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A Parametric Study on Effect of Drying Performance of Solar Dryer integrated with a Dehumidifier Unit

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ABSTRACT

In solar dryers, the atmospheric air with more humidity resulted in the low moisture removal from the product and led to prolonged drying time. Such a situation causes spoilage of food products. A suitable mechanism required to remove moisture from the ambient air before it subjected to the drying chamber. The present work addressed the moisture removal method of air for the humid climates with more than 80% relative humidity of air and the variation of subsequent drying rate through parametric analysis. The relative humidity of air preferred between 40% and 60% for the effective drying rate of fruits. A dehumidifier assisted solar dryer found to be more beneficial to the more humid sites.

Key words: Dehumidifier, Drying rate, Flat plate solar collector, Solar dryer.

1. INTRODUCTION

The use of solar energy for drying and preservation of food products has been used for a long time. Due to advancements in engineering technology, various solar dryers have been developed to harness solar energy effectively for drying foods. Solar dryers are eco-friendly and do not require any additional energy other than solar energy and the technology is highly useful for drying and preserving foods. The suitability of the dryer for specific drying applications may be governed by the type and the design of the dryer. Thus, solar dryers can meet out the industrial process heating. The properties of air are essential to utilize it for the drying process. The humidity ratio of the air is one of the significant factors to absorb the moisture from the products. Psychrometric properties of air play an essential role in the heating and drying characteristics. If the air is already with high humidity tends to absorb low moisture. Dry air is capable of absorbing maximum moisture due to the maximum moisture-holding capacity until saturation conditions. Hence, the dehumidifying air is vital to reducing the moisture content of food products is an efficient method to increase the shelf life of foods. A flat plate solar collector (FPSC) is typically used for solar drying. Solar dryers are operating under 40-60 °C to remove the moisture from the products. Solar drying is one of the low-cost methods for food security. Simple construction and easy maintenance are the significant advantages of solar dryers [1, 2]. The classification of conventional solar dryers is illustrated in Figure 1. For large-scale production, forced convection-based dryers used.

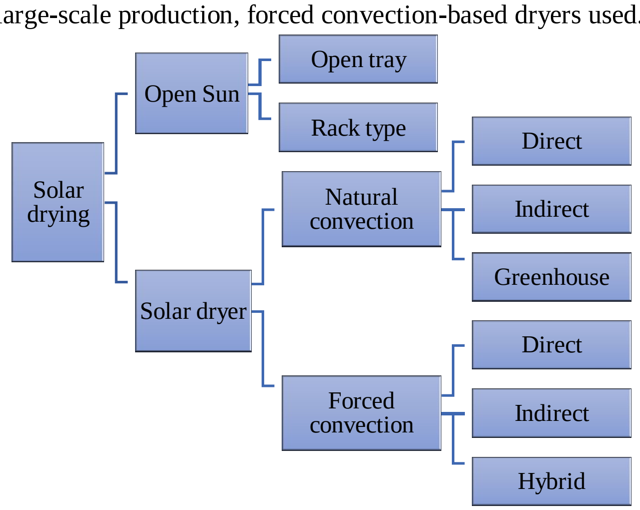

Figure 1: Classification of solar dryers

Several works carried out on solar dryers for several decades. A lot of investigations have conducted on the solar air heaters, drying chamber designs to produce effective drying technologies. Mehta et al. [3] studied the performance of mixed-mode solar dryers for fish drying. The collector outlet temperature estimated to be 75 °C with an efficiency of 25.42% using a mathematical model. The moisture content reduced from 89% to 10%, with an average drying chamber temperature being 60-65℃. The thermal diffusivity based on moisture ratio found to be 1.53 $\times 10^{-7}$ m_2/s.Islam et al. [4]

investigated three different types of chambers for natural convection solar dryer; thin-tube, attic-space, and natural draft chamber to calculate the potential of removing moisture from the fruits. The total moisture removal rate was about 58.9% in 6 hours. Solar dryer with a V-shaped absorber plate developed by Lingayat et al. [5] to dry the fruit slices. Essalhi et al. [6] compared the open sun drying and indirect solar dryer for drying grapes. Heat from water storage tank-maintained grapes temperature higher than the ambient temperature in off sunshine hours. Indirect solar dryer reduces the drying time with a moisture diffusivity of 2.34×10^{-11} m^2/s. For energy efficient and continuous solar drying operation.

