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DEHYDRATION PROCESS OF AGRICULTURAL PRODUCTS USING SOLAR ENERGY

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Abstract— **Drying food to preserve it is an energy-intensive process. Solar drying is one of the oldest methods used to preserve agricultural produce. The open sun drying can cause the degradation of the quality and quantity of the product and also it takes long time for drying. This technique is modified by using several technologies like solar air dryer. Solar thermal energy has tremendous potential for commercial and industrial drying applications with air temperatures as high as 80 degrees Celsius. The main objective of this research work is to examine the physical changes that occur during convective air-drying process of Thompson seedless type cylindrical grapes through experimental and numerical work. These include changes in the physical properties of the product, such as the moisture content, the temperature of the product, and the size of the product. The objective of developing mathematical model is to develop a universal diffusion model of drying kinetics that can be applied to a variety of shrinkable products such as fruits and vegetables are in cylindrical shape. Developed a one and two-dimensional transient diffusion model that takes into account convection, radiation, and evaporation phenomena under a variety of operating conditions for simulating grape drying and shrinkage. The dryer was tested at varying ambient temperature and solar radiation conditions to evaluate the performance. The experimental trial was done for the validation of the mathematical model. This mathematical model was developed by the integration of different models for predicting the performance of solar dryers, particularly for Thomson seedless grapes of cylindrical shape. A cabinet-type double-glazed solar dryer with a length of 2 m, a width of 1 m, and a height of 0.8 m that is installed in Pune, India and used for the experimental trails. Experimental tests was conducted for different ambient temperatures and different solar radiations, and rates of dehydration and reduced drying time were recorded in comparison to the tests conducted. The results obtained from the mathematical model are compared with experimental results and found to be in agreement with a maximum error of 14%. The dryer was tested at varying ambient temperature and solar radiation conditions to evaluate the performance. Around 15 kg of fresh grape with initial moisture percent of 86-88% on wet basis were kept in the natural convection dryer (10.00 AM – 5.00 PM). At the end of the test, the moisture percent of the grape was reduced to 13-14% for the tests conducted.**

Index Terms— **Dehydration Process, Solar energy, Solar air dryer, Agriculture products, etc.**

I. INTRODUCTION

A. Solar drying

Solar drying is a commonly used technique that relies primarily on solar radiation to heat the drying air. Airflow within the drying chamber can be generated naturally or mechanically through forced convection. In a solar dryer, the air can be heated separately in a solar heater before being transported to the drying chamber where products are placed. The products can be exposed to direct sunlight or a combination of direct sunlight and heated air. Heat from the hot drying air is transferred to the product through convection and conduction, causing the moisture in the product to evaporate. When exposed directly to solar radiation, heat is primarily transferred through radiation, with a smaller amount transferred from nearby hot surfaces. Heat absorption provides the energy required for water vaporization inside the product. Moisture imbalance causes the water to vaporize as the product's water vapor pressure rises above that of the surrounding air. The product's moisture level decreases due to this process, and the interior of the product diffuses to replenish moisture at the surface, which depends on the product's nature and moisture content.

B. Motivation

Given that grapes are a very perishable fruit that might deteriorate during storage and transit, grape drying is an especially relevant field of study. Mathematical modelling may be used to optimise the drying process and raise the quality of the dried grapes. Cabinet style solar dryers are a common and affordable way to dry grapes. The aforementioned discussion emphasises the significance of several variables in influencing the shrinkage and volume decrease of grapes during solar drying, including effective diffusion coefficient, surface transfer coefficients, and moisture content. Mathematical modelling for grape drying with cabinet-style solar dryers, however, is not well studied. The process of drying grapes may be made more efficient and effective by creating precise mathematical models that can forecast how the grapes will dry under various drying circumstances. The effects of different drying factors, such as drying air temperature, air velocity, and thickness, on the moisture content, shrinkage, and volume reduction of grapes may be predicted using mathematical modelling. Such models can be used to optimize the drying process and improve the quality of the dried grapes, ensuring that they retain their nutritional value and desirable sensory properties. Furthermore, mathematical modelling can be used to develop new drying techniques that are more energy-efficient and environmentally friendly, contributing to the sustainable production of high-quality dried grapes.

C. The research project's goals

When it comes to solar dryer systems, the opinions discussed in the earlier parts can be summarised as follows:

- To comprehend the current mathematical models for food product drying characteristics.
- To comprehend the effects of ambient temperature and radiation intensity on the drying properties of grapes; • To construct and evaluate the mathematical model for prediction of moisture ratio as a function of drying time (Thompson seedless grapes)

II. LITERATURE REVIEW

Barnwal and Tiwari (2008) calculated the hourly convective mass transfer coefficient, the amount of moisture that evaporated, and the amount of heat required for moisture evaporation using a Computational Fluid Dynamics (CFD) tool. A hybrid photovoltaic-thermal (PV/T) system was used to design and build a solar dryer that took the shape of a greenhouse and could hold up to 100 kg of materials. According to reports, the convective heat transfer coefficient values for grapes (GR-I) vary from 0.26-0.31 W/m2 K under greenhouse circumstances to 0.34-0.40 W/m2 K in open conditions. Convective heat transfer coefficient values for grapes (GR-II) vary from 0.45 to 1.21 under greenhouse settings and from 0.46 to 0.97 in open circumstances. For the purpose of dehydration, two different varieties of seedless Thompson grapes, Grade I and Grade II, were used. A direct current (DC) fan was used in the experimental configuration to create a forced convection mode. The convective heat transfer coefficients for Grade I and Grade II grapes were determined to be 0.26 to 0.31 W/m2 K and 0.45 to 1.21 W/m2 K, respectively, by Jairaj et al. (2009). Two programmes were offered by Khazaei et al. (2013) for the drying procedure. The first adjustment concerned the air flow rate, while the second one dealt with adjusting and controlling the drying air's temperature. The gadget allowed the camera to take pictures for 20 minutes at a time. Following the conclusion of an experiment, the resulting programme was used in computer vision studies. The consistency and moisture content of the grapes were taken into consideration while analysing the drying process kinetics. The models stated above were used and evaluated to improve the drying process. The results show that colour and shrinkage evaluations based on machine vision have the ability to digitally predict the uniformity and moisture content throughout the drying process. It was then discovered that the use of applied computer vision might make it easier to keep an eye on grape desiccation, namely on shrinkage and hue. The research used MACHINE VISION technology for picture acquisition and analysis. This allowed for the quantification of the grape specimens' shrinkage, colour ratio, and uniformity. After that, it would be possible to estimate the fruit's moisture content by using linear correlations that relate moisture content to either colour ratio or shrinkage. The solar dryer would be turned off and on again until the moisture content exceeded the desired result. At every step of the drying process, the consistency of the dried grapes could be checked.

