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Green Tea Drying in Continuous Vibro Fluidized Bed Dryer with Dehumidified Air

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Abstract. There is potential for the development of zeolite as an adsorbent material for drying high-value items. This study aims to compare the green tea drying characteristic utilizing vibro-fluidized bed dryers that operate without dehumidification and with dehumidification. The research was carried out experimentally. The drying chamber was set at temperatures of 50°C, 60°C, and 70°C. In the drying with dehumidification setup, zeolite was placed in a dehumidifier with a weight-to-tea leaf ratio of 1:2.86, 1:3.33, 1:4, and 1:5. The results showed that zeolite's impact on decreasing drying time is effective at a specific temperature, in this case is 60°C. The effect is negligible at low temperatures (50°C), while at high temperatures (70°C) it is minor and drying time is primarily influenced by temperature. Utilizing zeolite for dehumidification can enhance the rate of drying during the falling rate period.

Keywords: Drying, Tea, Vibro Fluidized Bed Dryer, Zeolite

INTRODUCTION

Tea, derived from the *Camellia sinensis* tea plant leaves, is the most widely consumed beverage globally. The four main categories of chemicals found in tea leaves are aromatic compounds, non-phenolic substances, phenolic substances, and enzymes. As a strong antioxidant, polyphenols counteract free radicals while scavenging superoxide, hydrogen peroxide, nitric oxide (NO), and hydroxyl radicals. Green tea's catechins have been shown in numerous studies to have the ability to prevent and treat a variety of degenerative illnesses, including hypertension, heart disease, cancer, metabolic syndrome, stroke, and type 2 diabetes (Reygaert, 2017; Pastoriza *et al.*, 2017).

The processing of green tea involves the deactivation of polyphenol oxidase, and hydroperoxide enzymes present in the cytoplasm of tea leaves. This is achieved by a series of steps, starting with the withering process, followed by rolling and drying procedures. The green tea drying process

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aims to decrease the moisture content and impede the enzymatic oxidation of polyphenols. Prolonged exposure to high temperatures during the drying process can lead to thermal degradation of catechins. This degradation process pertains to the conversion of catechins into thearubigins and theaflavins, decreasing the catechin content within the finished product (Ahmed and Stepp, 2012).

Green tea processing in the Indonesian tea industry usually utilizes endless chain pressure (ECP), two stage dryer (TSD), or vibro fluidized bed dryers. Vibro fluidized bed dryers offer numerous advantages in various drying applications, including their high efficiency (Zhang *et al.*, 2018), uniform temperature distribution (Vega and Briongos, 2012), large heat and mass transfer, and faster drying rate because the material being dried will be mixed ideally by hot air, uniform degree of dryness and has a large capacity (Perazzini *et al.*, 2017). Utilizing this technology in the green tea sector is expected to enhance the uniformity of the moisture content and reduce the duration of the drying process. To preserve the catechin content, it is possible to take advantage of a high heat transfer rate to decrease the drying temperature.

To encourage the fluidization of larger diameter tea particles, the tea industry uses vibro fluidized beds at higher air velocities. Increasing air velocity leads to excessive consumption of heating air, resulting in energy waste due to the persistently high temperature of the exhaust air. Since the drying process uses 69% of the energy used in tea processing, energy savings there can significantly impact on production costs (Djaeni *et al.*, 2007). The excessive use of drying air results in a retention of high temperatures in the exhaust air, hence enabling its potential for recirculation. Recirculating exhaust air into the drying chamber requires special treatment to reduce the water vapor content (Majumder, 2022).

Activated natural zeolite can absorb vapor in the heating air because zeolites have a high affinity for water. The absorption of water vapor by zeolite results in an increase in air temperature due to of the heat emitted during the adsorption process, hence leading to a substantial reduction in energy usage (Djaeni *et al.*, 2007). A decrease in atmospheric moisture levels can accelerate the drying process, particularly for materials that necessitate low-temperature drying. (Djaeni *et al.*, 2010; 2017). The combination of zeolite dehumidification in a low-temperature drying system also positively affects quality (Djaeni *et al.*, 2017)

Extensive research has been conducted on drying many crops, including corn, garlic, rice, seaweed, carraagenan, etc, employing zeolite as a moisture adsorbent and pre-dehumidified air (Djaeni *et al.*, 2012; M. Djaeni *et al.*, 2013; Mohamad Djaeni *et al.*, 2013; Djaeni and Sari, 2015; Asiah *et al.*, 2017). Zeolites have advantages compared to other adsorbent materials such as silica, natural clay, alumina, or pillared aluminum clay because zeolites are easily obtained in nature, have a large absorption capacity (Djaeni *et al.*, 2017) and can be regenerated (Kurniasari *et al.*, 2011). Zeolite can accelerate drying if used at low temperatures, but its effectiveness will be lower at higher temperatures (Atuonwu *et al.*, 2011).