Murali et al. [7] developed solar-hybrid dryer with FPSC and thermal energy storage (TES). The reduction of moisture content in shrimp was attained from 76.71% to 15.38% on wet basis. For non-electricity powered drying, Ndukwu et al. [8] used wind powered solar dryer with glycerol as TES. Vijayan et al. [9] used a solar dryer with a porous storage medium to extract moisture from the bitter gourd samples. The reduction of moisture content by 80% was done in 7 hours. Energy storage materials used in solar thermal systems to enhance the heat flux on the absorber [10, 11]. The nature of the solar-absorbing surface is essential to improve the heat augmentation of the incident radiation [12-15]. A secondary reflector is useful to attain high temperature in solar collectors [16]. The drying of products depends on the temperature and air moisture. Most of the solar dryers are operating under atmospheric pressure conditions. The material selection is essential to attain the required temperatures. Various desiccant materials are commercially available and the selection of materials to be carried out through proper measures regarding the moisture absorption capability, container compatibility, non-toxic to the food substances, recycling capability and cost-effectiveness for drying and human comfort [17, 18]. The use of modern technologies to control the operation of solar dryers are investigated recently [19-22]. High-temperature glass is used for solar collectors to avoid convection loss [23]. Further studies are required to integrate solar thermal collectors with thermal storage with nanomaterial-based enhancement techniques [24-27]. Shade and oven drying were determined to be effective at a temperature around 60°C and 40°C, respectively [28]. A forced convection with a higher airflow improves the drying capability [29]. Concentrator-based solar dryers are more effective to reduce the drying time [30]. The hybrid solar collectors are effective in drying the food grains at a faster rate [31]. Solar cells improve the sustainable utilization of solar energy to drive the flow circulation [32]. Drying chamber design studied using simulations to improve the effective circulation of hot air [33]. The concentrated solar dryers with TES [34, 35] and solar PV/Thermal collectors are more beneficial to improve the productivity of the solar dryers [36-38].

From literature, a minimal amount of work has addressed the reduction of air moisture before drying applications. In this work, a parametric analysis carried out on FPSC with the dehumidification unit using silica gel as a desiccant. The thermal performance studied for this controlled drying process. Moisture absorbed at a different airflow rate for varying silica gel mass on different types of fruit slices of specified thicknesses discussed. Fruit slices of mango, pineapple and banana considered for drying. Moisture ratio and drying constant calculated to analyse respective moisture removal rate. Based on the parameters, the performance of the drying process reported here.

2. MATERIALS AND METHODS

The main objective is to study the thermal performance of the FPSC with a dehumidifier unit through parametric analysis to drying the fruit slices. During the drying process, atmospheric air passed through the dehumidification unit where desiccants are kept to reduce the moisture of air passing over that. FPSC is used to heat the air. The hot air is used for food drying at the drying chamber and the fruit slices are kept at trays to distribute the hot air. The standard solar air heater of 1 $m^2$is considered in this analysis to unit mass of fruits. Figure 2 shows the schematic layout of the solar dryer with dehumidifying section. For this study silica gel is used as the desiccant and moisture absorbed at different airflow rate for varying silica gel mass is calculated by parametric analysis. Fruit slices of mango, pineapple, tomato, and banana are taken as drying samples. Moisture ratio and drying constant are calculated and moisture removal rate is analysed. Table 1 indicates the properties of silica gel.

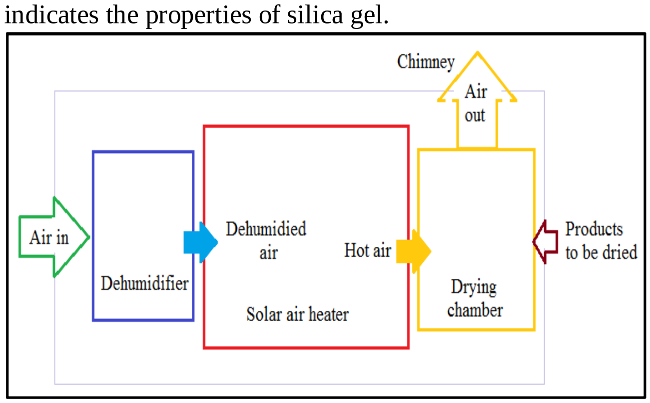

Figure 2: Solar dryer with dehumidifier section

The experimental setup consists of a dehumidifying unit along with a FPSC unit. A blower is used for supplying atmospheric air to the dehumidifying unit and the effect of varying the airflow rate which is used to calculate the different drying outcomes. Mass of fruit is considered in this analysis is one kg and the slices are uniform thickness of around 5-7 mm for all the fruits. The dehumidification unit has two ports, one for inlet of atmospheric air and the other for exit of the moisture reduced air which is transferred to the solar air heater. Inside the dehumidifier, the required desiccant is placed to absorb the moisture from the inlet atmospheric air. A FPSC is used for heating the dehumidified air, since some amount of heat is lost during dehumidification. Fins and surface modified absorber plate are used inside the solar collector to increase the contact surface area and two-pass is provided to effectively raise the temperature of air for drying applications.