In Chaudhari et al.'s (2021) mathematical model, the secondary energy required to control the drying chamber's temperature was found. The model is developed using the dryer control volume heat exchanges, the set temperature, and the intensity of solar radiation. The "computational fluid dynamics" approach is utilised to model the drying chamber's airflow under different operation scenarios. This work contributes to the identification of the additional inputs required beyond solar heat. Gupta et al. (2021) created a mathematical model to study the drying kinetics of green chilli generated in a hybrid PVT sun drying system. The model's output was checked against experimental data using a home test setup. Thermal performance improved when they used a hybrid PVT system. Mathematical modelling of the drying mechanism enables the design of solar dryers as well as the evaluation of the process' efficacy.

In their 2018 study, Hamdi et al. used numerical modelling and experimental methods to study the drying of grapes. The TRNSYS programme was used by the authors to create the mathematical model under suitable settings. A mathematical model was created by Yaldiz et al. (2001) to explain the Sultana grape thin-layer sun drying procedure. This is a Thompson seedless cultivar. In order to forecast how air temperature and velocity will affect Sultana grape thin layer drying, regression models were used. Sultana grapes were dried in a sun dryer using indirect forced convection. The researchers concluded that the sun drying curve of Sultana grapes may be properly represented by a two-term model. Djebli et al. (2020) investigated seven different models to find the potatoes' moisture ratio (MR) throughout the sun-drying process. The model's effective diffusion coefficient is found by using the Fourier series and Laplace transform techniques. In order to investigate how temperature affects food quality degradation during drying, Lopez-Vidana et al. (2017) looked at the antioxidant activity, anthocyanin content, and phenol content of martino. Based on the R2 and RMSE values between the experimental and projected models for MR, the drying kinetics models were compared. A mathematical framework for simulating the mixed-mode sun drying process of grapes was created by the authors Ramos et al. (2015). Heat and mass transport phenomena are both included into the model. In order to explain an open sun drying technique used for dehydrating fragrant plants like parsley, mint, and basil, Akpinar (2006) created a mathematical model. By comparing the decreased chi-square and RMSE values that resulted from the comparison of the observed and predicted MRs, the models' performance was assessed. A model created by Akpinar (2008) was put to the test using experimental data from open sun and solar drying. It was discovered that the model was similar to other models in the area. The drying model and the actual results from a solar dryer using the forced air-drying approach showed good conformance.

III. EXPERIMENTAL ANALYSIS

A. Experimental Test Setup

A solar cabinet type natural convection based dryer is a type of solar dryer that uses natural convection to circulate air inside a closed cabinet for drying various agricultural products. Natural convection is used to circulate air inside the drying chamber. Hot air rises and creates a low-pressure zone at the top of the chamber, which draws in cooler air from the bottom of the chamber. The developed solar dryer for the work presented is designed to preheat the air using solar radiation through absorber plate and circulating heated air over the sample through natural convection. The dryer consists of an absorber plate, a drying unit, an auxiliary heating element and opening vents to facilitate inlet and exit of air as depicted in figure 3.1(a). To absorb maximum solar radiations, an absorber plated is black coated and is covered with toughened glass. Figure 3.1 (b) displays the pictorial view of the dryer. Two strip type electric heaters are located beneath the trays to facilitate the drying during winter season and low intensity solar radiation conditions. Heating element is comprised of a heating layer sandwiched between stainless steel cover with mica sheet insulation as represented in figure 3.1. The efficiency of a solar cabinet type natural convection based dryer depends on various factors such as the size of the collector, the size of the drying chamber, and the ambient temperature and humidity.

The design of a cabinet-type double-glazed solar dryer erected in Pune, India, measuring 2 metres in length, 1 metre in width, and 0.8 metres in height, is shown in Figure 3.1(a). Above the cabinet, a double-glazed flat plate collector is installed, and a black paint job covers the top of an aluminium absorber plate. As shown in figure 3.1 (b-c), the dryer's input and exit pipes are located at the top and front, respectively, to facilitate air circulation. The circular meshed trays made of stainless steel are filled with grapes to be dried. The cabinet is designed to fit the trays, as seen in figure 3.1 (b-c). In Pune, India, experiments were conducted in March 2019. Grapes of the Thompson seedless cylindrical variety were utilised. 15.6 kg of grapes were placed into the dryer for the trial runs. For three days, grapes were frequently sprayed with an oil and carbonate combination to speed up the drying process. The drying process continued till 6:00 PM. Because of the stratification, hot air rises from the intake to the outlet. An electronic balance was used to weigh grape samples daily at the beginning of the observation recording (10:00 AM) and the conclusion of the test (6:00 PM).

