Heat Transfer Analysis During Chili Drying in a Packed Bed Dryer

Muditha Rajapakshe[1#] , Madhumadhi k Premanath[1], G. K. Jayatunga[2], B. M. W. P. K. Amarasinghe[1]

[1] Department of Chemical and Process Engineering, University of Moratuwa, Sri Lanka
[2] Institute of Technology University of Moratuwa, Sri Lanka
#Corresponding Author: mudithrajapakshe@gmail.com

1 Introduction

Drying is a fundamental process in the preservation of agricultural products, particularly for spices such as chili peppers. This process reduces the moisture content in the product, thereby inhibiting microbial growth and enzymatic activity, which can lead to spoilage. Consequently, drying extends the shelf life of the product, maintains its quality, and facilitates transportation and storage. The efficiency and effectiveness of the drying process are significantly influenced by the heat transfer coefficient, a critical parameter that dictates the rate at which heat is transferred from the drying medium to the product.

The drying of agricultural products has been extensively studied, with various methods and technologies being explored to optimize the process. Among these, hot air drying is one of the most common methods due to its simplicity and cost-effectiveness [1]. In this method, hot air is used as the drying medium, and the temperature and vapor pressure differences between the hot air and the moisture-laden product drive the moisture removal process. The heat transfer coefficient in such processes is influenced by several factors, including air temperature, air velocity, bed height, and the physical properties of the product being dried [2].

Chili peppers are widely cultivated and consumed globally, valued not only for their flavor and nutritional content but also for their potential health benefits. However, their high moisture content necessitates effective drying techniques to ensure product stability and quality. Previous studies have indicated that drying temperature significantly impacts the drying kinetics and quality of dried chilies [3]. Thus, understanding the variation in the heat transfer coefficient at different drying temperatures is crucial for optimizing the drying process.

In this study, we investigate the drying of fresh red chilies in a packed bed dryer and conduct analysis on heat transfer during drying. The packed bed dryer, characterized by its cylindrical column and controlled air flow, provides an efficient setup for studying the drying behavior of granular and particulate materials. The specific objectives of this research are to measure the drying rates and calculate the heat transfer coefficients at different drying temperatures (50°C, 55°C, and 60°C), thereby providing insights into the optimization of the drying process for chili peppers.

2 Materials and Methodology

The raw material used in this experiment was fresh red chili, which was supplied by a local farmer and stored in a refrigerator at 5 °C to 10 °C. The experimental setup of the packed bed dryer is shown in **Fig. 1**. The setup includes a cylindrical column, an air blower with a 2.2 kW motor, a 12 kW air heater, and a cyclone separator to retain fine particles. A perforated plate at the bottom of the column prevents chilies from entering the air inlet. The column measures 0.15 meters in diameter and has a total height of 1 meter. An EXTECH CFM thermo-anemometer, model 407113, is installed at the air inlet to measure the air flow rate.

Drying experiments were conducted to examine the impact of hot air temperature on the drying process. A measured quantity of fresh red chilies was placed in the bed, and hot air was passed through it. Maintained the constant bed height of 0.3 m and constant air velocity of 1.111 m/s. The bed weight was measured after every one hour and bed materials were mixed. Using oven drying method, moisture content of chili was calculated. These experiments are carried out at 50 °C, 55 °C and 60 °C temperatures, because the maximum temperature can be achieved without losing the content of nutrients is 70 °C [4].

