Results of tomato drying in a greenhouse type solar dryers with natural convection

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Abstract: In this work, the process of drying tomato products using two types of polyethylene as a transparent surface in natural convection solar dryers operating in direct heat transfer mode was studied. Traditional ordinary polyethylene and functional ceramic composite polyethylene based on mullite $Al_6Si_2O_{13}$, designed for solar dryers that convert sunlight into infrared pulses, were used as transparent coatings. In functional ceramic composite polyethylene solar dryers, high-energy pulsed radiation energy allows to penetrate deep layers of dried products and evaporate water. This will cause excess moisture to remain in the product to be dried.
Keywords: solar energy, dryers, tomato, functional ceramic composite polyethylene, temperature, mass, convection, wind speed, radiation.

1 Introduction

Fossil fuels are an important basis of global energy systems and are used in all industrial sectors, from marine and ocean transportation. Over the past 2 centuries, global consumption of fossil fuels has increased approximately 1300 times. But we all know that these fuels are non-renewable resources. According to recent estimates by scientists, we have reserves of coal that will last about 132 years, oil that will run out in about 47 years, and natural gas that will run out in 90-120 years [1]. For this reason, food and energy security are two of the biggest challenges facing the world community today. Agro-food products are the most widely grown and consumed products worldwide [2]. However, losses of agricultural produce from harvesting to marketing and consumption vary from 20% to 50%. Let's take tomatoes as an example, they are perishable products and start to spoil 2-3 days after harvest [3]. Research in Dugda wereda, Ethiopia found that tomato post-harvest mortality along the supply chain was 38.7 % from harvest [4]. Wet fruits and vegetables are dried to increase shelf life, reduce shipping costs and provide convenient packaging. [5]. At the same time, there may be changes in product quality indicators during product drying. [6]. Therefore, it is necessary to control that it is carried out in a way that causes the least damage to the quality of the product. [7-8] Various experimental and semi-empirical mathematical equations have been proposed to evaluate food drying processes in solar dryers [9-12]. Considering that the solar radiation falling on the earth is $3*10^{24}$ J per year, product drying using solar energy can be shown as one of the alternative solutions [13]. One of the main indicators of product drying in solar dryers is energy consumption and drying efficiency. In a number of scientific studies, it has been proven that the flow of

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air and heat energy inside dryer devices are the main factors for drying agricultural products [14-17].

2 Materials and Methods

Experimental set up. The main parameters of the dryer prepared for the experiment are presented in Table 1. Two identical dryers were prepared for the experiment, both dryers were placed on a table at a height of 1.2 m from the ground. These dryers are coated with ordinary polyethylene and functional ceramic composite polyethylene (Fig. 1). The sun's rays fall directly on the transparent polyethylene film, pass through it into the device and heat the product and the air placed inside the device. As a result, due to the increase in energy, moisture in the product begins to evaporate. Moisture removed from the product is removed from the dryer to the outside environment using a chimney.

Table 1. Technical parameters of the experimental device.

The maximum height of the device	0.6 m
The height of the side wall	0.4 m
The surface of the floor	1.2×0.8 m^2
Length of plastic pipe used for one device	16.5 m
The outer diameter of the plastic pipe	25 mm
Internal diameter of the plastic pipe	20 mm
The height of chimney	1 m
The diameter of chimney	0,1 m

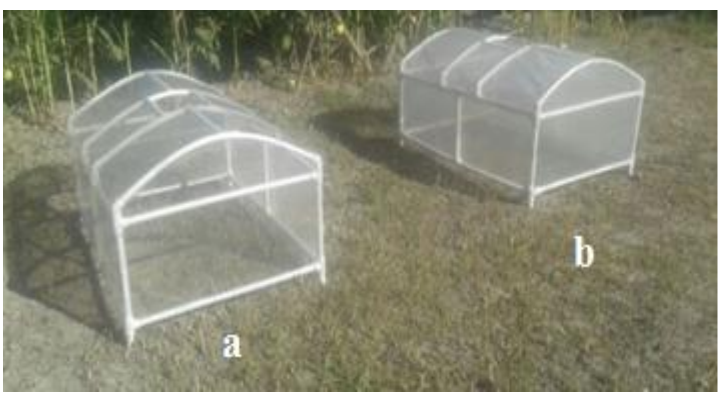
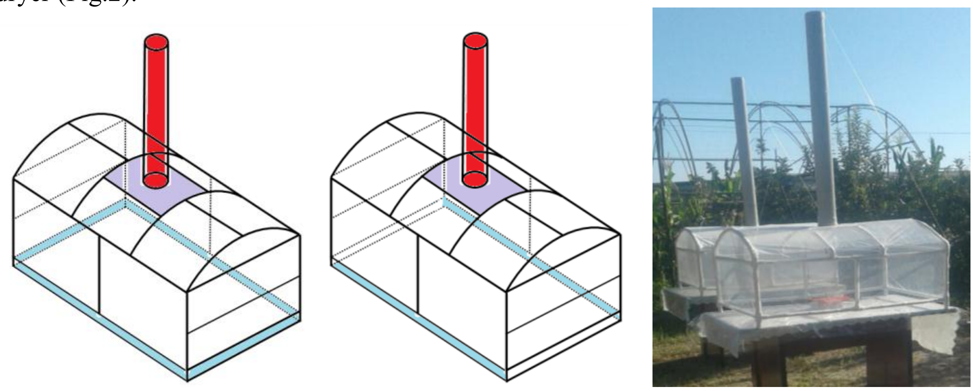