Every day at 10:00 AM, 1:00 PM, and 6:00 PM, the moisture was measured. Photographs of graphs of raisins at the beginning of the test, after 7 days, and after 14 days, showing the various attributes of raisins discovered throughout the test, are shown in Figure 3.1. The yellowish green colour is of the best quality and is accepted in the domestic and international markets. The air inlet and outlet vents are shaped up using poly vinyl chloride (PVC) pipes with less number of vents at outlet to increase the retention time of air in the drying unit. The dimensional features and specifications of the dryer are presented in the table 3.1. The incoming air through inlet air gets heated through absorber plate and rises up through the drying unit due to natural convection. The heated air passes over the dryer plates and dehydrates the grape over it and finally escapes through the outlet vents. Detail specifications about the experimental test setup are given in table 3.1.

Table 3.1 Specification of solar cabinet type dryer experimental test setup

Parameters	Particulars
Length of cabinet, m	2
Width of cabinet, m	1
Height of cabinet, m	0.8
Number of inlet tubes	12
Diameter of inlet tubes, m	0.075
Number of outlet tubes	8
Diameter of outlet tubes, m	0.155
Number of big size tray	2
Size of big tray, mm	750*730
Number of small size tray,	2
Size of small tray, mm	750*210
Thickness of tray material,mm	2
Insulation used	Glass wool
Area of toughened glass m	2*1
Thickness of glass mm	8
Inlet pipes height of from the surface,m	0.36
Construction material	Wood, glass and mild steel
Two strip type plate electric heaters	1.5 kW each
Location of experiments	Pune, India
Latitude	18° 31' 48.00" N
Longitude	73° 50' 60.00" E

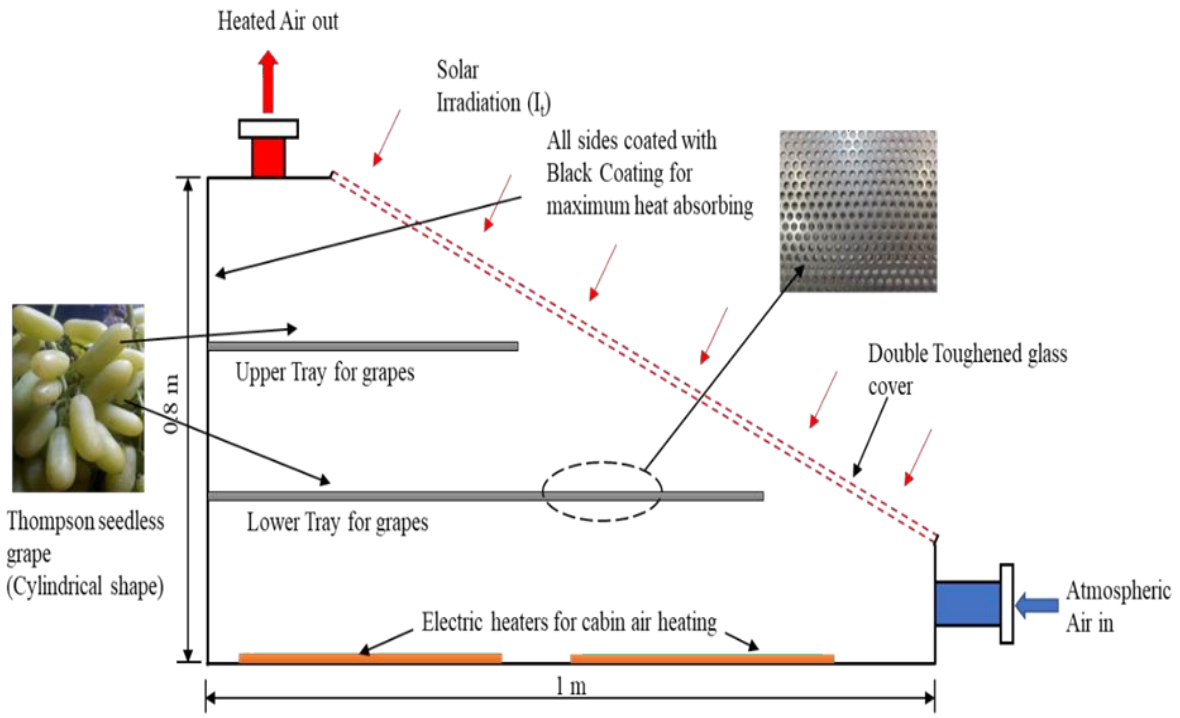
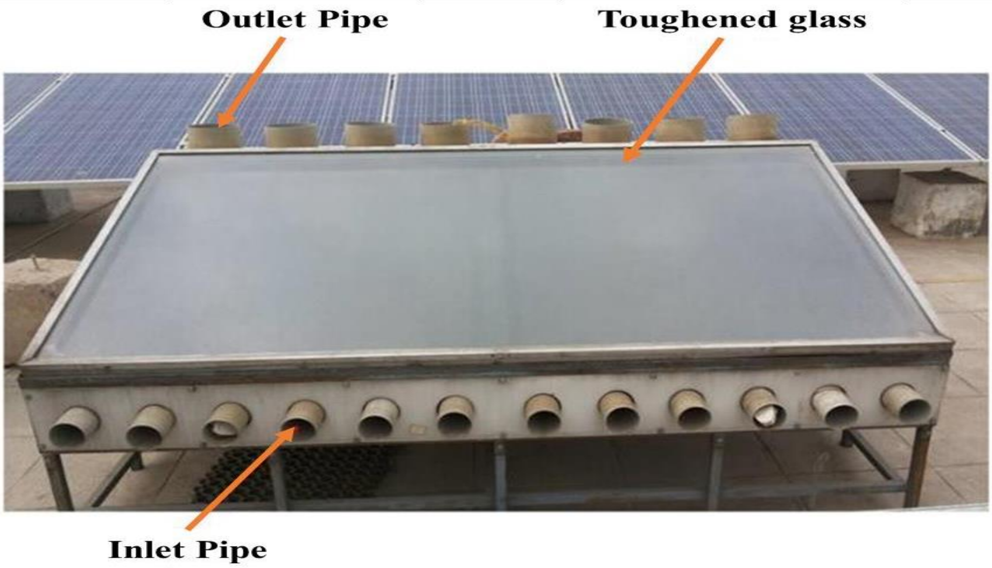
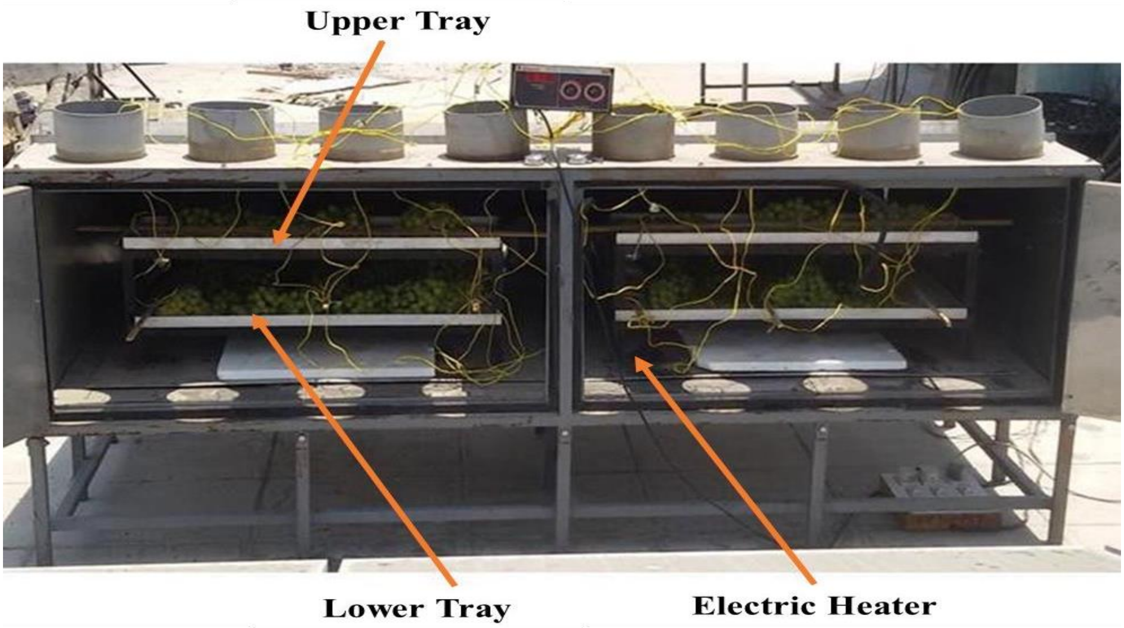