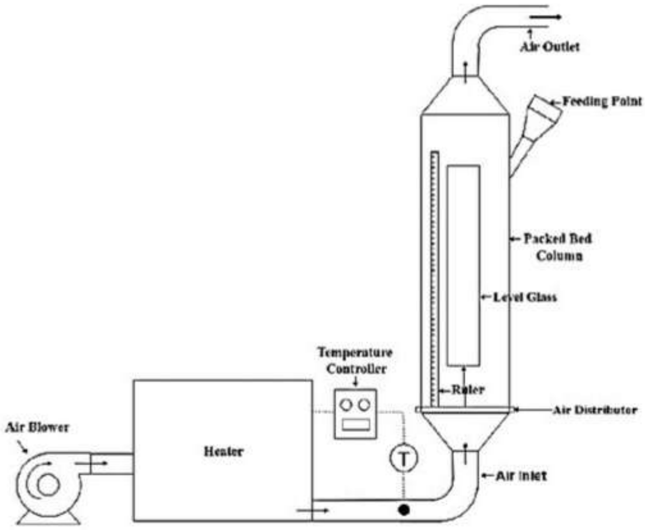

Fig. 1. Schematic diagram of the experiment set up

3 Results and Discussion

3.1 Drying characteristics of chili

The dry basis, moisture content of a material is given by the equation 1

$$MC = \frac{(W_w - W_d)100}{W_d} \qquad (1)$$

Where,

MC - Moisture content

W_w - Weight of the wet solid

W_d - Weight of the dry solid

Obtained moisture content values as a function of time for drying experiments are shown in **Fig. 2**. Results are shown for the temperatures 50 °C, 55 °C and 60 °C. The results indicate a constant drying rate throughout the entire drying period of 7 hrs for 50 °C and 55 °C, and 5 hrs for 60 °C. Gradient of the straight line is giving the rate of drying.

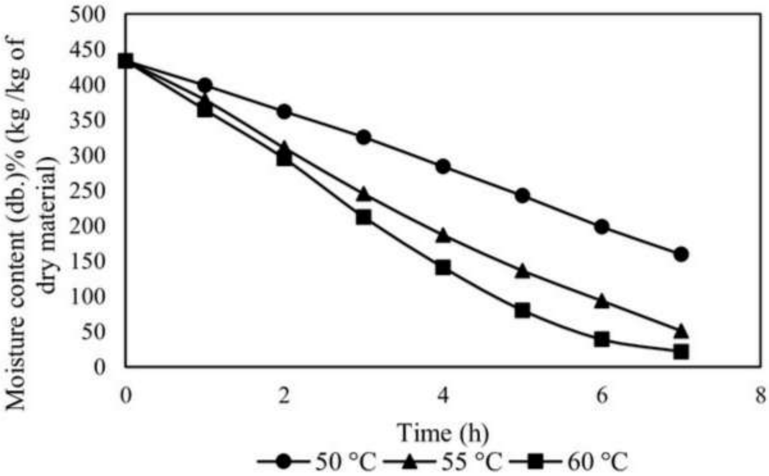

Fig. 2. Moisture content (dry basis) % as a function of time for chili drying

Drying rates at the different temperatures are calculated using the gradient of the straight line of moisture content vs time graph and shown in table 1. According to the results obtained, drying rate is increasing with the increasing air temperature. Consequently, the drying time required to reach the desired moisture content is reduced.

3.2 Heat transfer coefficient

Heat transfer coefficient (HTC) is one of the main parameters for drying process. The temperature difference between inlet air and moisture inside the chili is the driving force for the heat transfer. In this process, the heat energy requirement for vaporizing the moisture inside the chili is equal to the rate of heat transfer from hot air to fresh chili. Rate of heat transfer is given by equation 2.

$$q = h_s A \Delta T \qquad (2)$$

Where,

q – Rate of heat transfer

h_s – Heat transfer coefficient

A – Heat transfer area

ΔT – Temperature deference

Using equation 2, heat transfer coefficient values are calculated for the drying experiments and shown in Table 1 and **Fig. 3**. Heat transfer coefficient values vary from 0.1439 kJ/m^2°Cs to 0.2123 kJ/m^2°Cs when the temperature increases from 50 °C to 60 °C. According to the values obtained, HTC is increasing with the increasing initial air temperature and agreed with the results obtained by other workers [5, 6, 7].

Other than air temperature, HTC also depends on the air velocity through the bed. Literature shows HTC is increasing with the increasing air velocity [6]. However, the effect of air velocity is not tested in this study.

