modified parabolic types have been tested. Parabolic greenhouse drying system gave the best thermal and drying performance. In the second step of the work, three parabolic greenhouse dryer with same dimensions have been manufactured. First parabolic greenhouse dryer was designed as conventional type. Zinc oxide (ZnO) and copper oxide (CuO) nanoparticle-enhanced black paints have been applied to the second and third parabolic dryers, respectively. According to the obtained findings, utilizing ZnO and CuO-embedded absorber coating materials in parabolic greenhouse dryers decreased drying time as 7.14% and 21.42% minutes, respectively in comparison to the conventional parabolic dryer. Also, specific moisture extraction rate values were attained in range of 0.57-0.94 kg/kWh.

Keywords: Greenhouse dryer, nanoparticles, black paint, ZnO, CuO.

INTRODUCTION

Solar energy is of quite importance impacts in reducing harmful environmental emissions. Solar energy can be used in different types of applications such as electrical energy generation, hot water production, space heating and drying.

Solar dryers are divided into two groups including direct and indirect dryers. Greenhouse drying system is one of the direct solar drying systems and they widely utilized worldwide. Greenhouse drying systems mostly employed in agricultural product drying applications. Therefore, shelf lives of the fresh products can be extended. There are some efficiency enhancement methods in greenhouse drying systems. These methods mostly include utilizing auxiliary heating systems (Tuncer et al., 2020), applying thermal energy storage systems (Selimefendigil and Şirin, 2022), north-wall modifications (Chauhan and Kumar, 2016), flooring modifications (Ahmad and Prakash, 2019).

In recent years, utilizing nanoparticles in solar-thermal systems has become a popular performance enhancement technique. Nanoparticles with high thermal conductivity values can be applied in absorber surface materials to improve the performance of solar-thermal systems (Abdelkader et al., 2020; Sivakumar et al., 2020). In a study, Kumar et al. (2020) utilized nano-embedded absorber coating in a solar heater. Graphene nanomaterials were used in the study and thermal performance was improved extensively. In another work, Selimefendigil et al. (2022) used nanoplatelets in black paint to improve the performance of a greenhouse dehumidifier. Exergy efficiency of the system was improved as 4.87% by employing nano-embedded absorber coating. There are also some studies that analyzed nano-enhanced absorber coating applied solar desalination systems (Thakur et al., 2018; Kabeel et al., 2019).

In this study, the impact of applying nano-embedded black paint on the absorber surface of a greenhouse dryer has been analyzed experimentally. The main aim of this work is to enhance thermal performance of a greenhouse dryer without utilizing complex additional components. In the first part of the work, different geometrical modifications have been tested. The most successful greenhouse geometry (parabolic) was selected to be tested in the second part of the experimental process. The parabolic greenhouse dryers with same dimensions have been manufactured. One of the greenhouse dryer was designed as a conventional type. Zinc oxide (ZnO) and copper oxide (CuO) nano-integrated black paints have been applied to the second and third greenhouse dryers, respectively. Designed three parabolic greenhouse dryers have been tested in same environmental conditions and results have been discussed.

MATERIALS AND METHODS

Preparation of Nano-enhanced Absorber Coating Materials

In this study, two of the parabolic greenhouse dryers have been modified with nano-enhanced matt black paint. In this regard, two different nano-embedded absorber coating materials were prepared. Copper oxide (CuO) and zinc oxide (ZnO) nanoparticles (Nanografi Co, Turkey) were selected to be utilized in matt black paint in the current study. Nanoparticles have been integrated industrial matt black paint in the initial stage of the preparation process. Then, obtained mixtures were stirred for two hours with a mechanical mixer and applied to 1 mm thick aluminum sheet bottom plates of two greenhouse dryers. Both concentration ratios are 2% (wt/wt). Specific surface area and mean particle size of the CuO nanoparticles are >20 m^2/g and <77 nm, respectively. Same parameters for ZnO nanoparticles are 20.0-65.0 m^2/g and 18 nm, respectively. Scanning electron microscope (SEM) images of employed nanomaterials are shown in Fig. 1. Similar surveys were considered in the preparation process of the nano-enhanced black paint (Sivakumar et al., 2020; Selimefendigil et al., 2022; Abdelkader et al., 2020).