Figure 3.1 Schematic diagram of test setup.



(a)



(b)

Figure 3.2 (a) Photographs of front and (b) side view of the solar dryer test setup.

B. Details about the Instrumentation

The measurement of direct normal irradiance is conducted with a Seaward irradiance meter, while global and diffuse solar radiation are measured using a Dynalab pyranometer (Model: RN 2104). The details about Dynalab pyranometer and specifications are given in appendix A1. The Dynalab indicator utilizes sensors to detect sun radiation and provides readings in mV, which are then converted into W/m2 using a calibration constant of 18.33 µV/W/m2. By dividing the Dynalab reading by the calibration constant, the incident radiation in W/m2 can be obtained. To measure diffused solar radiation, a shading ring is used. A total of sixteen K-type thermocouples are used to measure temperature at different places with an accuracy of ±0.01°C. An IR emitter-based moisture analyzer manufactured by RADWAG measures the grapes' moisture content with a 0.001% accuracy. An anemometer is used to monitor the drying air velocity at the outlet. All instruments are calibrated by their respective manufacturers, and certificates are provided in appendix A1. Table 3.2 presents the details of the instruments used in the experimentation.

Table 3.2 Instruments Used for experimental test.

Instrument	Make	Accuracy	Parameter Measured
Global solar Irradiation	Dynalab	±0.05W/m^2	Solar Irradiations
Moisture Analyzer	RADWAG-made	±0.001%	moisture content of the grapes
RTD (K-type)	Krishtech	±0.01 °C	Temperature
Digital Weighing Machine	Sharp	0.5g	Weight
Anemometer Vane Probe	MEXTECH(AM-4208)		Air velocity
Air Humidity	Dimple		Air Humidity

C. Selection of raw material, sample preparation

In this study, the grapes used for experimentation were specifically of the Thompson Seedless variety. This particular grape variety is known for its seedlessness, small size, and light green-yellow color when ripe. It is commonly used for making raisins and is also used in winemaking. The Thompson Seedless grapes were sourced from the Pune region in Maharashtra, India. The grapes were carefully selected based on their uniform size, and bright green-yellow color, which is indicative of their ripeness and quality, as well as their overall appearance and quality. Initially they were kept for 3 days in the refrigerator to maintain their freshness as it is. Then grapes were taken out and immersed in normal water to maintain temperature its temperature at ambient. To prepare the grapes for experimentation, various chemicals were procured in the prescribed quantities. One such chemical was homobrassinolide, which is a plant growth regulator that has been shown to promote plant growth and enhance plant resistance to environmental stress. A second substance was an emulsifier, which is an ingredient that aids in the mixing of two liquids that would not normally combine, such as oil and water. In addition to these compounds, an adjuvant was utilized to boost the efficacy of the homobrassinolide treatment. Adjuvants are substances added to a chemical mixture in order to enhance its efficacy or stability. The pH of the treatment solution was adjusted with carbonate to assure optimal conditions for the grape pretreatment process. This pretreatment is intended to reduce drying time, thereby accelerating the appearance of surface cracks on grapes and enhancing moisture diffusion through the oily cuticle. After placing these grapes on the trays of a solar dryer for drying purposes in such a way that the radiation falls readily on the trays, moisture transport and evaporation occur within the grapes.