Table 1. Rate of drying and Heat Transfer Coefficient values for chili drying

Temperature (□C)	Drying rate (kg of moisture/ kg of dry material / min)	Heat transfer coefficient (kJ/m^2°Cs)
50	6.52×10^{-3}	0.1439
55	9.43×10^{-3}	0.1914
60	12.30×10^{-3}	0.2123

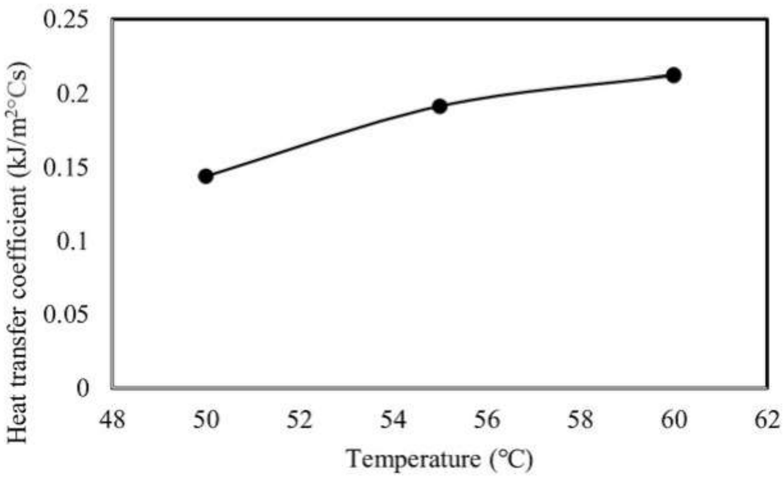

Fig. 3. Effect of temperature on the Heat Transfer Coeffcient during chili drying

Furthermore, according to the study carried out by E.K. Akpinar [5], HTC is decreasing over the drying time due to the temperature increment of the drying sample. Hence, having a high initial HTC is more efficient and more economical for the process. In simple terms, the drying time will be reduced. To obtain a high HTC value the initial air temperature must be increased. However, according to the study carried out by S, Gupta & Sharma et al. 70 °C is the highest temperature can be achieved without losing the nutrient content of red chili. Therefore, choosing a suitable high initial air temperature is critical to achieve the highest heat transfer coefficient.

Conclusion

This study examined the variation of the heat transfer coefficient during the drying of fresh red chilies in a packed bed dryer at different temperatures (50 °C, 55 °C, and 60 °C). The findings demonstrated that the drying rate and heat transfer coefficient increased with temperature. Specifically, the heat transfer coefficient ranged from 0.1439 $kJ/m^2°C$ at 50 °C to 0.2123 $kJ/m^2°C$ at 60 °C. These results highlight the importance of temperature control in optimizing the drying process for chilies, as higher temperatures enhance heat transfer efficiency, thereby reducing drying time. Understanding the relationship between drying temperature and the heat transfer coefficient can aid in the design and operation of more efficient drying systems, ensuring better preservation of quality and nutritional content in dried chilies. Future research should explore the effects of other variables, such as air velocity and bed height, to further optimize the drying process.

Keywords: Packed bed dryer, Chili drying, Heat transfer coefficient

References

1. Mujumdar, A. S.: Handbook of Industrial Drying. CRC Press (2014).
2. Kumar, C., & Sagar, V. R.: Drying kinetics and physicochemical characteristics of green chillies dried by different drying techniques. International Journal of Food Properties, 21(1), 1-13 (2018).
3. Hossain, M. A., Woods, J. L., & Bala, B. K.: Thin-layer drying characteristics of hot chilli. Journal of Food Engineering, 79(1), 115-121 (2007).
4. S, Gupta & Sharma, Sajeev & Mittal, Tarsem & Jindal, Salesh & Gupta, Satish.: Study of drying behavior in red chillies. Green Farming. 8. 1364-1369 (2017).
5. J. Poonam Ekka, M. Palanisamy: Determination of Heat Transfer Coefficients and Drying Kinetics of Red Chilli Dried in a Forced Convection Mixed Mode Solar Dryer, Thermal Science and Engineering Progress (2020)
6. E.K. Akpinar; Evaluation of convective heat transfer coefficient of various crops in cyclone type dryer, Energy Conversion and Management. 46 2439–2454 (2005).
7. K.N. Çerçi, M. Das: Modeling of heat transfer coefficient in solar greenhouse type drying systems, Sustainability. 11 (2019).