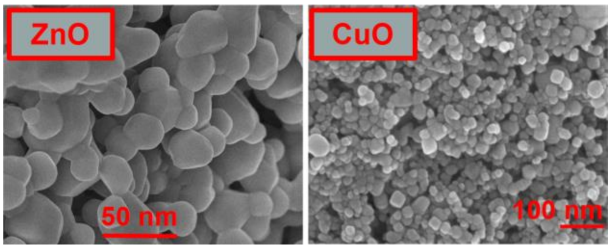

Fig.1. SEM view of the used nanoparticles

Experimental Setup

Three different greenhouse dryer geometries including and uneven-span (UGD), parabolic (PGD-I) and modified parabolic (MPGD) types have been analyzed for selecting the system with highest performance. According to the result of the first test, parabolic greenhouse gave the best performance result. Therefore, three same-sized parabolic greenhouse dryers have been manufactured to observe the effect of adding nano-enhanced absorber coating on the drying performance. One of the parabolic greenhouse dryer was designed as a conventional type (PGD-I). Zinc oxide (ZnO) and copper oxide (CuO) nano-integrated black paints have been applied to the second (PGD-II) and third (PGD-III) parabolic greenhouse dryers, respectively. Frames and transparent cover of the greenhouse dryers were made from wood and polyethylene greenhouse cover with 91% transmissivity, respectively. 50 W powered AC fans have been placed to each greenhouse to provide air flow. Dimensions of the developed greenhouse dryers are shown in Fig. 2. Also, photographs of the experimental setups are given in Fig. 3.

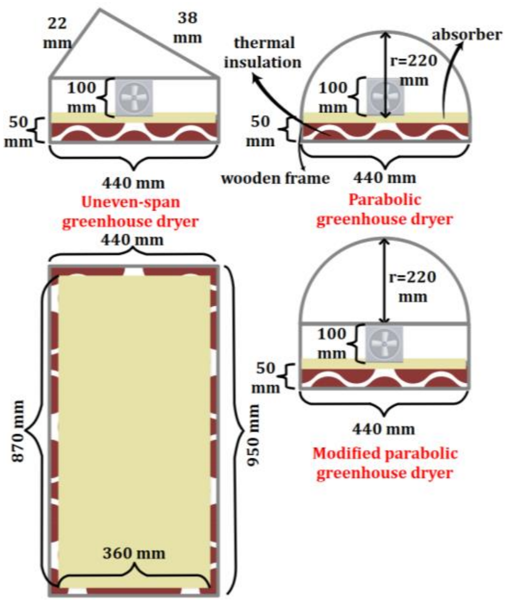

Fig.2. Dimensions of the developed systems

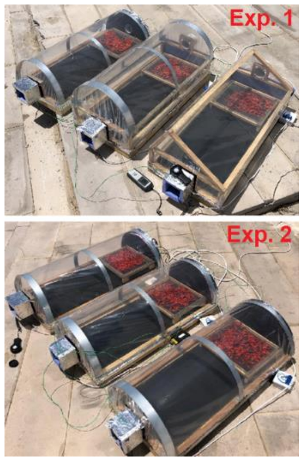

Fig.3. A photograph of the experimental setup

Experimental Procedure

Two experiments have been performed within the scope of this work. Experiments were done in Manisa, Turkey in July 2021. In the first experiment (Exp. 1), uneven-span, parabolic and modified parabolic types greenhouse dryers have been tested to determine the system geometry with best performance. In the second experiment (Exp. 2), the effect of integrating nano-enhanced absorber coating on the drying performance of a parabolic greenhouse dryer has been analyzed. Both experiments have been performed at constant 0.014 kg/s flow rate. Moreover, 100 grams of fresh red pepper samples (sliced in 5 mm pieces) have been utilized for each system. Initial moisture content of the samples is 5.21±0.22 $g_{water}/g_{dry\ matter}$. Tests were started at 10:00 and finished when the difference among two mass measurements was lower than 1 percent. Temperature values were measured and recorded 10 every 10 seconds while other parameters were observed 20 minutes intervals. Accuracy values of utilized thermocouples, dataloggers, solarmeter, anemometer and digital balance are ±0.5 °C, ±0.3 °C, ±10 W/m^2, ±2% and ±0.02 g, respectively.