In this study, the grapes were dried using a cabinet type dryer, which is a common method for drying fruits and vegetables. The grapes were first loaded onto two trays, with an equal distribution of grapes on each tray based on their weight. This ensured that the grapes would be dried evenly and consistently throughout the drying process. Once the grapes were loaded onto the trays, both trays were then placed into the tray dryer, with each tray located in its designated location within the dryer. The dryer was set to the appropriate temperature and humidity levels for grape drying, and the drying process was initiated. Figure 3.3 in the thesis draft shows a snapshot of the grape drying process on the first day of drying.

Figure 3.3 Snapshot of grape drying

D. Experimental Procedure:

In Pune, India, a cabinet-style double-glazed solar dryer measuring 2 m in length, 1 m in width, and 0.8 m in height was erected. The design of the solar dryer utilised in the experimental test is shown in Figure 3.1. In order to validate the outcomes of the mathematical model, a moisture content experiment was conducted and the results were compared. Above the cabinet, a double-glass-cover flat plate collector is installed, and an aluminium absorber plate's upper surface has been coated in black paint. For optimal effectiveness, the sides of the solar dryer are insulated. Natural convection in an indirect form is what the drying system does. The input and exit pipes, which are situated at the top and front of the solar dryer, respectively, are used to circulate air through the device. The grapes to be dried are placed onto stainless steel trays with holes in them. Inside the cabinet, perforated trays are kept in the proper places (see fig. 3.1). In Pune, India, experiments were carried out for 14 days in a row with the aim of validating the mathematical model and verifying the results with those reported in the literature. Thompson seedless grapes, with a cylindrical form, were utilised. To improve the permeability of the waxed coat, the grapes were first cleaned and then submerged in a mixture of ethyl oleate oil, potassium carbonate, and water for five minutes. For the trial runs, 15.6 kg of grapes were put into the drier. To expedite the drying process, grapes were sprayed with an oil-carbonate combination for three days. The time frame for drying was 8:00 a.m. to 6:00 p.m. At first, the dryer's air is room temperature and stagnant. Solar radiation heats the air within the dryer cabinet. By sweeping hot air over the grapes' surface, the moisture content is eliminated. The vent seen in figure 3.1 (a) is where the heated air within the cabinet leaves. From the entrance to the exit, heated air rises due to stratification. To weigh grape samples, an electronic balance was employed. Utilising sixteen K-type thermocouples with an accuracy of 0.01°C, temperatures within the dryer were recorded at various points. To measure the temperature of the surrounding air, a single thermocouple is stored outside the cabinet. Relative humidity sensors were used to detect the humidity of the air entering and leaving the room. Using a vane anemometer, the air velocity of natural convection was determined. The grapes' moisture content was eliminated by convective heat transfer as hot air moved over them. Using a RADWAG moisture analyzer with an IR emitter and 0.001% accuracy, the moisture content of the grapes was ascertained. Moisture levels were recorded daily at 8:00 AM, 1:00 PM, and 6:00 PM.

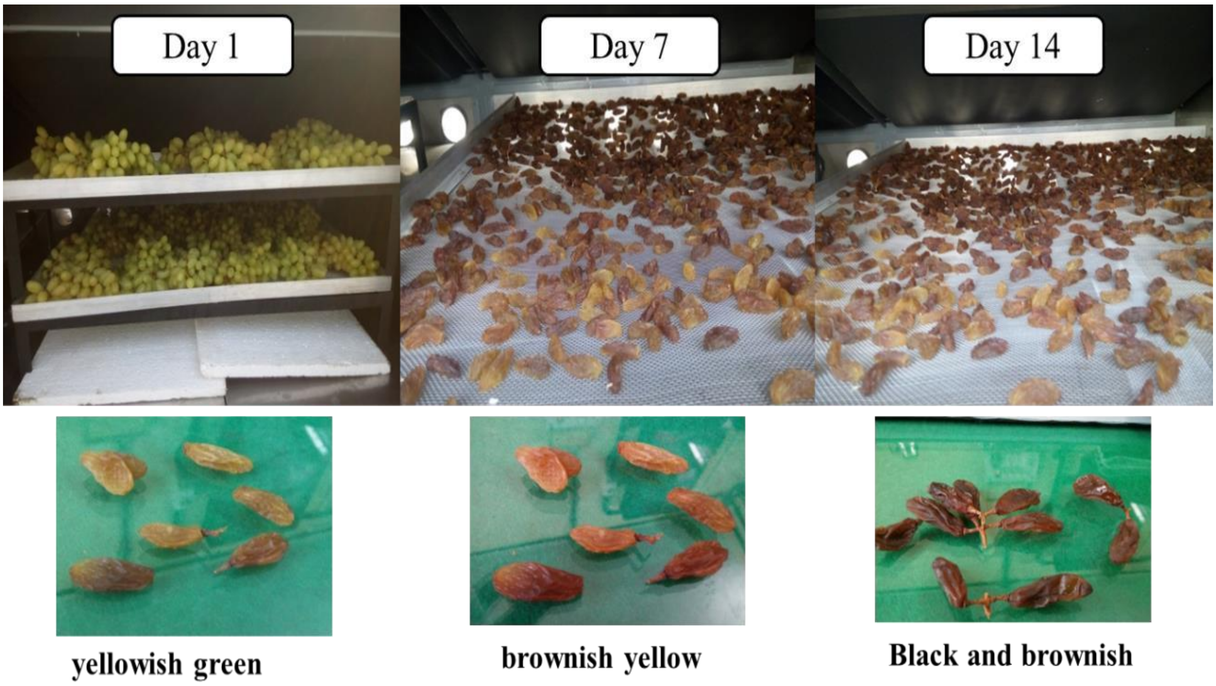


Figure 3.4 Photographs of graphs of raisins for initial, 7 days and 14 days with different quality of raisin found during the test.

IV. RESULT AND DISCUSSION

In this chapter, we present the results of our study and provide an in-depth analysis of our findings. The beginning of this chapter will summarizes the data used for the analysis for one dimensional study and proceed to analyse the results in detail.