Table 1: Properties of silica gel

Properties	Value
Chemical formula	SiO_2
Surface area (m^2/g)	510
Specific heat(J/g.K)	1.012
Bulk density (kg/m^3)	650
Thermal conductivity (W/m. K)	0.115
Specific pore volume (ml/g)	0.405
Minimum moisture holding range (%)	22
Maximum moisture holding range (%)	40
Moisture removal temperature (°C)	110

Moisture ratio is determined using Eq. (1),

$$MR=M_f/M_i \quad (1)$$

Where,M_i and $M_f$are the initial and final moisture content.

Drying rate constant (K_o) is calculated using Eq. (2),

$$\ln (MR) = K_o t + \ln(8/\pi^2) \quad (2)$$

where, t is time (min) and K_o is drying constant.

3. RESULTS AND DISCUSSION

The parametric analysis studied the moisture absorbed at different flowrates for varying mass of silica gel on different types of fruit slices of specified thicknesses. Fruit slices of mango, pineapple and banana are taken as drying samples. MR and drying constant are calculated to analyse respective moisture removal rate. Figure 3 shows the air moisture over the relative humidity (RH). The preferable RH for the solar dryer is to be below 60% RH. The moisture holding capacity of air above 60% is very smaller; hence, the moisture to be removed before applying for drying purposes.

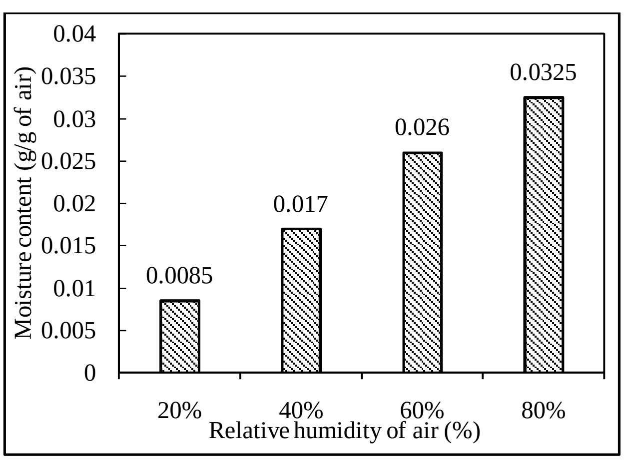

Figure 3: Moisture of air over RH value

Figure 4 depicts the comparison between the maximum moisture absorption (kg) and silica gel mass (kg). The moisture removal improved with desiccant materials. Varying the mass flowrate of air also contributes in the process of decreasing the moisture and the calculated valued were plotted in the graph as shown in Figure 5, with the moisture absorbed against the silica gel mass for three different air mass flowrates, 0.010 kg/s, 0.015 kg/s and 0.020 kg/s. Mass flowrate of 0.015 kg/s and 0.020 kg/s is found to be effective to remove moisture effectively with minimal mass of silica gel.

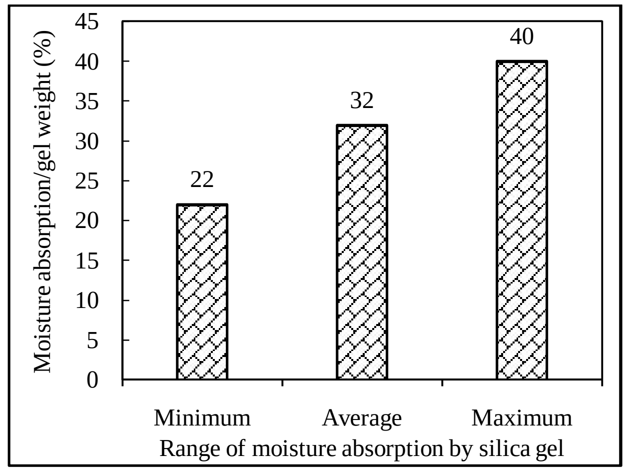

Figure 4: Mass of desiccant and moisture absorbed

Mass of desiccant required to reduce the RH of air is depicted in Figure 6. The range of desiccant mass required to reduce the RH from 80% to 60% is 1.6 to 2.9 kg. About 8 to 15 kg of silica gel is required to bring the RH to zero. However, such a condition of air is not required for drying of food grains. Such condition is applicable for fryer-based applications.