THEORETICAL CALCULATIONS

Moisture ratio parameter is employed to model the loss of the drying product mass in the drying process and it could be obtained by using the equation below (Aghbashlo et al., 2012):

$$MC_{db} = \left(\frac{M_i - M_d}{M_d}\right) 100 \tag{1}$$

Here, M_i and M_d depict initial wet mass (g) and final dry mass (g), respectively.

Specific moisture extraction rate is a crucial performance indicator in evaluating drying systems and it can be expressed as (Ismaeel and Yumrutaş, 2020):

$$SMER = \frac{m_w}{E} \tag{2}$$

In Eq. (2), m_w and E show extracted water mass (kg) and consumed electrical energy (kWh), respectively.

RESULTS AND DISCUSSION

In this section, experimentally obtained results have been presented and discussed. Fig. 4 presents the change in environmental conditions via drying time. Mean solar radiation values in Exp. 1 and Exp. 2 were obtained as 862 and 885 W/m^2, respectively. Also, obtained mean ambient temperatures in Exp. 1 and Exp. 2 are 31.5 °C and 31.8 °C, respectively. It should be indicated that in each experiment, all greenhouse dryers were operated till the drying process of the last greenhouse dryer terminated to observe the thermal behavior of the greenhouse dryers. In Exp. 1, average outlet air temperature values for UGD, MPGD and PGD-I were attained as 42.87 °C, 41.96 °C and 43.81 °C, respectively. In Exp. 2, obtained mean outlet temperatures for PGD-I, PGD-II and PGD-III are 44.01 °C, 45.11 °C and 45.95 °C, respectively. As it can be seen, applying ZnO and CuO nanoparticles in absorber coating material enhance the outlet temperature of the greenhouse dryer as 2.49% and 4.40%, respectively.

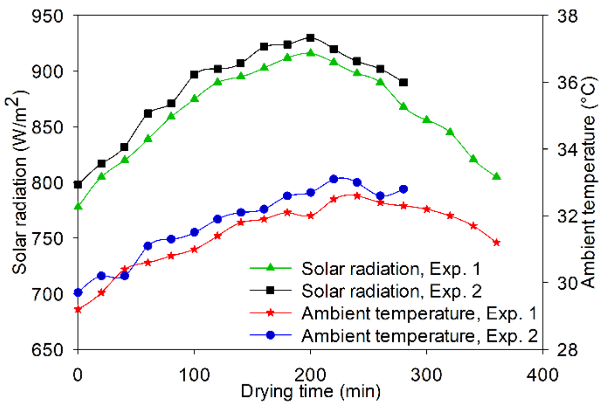

Fig.4. Change in environmental conditions via time

Fig. 5 presents change in moisture content values via drying time. In the first test, drying time for UGD, MPGD, PGD-I were obtained as 320, 360 and 300 minutes, respectively. In Exp. 2, obtained drying times for PGD-I, PGD-II and PGD-III are 280, 260 and 220 minutes, respectively. Modifying greenhouse dryer geometry and applying CuO nano-enhanced black paint decreased drying time significantly.

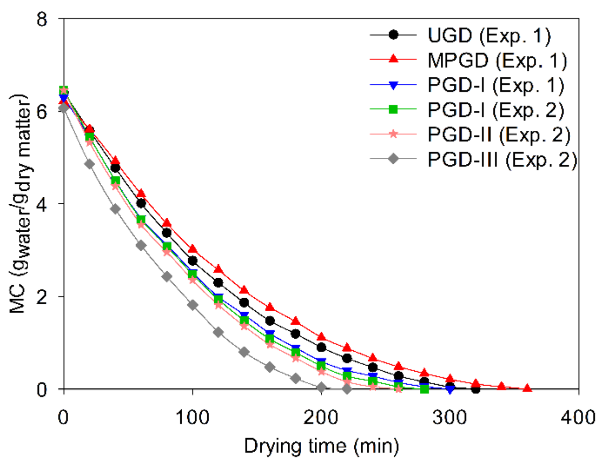

Fig.5. Change in moisture content values via time

Fig. 6 presents change in SMER values via drying time. In the first experiment (Exp. 1), SMER value for UGD, MPGD, PGD-I were obtained as 0.65, 0.57 and 0.69 kg/kWh, respectively. In Exp. 2, attained SMER metrics for PGD-I, PGD-II and PGD-III are 0.74, 0.80 and 0.94, respectively. As it can be seen, drying time and SMER results of PGD-I in Exp.1 and Exp.2 varied in small amount. As it is known, many parameters impacts drying performance such as environmental conditions and moisture content of the specific drying product. SMER results of this study showed the successful utilization of nanoparticles in absorber coating to enhance the performance of active greenhouse dryer.