A. One dimensional study

After measurement, the initial average moisture content of the grapes was found to be 83 ± 0.5%. The grapes were chosen based on their average length of 30 ± 0.47 mm and their average diameter of 15 ± 0.24 mm. Using a sun drier to estimate moisture content, grape weight, relative humidity, and inlet and output air temperature over a period of days, the heat and mass transfer study was performed. The model is also used to look at different types of losses that occur during the process of heat and mass transfer.

1) Calculating the parameters of mass transfer

Heat transmission causes a temperature gradient to form inside a wet solid, and moisture evaporation happens from the surface of the solid. As a result, moisture migrates from the solid's interior to the surface by one or more processes, including diffusion and internal pressures created by the solid's shrinking during the drying process. A variety of curves for an increase in the temperature of the product (grape) with drying time, a change in the grape radius, and a change in grape temperature are displayed in Figure 4.1. Figure 4.1 shows how grape temperature increases with drying time. There was a maximum increase in grape temperature of about 18°C. This is explained by the grapes' decreased moisture content. Accelerated diffusion is indicated by a reduction in moisture. Figure 4..2 (a) depicts how the model represents the grape's change in form (radius). The grape radius might shrink by up to 2.6 mm as a result of drying. After 14 days, the lowered resultant radius is determined to be 4.9 mm from an initial radius of 7.5 mm. This mathematical model, which is derived from the GAB equation, places significant emphasis on the concept of water activity (Bilanski and Fisher, 1976). A grape's water content may be determined by measuring its water activity. The ratio of water vapour pressure at the solid-gas interface to vapour pressure at the same temperature is known as water activity. A plot of equilibrium water activity against moisture content is shown in Figure 4.2(b). The GAB model considers the fluctuation in moisture at the surface and in the surrounding environment. Water diffusion is driven by the difference between the water content at each moment and the equilibrium water content. A model for the moisture sorption isotherm, such the GAB model, can be used to compute this. This work takes into account the changing external factors that impact the equilibrium moisture variation at each moment in time. Grapes' equilibrium moisture content progressively rises as water activity does. Variation in water activity provides crucial guidance because it is a consequence of temperature and relative humidity. The greatest moisture content corresponds to a maximum water activity of 0.37. A low water activity (aw) suggests a strong biopolymer connection between the grape's water and other constituents. The grapes transition from a crystalline to an amorphous condition when the water activity rises (Vazquez et al. 1999).

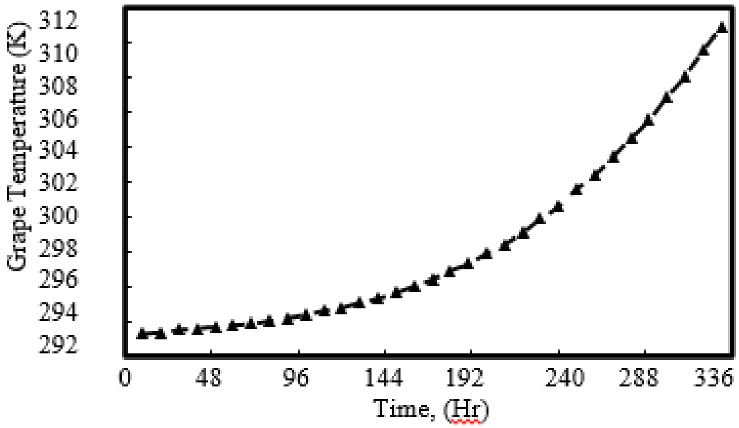
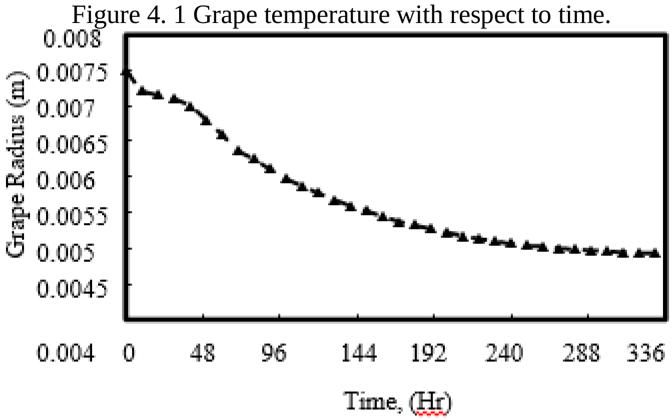


Figure 4. 1 Grape temperature with respect to time.



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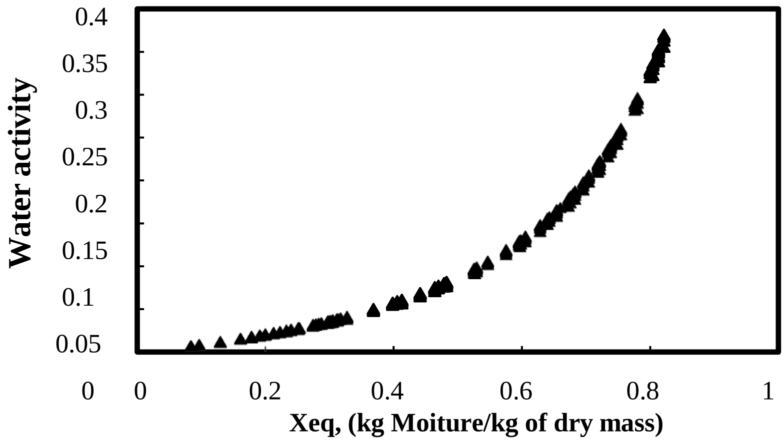
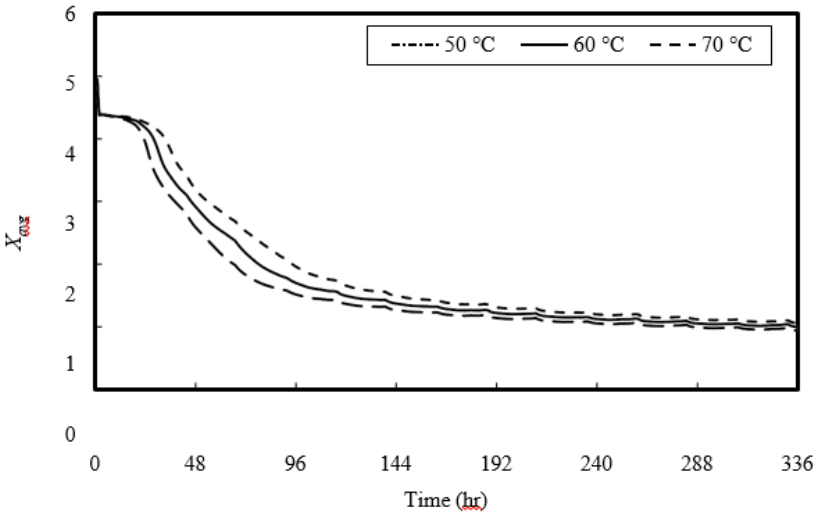