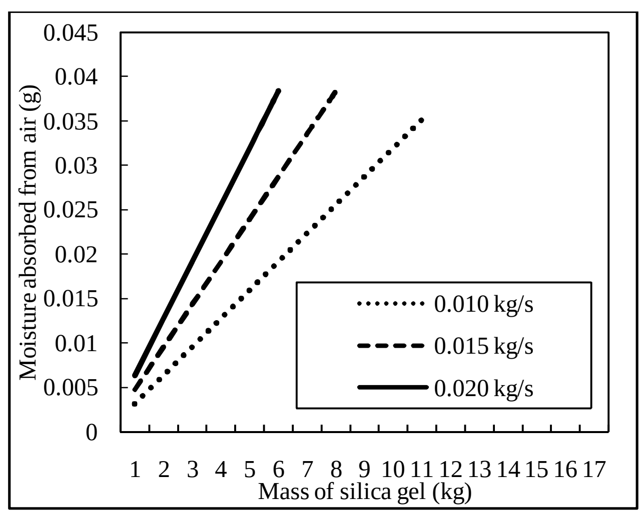

Figure 5: Effect of mass flowrate of air over the moisture absorbed over the mass of silica gel required

Figure7 shows the drying constant with time. Table 2 shows the drying rate correlations formed from the parametric study on the selected fruits. The formed correlations are useful to design the solar dryers. The removal of moisture from silica gel is carried by heating around 110-120°C for 1 to 2 hours. The absorbed moisture removed; the desiccant is made reusable for the next day. Figure 8 shows the effect of air temperature over the moisture removal rate for the foods with an initial moisture of 90%. The higher the air temperature, the drying time is observed to be lower. However, the operating temperature of hot air depends on the type of products to be dried and the RH values to be maintained according to the nature of food products.

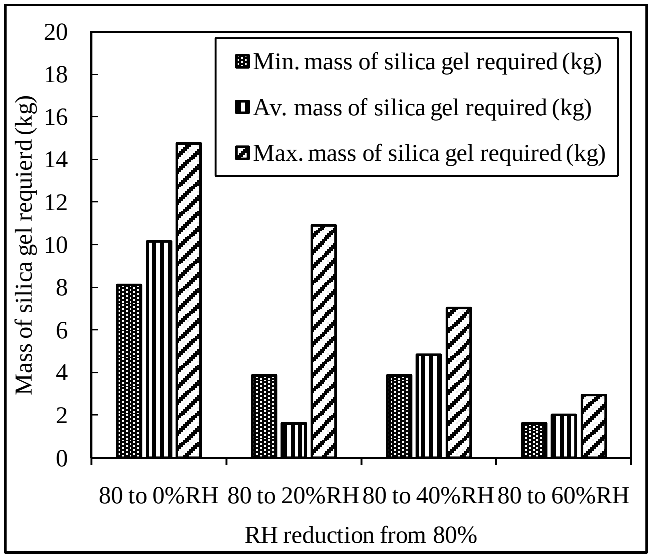

Figure 6: Mass of silica gel required to reduce the RH value of air

Table 2: Drying rate correlations for the selected fruits

Items	Correlations	R^2 value
Pineapple	$K_o = 6.0923\ t^{-1}$	0.999
Mango	$K_o = 6.0623\ t^{-1.012}$	0.993
Banana	$K_o = 5.4833\ t^{-0.959}$	0.998

The thermal performance of a FPSC coupled with a dehumidifying unit was studied parametrically. The unit was used to reduce the moisture content of inlet air which was further heated and allowed to absorb more moisture from fruit slices of specific thickness. The present parametric study gives an overview of the usage of silica gel as the humidifying agent and the way of capturing the moisture from the airflow. Thus, the captured moisture is beneficial to use directly for the cleaning of solar PV panels at the hybrid solar dryer systems. To make the water potable, it could be treated further to remove the traces.