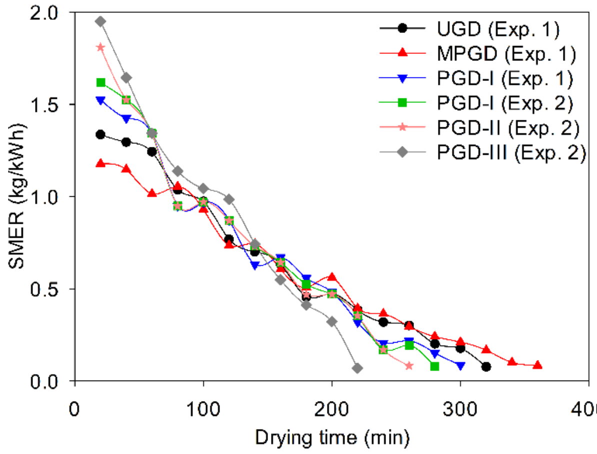

Fig.6. Change in SMER values via time

Table 1 presents a comparison of obtained SMER values in the current research with similar studies that investigated various types of drying application available in the scientific literature. As it can be seen, parabolic-formed greenhouse dryer had better performance in comparison to the uneven-span and modified parabolic greenhouse drying systems. Also, integrating ZnO and CuO nanoparticles in absorber coating of parabolic greenhouse dryer improved SMER value as 8.10% and 27.02%, respectively in comparison to the conventional forced convection parabolic greenhouse dehumidification system. In addition, designed, manufactured and tested greenhouse drying systems in this study are in good line with some studies about drying systems including indirect solar drying applications, heat pump dryers and greenhouse dryers.

It should be stated that developed greenhouse dryers in this work are pilot-scale systems. In further studies, large-scale applications can be tested. Also, in this study, only the drying performance of the systems were analyzed. The main goal of this work to show the applicability of this nanoparticles for improving the drying performance. It should be said that sample quality investigation and analysis of toxic impact on the sample have not been surveyed within the scope of this work. To overcome this bottleneck, various nano-additives can be chosen and additional coating applications can be considered. Moreover, tested systems can be utilized to dry products other than food materials including timber, manure and municipal sewage sludge.

Table 1. Comparison of obtained SMER values with similar works available in the scientific literature

Reference	Dryer type	SMER (kg/kWh)

Fudholi et al. (2015)	Indirect solar dryer	0.29
Dorouzi et al. (2018)	Indirect solar dryer	0.2740
Sözen et al. (2020)	Indirect solar dryer	0.73
Chapchaimoh et al. (2016)	Heat pump dryer	0.47
Mohanraj and Chandrasekar (2009)	Indirect solar dryer	0.84
Tuncer et al. (2020)	Greenhouse dryer	0.36
Selimefendigil and Şirin (2022)	Greenhouse dryer	1.29
This study (UGD)	Greenhouse dryer	0.65
This study (MPGD)	Greenhouse dryer	0.57
This study (PGD-I)	Greenhouse dryer	0.69-0.74
This study (PGD-II)	Greenhouse dryer	0.80
This study (PGD-III)	Greenhouse dryer	0.94

CONCLUSIONS

In this study, the effect of integrating ZnO and CuO nano-additives in black paint on the drying performance of parabolic greenhouse dryers have been investigated. Main outcomes of this work can be given as:

- In the initial stage of the experimental process, parabolic greenhouse dryers gave better performance in comparison to uneven-span and modified parabolic greenhouse dryers.
- Geometrical modifications and applying nanoparticles to the system significantly decreased drying time.
- SMER value of the parabolic greenhouse dryer was improved as 8.10% and 27.02%, respectively by adding ZnO and CuO nanoparticles to the absorber coating.

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