Fig. 1. Experimental devices covered with polyethylene film: a - ordinary polyethylene; b - functional ceramic composite polyethylene

Instrumentation. Solar radiation, wind speed and outdoor air humidity for Bukhara region were obtained from https://data.meteo.uz/. The following measuring instruments were also used: RS PRO TA298 Digital Hygrometer (Indoor: 0-50°C, Outdoor: -40 to 70°C), Digital Panel Thermometer Hygrometers (-20 to 70°C), TEJ-1000B laboratory scale (1000±5 g).

Sample purchase and preparation. Tomatoes of the "MADERA" variety were purchased from the local market for drying in the experiment. Flawless freshly picked tomatoes were sorted, washed with water, and the surface was cleaned of external dust and parasites. then the tomatoes were cut into 5 mm thick slices. Tomato slices weighing 300 g were placed in each dryer and hourly mass changes were measured with high accuracy on a scale. The experiment started at 8:00 am.

Experimental procedure. The experiments were conducted in August 2022. Drying of tomato slices was carried out in dryers under the following conditions: (i) air inlet area $A_{in} = 0.2\ m^2$, air enters through 0.05 m openings on all sides of the dryer; (ii) air inlet area $A_{in} = 0.12\ m^2$, air enters through 0.05 m slots on the south and north sides of the dryer (Fig.2).



(i) (ii)

Fig. 2. Schematic and overview of experimental devices in the experimental process (blue color – air inlet surface; red color – air outlet surface).

3 Results and Discussion

In case (i), the total surface of the air inlet slits is $A_{in} = 0.2\ m^2$, and the surface of the air outlet is $A_{out} = 0.00785\ m^2$. The experiment was held on August 8-9. At 8:00 a.m. tomato products of the same mass were placed in the dryers. On August 8, the maximum solar radiation was 824.7 W/m^2 at 13:00, and the maximum ambient temperature was 33.6 ºC at 16:00. The maximum air temperature inside the driers was 49.3 ºC at 16:00 in the ordinary polyethylene coated drier and 52.9 ºC in the ceramic composite polyethylene coated drier at 15:00, respectively. The experiment lasted until 13:00 on August 9, when the solar radiation was 823.6 W/m^2, the ambient temperature was 32.1 ºC, and the temperature inside the ordinary and ceramic composite polyethylene dryers were 48 ºC and 50.1 ºC, respectively. The results of hourly tomato mass changes obtained in the devices on August 8-9 are presented in the form of a diagram in Fig. 3. The tomato product was dried in 15 hours and had a mass of 30 g in a ordinary polyethylene coated dryer and 21 g in a functional ceramic composite polyethylene coated dryer.