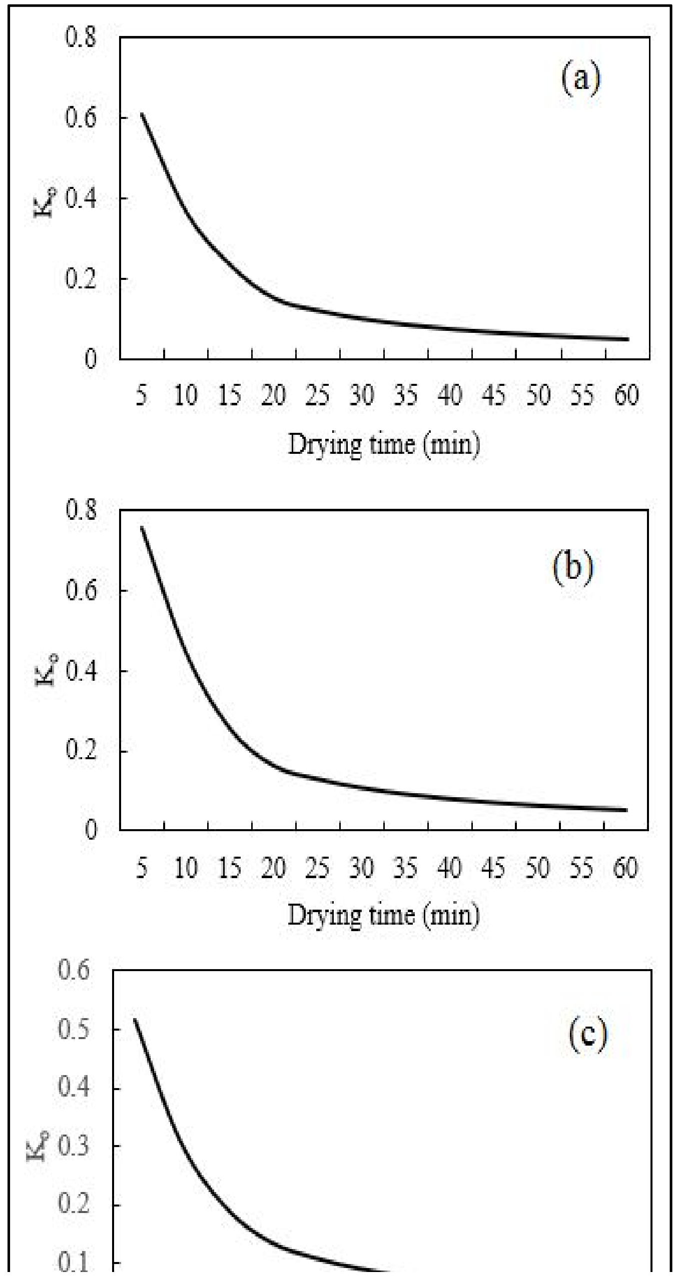

Figure 7: Variation of drying constant over the drying rate of selected fruits:(a) Pineapple, (b) Mango, (c) banana

The parametric study outlines the effective use of moisture removal of air to drying fruits. The design of desiccant bed materials on the solar air heater is essential to absorb the moisture. An effective heating mechanism is required for moisture retrieval and the production of water for non-drinking applications. The water output from the desiccant is smaller in quantity due to the mass of absorbing materials. Thus, solar dryer integrated with other renewable sources like biomass, wind, solar PV with energy storage are enhancing the overall fossil fuel independence for low-temperature applications.

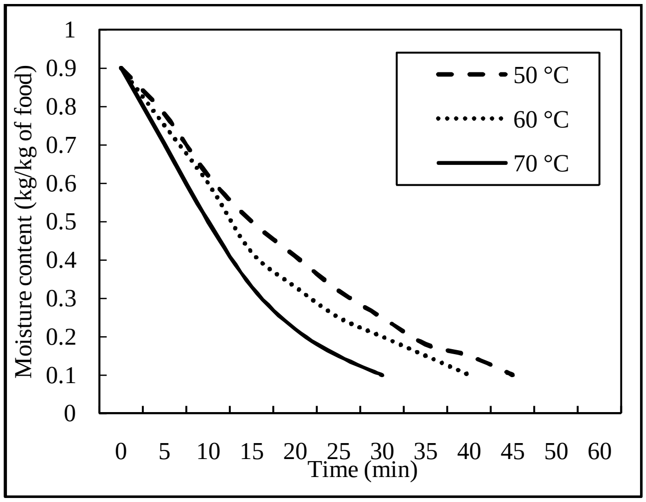

Figure 8: Drying rate over the temperature of air temperature

4. CONCLUSIONS

The experiments were done on fruit slices of mango, pineapple and banana with varying parameters like amount of silica gel, air mass flowrate and temperature. The major conclusions are listed below.

- The moisture absorption rate increases with increase in the amount of desiccant used. An optimum mass of desiccant is to be selected for the cost-effectiveness.

- The airflow rate also contributes to the amount of moisture absorbed. Lower flowrate is useful during the drying.

- The rate of drying depends on the temperature and humidity to which the food products are exposed. The hot air to be passed to the drying chamber well below 60% RH for the effective drying rate.

Different food products dry at a variable rate. The process of food preservation using solar energy with dehumidification improved by using different kinds of desiccants like dry ice or chilled water, using modified solar collectors and by integrating with energy storage.

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