(b)

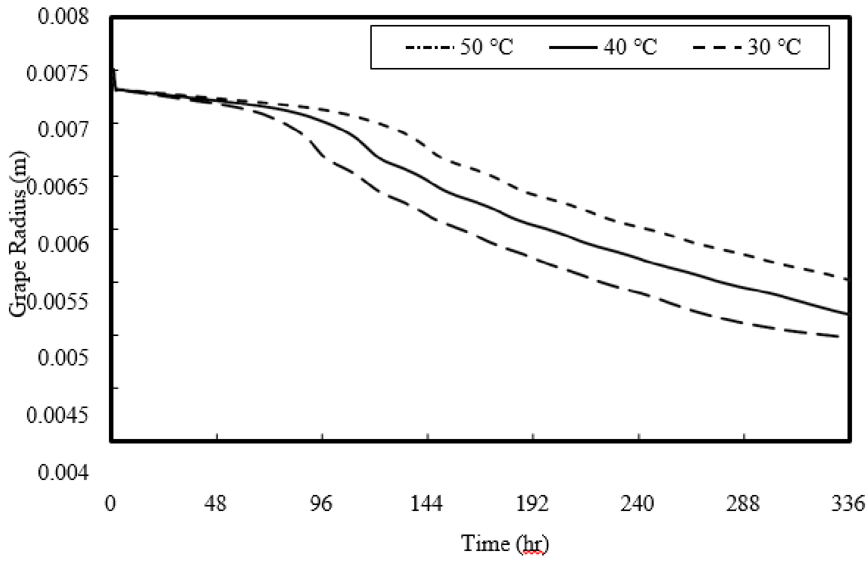
Figure 4. 2 (a) Grape radius with respect to time, (b) Water activity vs. equivalent moisture content.

2) Effect of the cabin temperature

Analysis was done on how different drying temperatures—30, 40, and 50 degrees Celsius—affected the drying properties of the product, including its temperature, moisture content, and radius. Next, drying characteristic curves and grape drying rate were calculated. Thompson seedless grapes were subjected to several drying procedures with temperature intervals of 10°C at constant temperatures between 30 and 50°C. Figure 4.3 (a, b) shows how the temperature within the cabin affects the moisture content, product temperature, and product radius. All of the temperatures examined had a similar moisture plot structure, however for consistent drying times, the temperature has a significant impact on the moisture content. The moisture content seems to vary essentially unchanged for the first 48 hours, but after that period, a notable shift is seen. At 30 °C, the maximum moisture content decreased to 1.35 kg of water/kg of dry mass, while at 50 °C, it increased to 0.39 kilogramme of water/kg of dry mass.When there is not enough surface moisture, the diffusion of moisture from the interior to the surface controls the drying speed; that is, the drying rate decreases with time as the moisture content decreases. It is evident that all drying processes take place during the decreasing rate phase and that there is no constant-rate drying period. As was to be predicted, raising the drying temperature caused the water to evaporate more quickly and increased mass transfer. Another species was noted in a similar manner. The highest radius change for the 50 °C instances was determined to be 4.9 mm from 7.5 mm. The drying rate in the solar dryer running at a higher air temperature may be significantly higher than the lower air temperature during the open-air sun drying process, as Figure 4.4 makes abundantly evident. After 200 hours, the product temperature was seen to be greater during the final drying phase. This occurred as a result of the product's decreased water content.

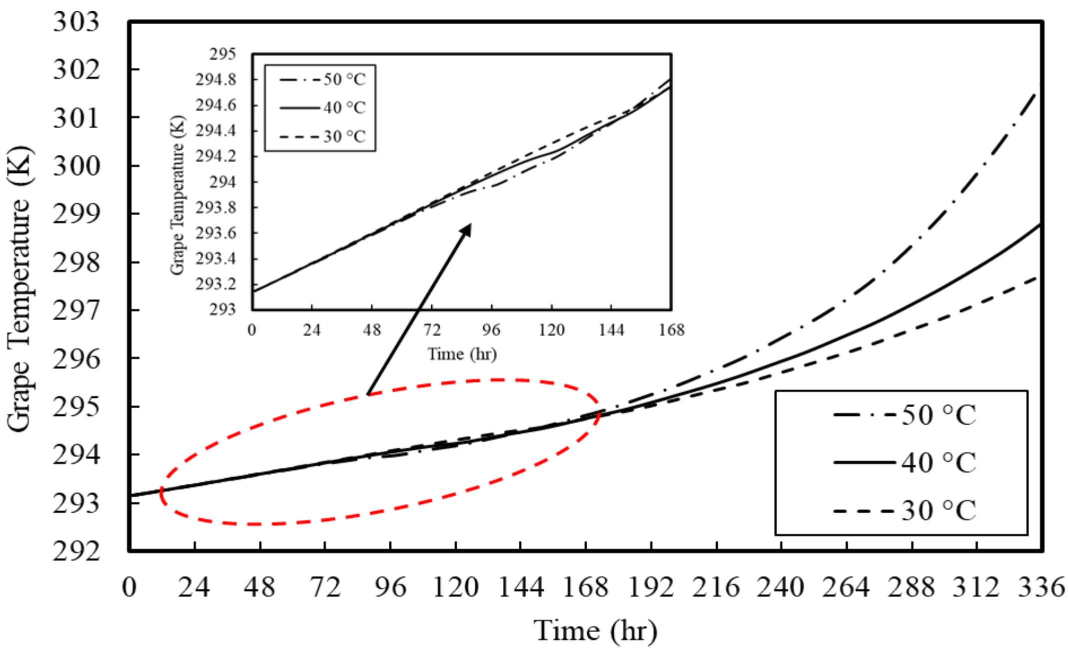


(a)