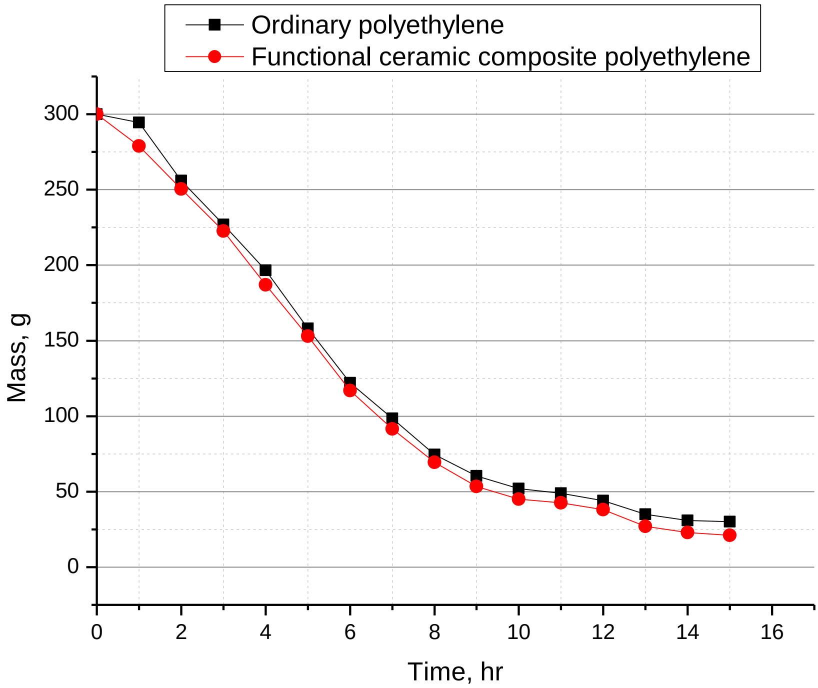


Fig. 3. Hourly variation of tomato mass (August 8-9).

In case (ii), the total surface of the air inlet slits is $A_{in} = 0.12\ m^2$, and the surface of the air outlet is $A_{out} = 0.00785\ m^2$. The experiment was held on August 10-11. At 8:00 a.m. tomato products of the same mass were placed in the dryers. On August 10, the maximum solar radiation was 821,4 W/m^2 at 13:00, and the maximum ambient temperature was 33,5 ºC at 15:00. The maximum air temperature inside the driers was 46,3 ºC at 15:00 in the ordinary polyethylene coated drier and 52 ºC in the ceramic composite polyethylene coated drier at 15:00, respectively. The experiment lasted until 18:00 on August 11, when the solar radiation was 819,6 W/m^2, the ambient temperature was 32,9 ºC, and the temperature inside the ordinary and ceramic composite polyethylene dryers were 46,9 ºC and 50,7 ºC, respectively. The results of hourly tomato mass changes obtained in the devices on August 10-11 are presented in the form of a diagram in Fig. 4. The functional ceramic composite polyethylene coated dryer had 24 g of mass remaining at 20 hours, while the ordinary polyethylene coated dryer had 26 g of mass remaining at 22 hours.

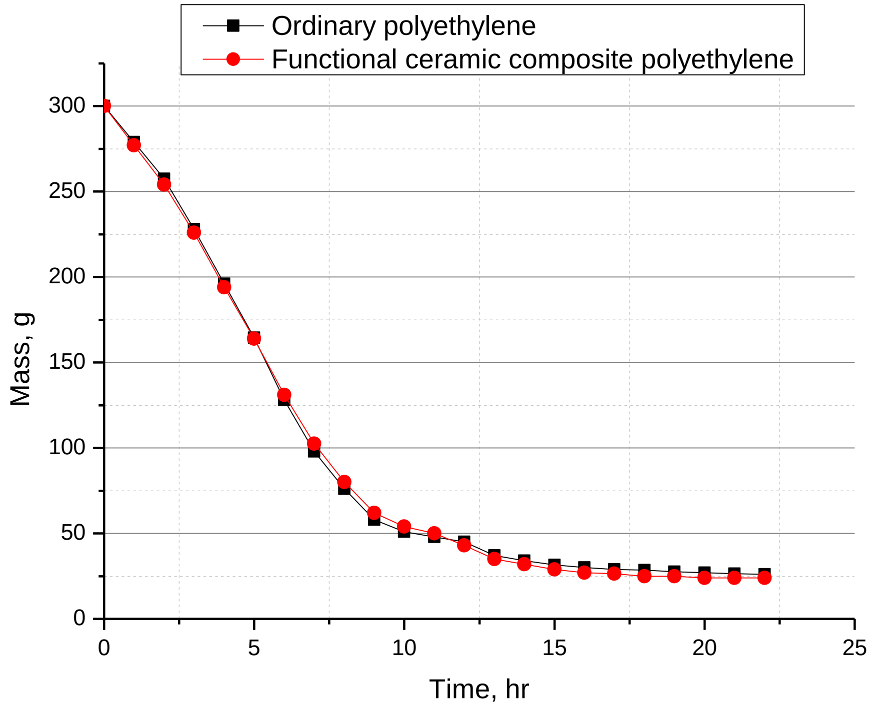


Fig. 4. Hourly variation of tomato mass (August 10-11).