(b)

Figure 4.3 Change in (a) moisture content, (b) product radius.



(c)

Figure 4.4 Product temperature with respect to time for three different cabin temperatures.

V. CONCLUSIONS

- Product temperature, product size, and moisture decrease with respect to time may all be predicted using this model.
- The grape's radius, which may be thought of as its spherical form, can be predicted using a one-dimensional model.
- An analysis was conducted on the impacts of drying temperature (30, 40, and 50 degrees Celsius) on drying parameters such as product size (radius) and moisture content throughout the drying process. At 30 °C, the maximum moisture content was lowered to 1.35 kilogramme of water/kg of dry mass, and at 50 °C, it reduces to 0.39 kg of water/kg of dry mass.
- By the time the grape dries (moisture content <13%), its average radius has decreased by 34.67%. A decrease in moisture content causes the grape's temperature to rise. Regarding drying time, the maximum temperature rise for grapes is 18 °C.

- For the 50 °C example, the greatest radius change was determined to be 4.9 mm, down from 7.5 mm. At 30 °C, the maximum moisture content decreased to 1.35, and at 50 °C, it reduces to 0.39 levels.
- The study shows that one important external variable influencing volumetric shrinkage is air temperature. The drying curves were clearly impacted by air temperature; rising air temperature led to a reduction in drying time and an increase in the moisture diffusion coefficient.
- Thompson seedless grapes' moisture content, product temperature, and structure changed while keeping the (L/D=2).

A. Research contributions

- Creation of an experimental test system that may be helpful in validating the findings and forecasts the drying properties of various raw food products.
- The outcomes of the experimental trials may be used to forecast the dryer's performance as well as the amount of time needed to achieve a given drying quality in food products.
- The created mathematical model might be helpful in optimising the manufacturing of dried foods as well as precisely forecasting the product's temperature, moisture content, and size change.
- It is possible to forecast the dimensional changes, such as length and radius, caused by the cylindrical product shrinking.
- The change in drying properties in relation to atmospheric factors like temperature and sun radiation.

REFERENCES

[1] Aghbashlo, M., Müller, J., Mobli, H., Madadlou, A., & Rafiee, S. (2015). Modeling and simulation of deep-bed solar greenhouse drying of chamomile flowers. Drying Technology, 33(6), 684-695.

[2] Akinola, A. O. (1999). Development and Performance Evaluation of a Mixed-Mode Solar Food Dryer. M. Eng (Doctoral dissertation, Thesis, Federal University of Technology, Akure, Nigeria).

[3] Akpinar, E. K. (2006). Mathematical modelling of thin layer drying process under open sun of some aromatic plants. Journal of Food Engineering, 77(4), 864–870.

[4] Akpinar, E. K. (2008). Mathematical modelling and experimental investigation on sun and solar drying of white mulberry. Journal of Mechanical Science and Technology, 22(8), 1544–1553.

[5] Akpinar, E. K., & Koçyiğit, F. (2010). Energy and exergy analysis of a new flat-plate solar air heater having different obstacles on absorber plates. Applied energy, 87(11), 3438-3450.

[6] Al-Jumaah, A. A., Asiri, A. M., Alshehri, M. F., Deash, A. M., & AlHamzi, F. M. (2010). Design and construction of a solar drying system for food preservation. BSc, 13(07), 1435.

[7] Bal, L. M., Satya, S., & Naik, S. N. (2010). Solar dryer with thermal energy storage systems for drying agricultural food products: A review. Renewable and Sustainable Energy Reviews, 14(8), 2298-2314.

[8] Bala, B. K., & Janjai, S. (2012). Solar drying technology: potentials and developments. In Energy, environment and sustainable development (pp. 69-98). Springer, Vienna.

[9] Bala, B. K., Mondol, M. R. A., Biswas, B. K., Chowdury, B. D., & Janjai, S. J. R. E. (2003). Solar drying of pineapple using solar tunnel drier. Renewable Energy, 28(2), 183-190.

[10] Banout, J. (2017). Solar drying systems. In Solar Drying Technology (pp. 39-67). Springer, Singapore.

[11] Banout, J., Ehl, P., Havlik, J., Lojka, B., Polesny, Z., & Verner, V. (2011). Design and performance evaluation of a Double-pass solar drier for drying of red chilli (Capsicum annum L.). Solar energy, 85(3), 506-515.

[12] Banout, J., Kucerova, I., & Marek, S. (2012). Using a double-pass solar drier for jerky drying. Energy Procedia, 30, 738-744.

[13] Barnwal, P., & Tiwari, G. N. (2008). Grape drying by using hybrid photovoltaic- thermal (PV/T) greenhouse dryer: an experimental study. Solar energy, 82(12), 1131- 1144.

[14] Barrett, D. M. (2007). Maximizing the nutritional value of fruits & vegetables. Food technology (Chicago), 61(4), 40-44.

[15] Bartzanas, T. B. T. K. C., Boulard, T., & Kittas, C. (2004). Effect of vent arrangement on windward ventilation of a tunnel greenhouse. Biosystems Engineering, 88(4), 479-490.