Changes in solar radiation, wind speed, humidity and temperature of the external environment were measured every hour during the experiments on August 8-9 and 10-11 are presented in Figures 5-6.

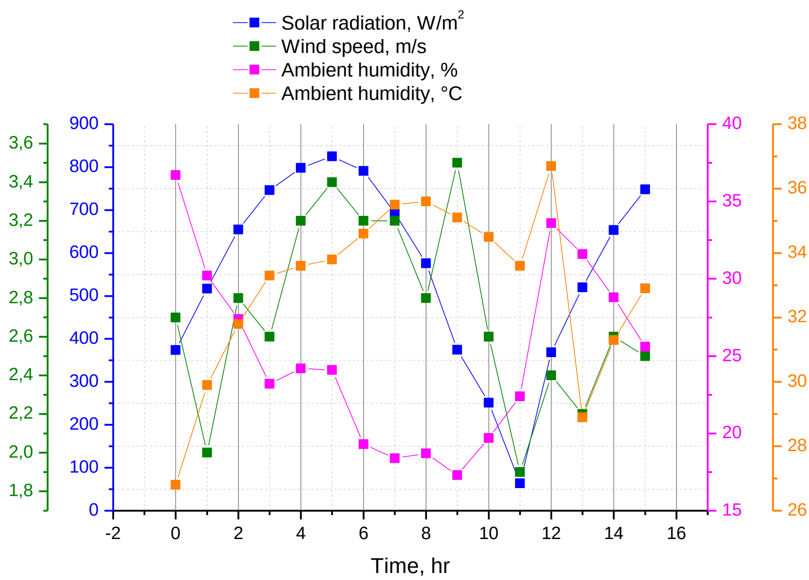


Fig 5. Hourly change of external environment parameters (August 8-9)

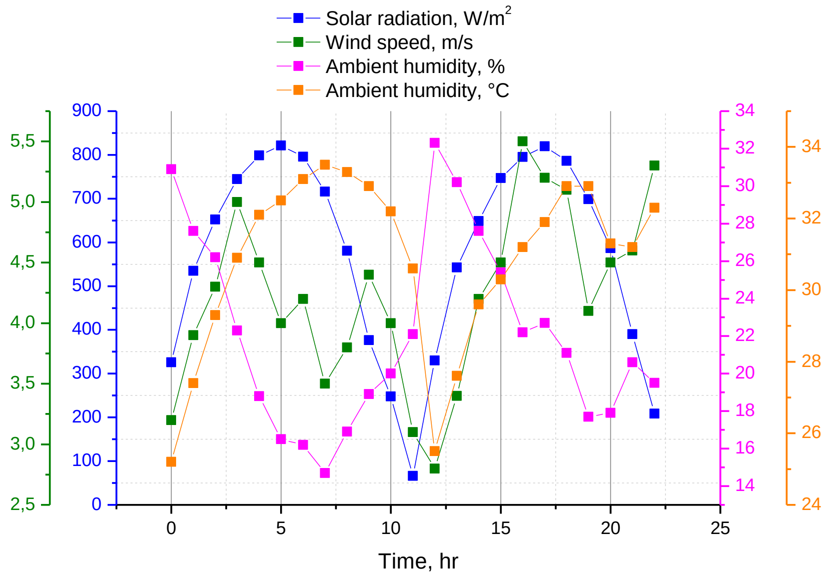


Fig 6. Hourly change of external environment parameters (August 10-11)

4 Conclusions

The experiment was carried out under natural convection conditions on two different air-inlet surfaces. The product dried in 15 hours with air inlet surface $A_{in} = 0.2\ m^2$. It had a mass of 30 g in the ordinary polyethylene-coated dryer and 21 g in the functional ceramic composite polyethylene-coated dryer. The drying process slowed down and lasted 20-22 hours with the air inlet surface $A_{in} = 0.12\ m^2$. In this case, 24 g of mass remained in the functional ceramic composite polyethylene-coated dryer at 20 hours, and 26 g of mass remained at 22 hours in the ordinary polyethylene-coated dryer. During the experiment, it was observed that the temperature of the product inside the dryer with ceramic composite coating is higher than that of the dryer with ordinary coating. In further studies, attention should be paid to determining the optimal dimensions of the air inlet surface in order to speed up the drying process.

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