Research on drying simulation using pinch analysis shows that the dryer's efficiency using a zeolite dehumidifier is 10 - 18% higher than the conventional dryer (Djaeni *et al.*, 2007). Applying a tray dryer for garlic and a fluidized bed dryer for rice operated at temperatures between 50-60^{o}C shows that dehumidification of the intake air will increase the dryer's efficiency by up to 75% with reasonable product quality (Djaeni *et al.*, 2017). Several ways have been carried out, such as making a multistage system to increase the efficiency of the adsorption dehumidification drying system (Djaeni *et al.*, 2009), sequential and simultaneous optimization using a heat recovery system (Atuonwu *et al.*, 2011).

With its advantages, zeolite combines it with a closed cycle vibro fluidized dryer. There is no reference from the literature search about the vibro fluidized bed dryer combined with zeolite adsorption dehumidification. This study aims to compare the characteristics of green tea drying utilizing vibro-fluidized bed dryers that operate without dehumidification and with dehumidification.

The determination of the drying characteristic is significant in assessing the drying behavior, hence providing drier design, optimization, identification of optimal drying settings, and enhancement of the quality of the dried material. Engineers and researchers can enhance the efficiency and quality of drying operations by analyzing the drying characteristics. To achieve optimal results, it is necessary to determine the optimum combination of drying parameters, including temperature, humidity, airflow, velocity, and drying time, in order. The drying kinetics are determined by factors such as the type of dryer, the drying conditions, and the item being dried (Giri and Prasad, 2007).

METHOD

Experimental Setup

The schematic configuration used in this study is shown in Figure 1. The system consists of a vibro fluidized bed dryer with a blower, air heater, and dehumidifier. The dehumidifier has two shelves measuring 30 x 10 x 5 cm and contains activated zeolite. The weight of tea leaves is constant at 1 kg, while the weight of zeolite changes from 350, 300, 250, and 200 g. It was equal to the zeolite to tea ratio of 1:2.68, 1:3.3, 1:4, and 1:5.

Air velocity, temperature, and relative humidity were measured at the inlet side of the vibro fluidized bed dryer using a Lutron AM 4205A anemometer equipped with a thermometer and hygrometer probe. The Autonic TCN4S-24R thermocontrol set the drying air temperature at 50, 60, and 70°C. A Siemens Sinamic V20 inverter was used to regulate the blower's motor velocity to adjust the air mass flow rate. Green tea was weighed with an ADAM WBW 4 digital scale out of the vibro fluidized bed drier. Once dried, tea leaves that exit on the outlet side are then put back into the inlet side. This procedure was repeated until the weight remains constant.

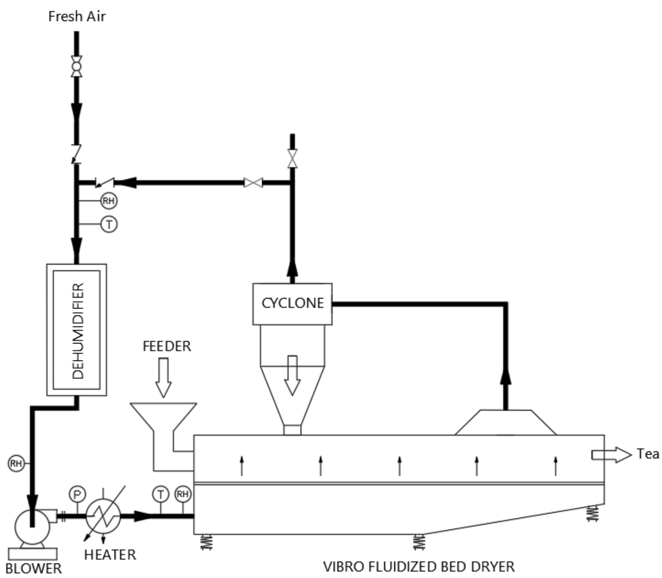


Fig. 1: Experimental setup

The system can be set into an open cycle (without dehumidification) and a closed cycle (with dehumidification) by adjusting the valve opening. In an open system setting, fresh air was sucked in by a blower through an empty dehumidifier, then heated by a heater and flows into the drying chamber. After drying the tea leaves, the air passed through the cyclone to separate small particles that may be carried away and then released into the atmosphere. In a closed system setting, after starting, the fresh air valve was closed, and the drying air from the cyclone was sucked by a blower into the dehumidifier filled with zeolite in a certain ratio to reduce the humidity. Then it flowed through the heater to the drying chamber.

Model Development

The green tea's moisture content (M) and moisture ratio (MR) were determined by Eq. (1) and Eq. (2).

$$M = \frac{m - m_d}{m_d} \quad (1)$$

$$MR = \frac{M - M_e}{M_o - M_e} \quad (2)$$

In the given context, M represents the instantaneous moisture content of the product, M_o denotes the initial moisture content of the product, and M_e indicates the equilibrium moisture content. During prolonged periods of drying, the value of M_e will be relatively low compared to M and M_o, resulting in a moisture ratio of M_d/M_o (Evin, 2012).

The drying rate (DR) was calculated using Eq. (3).

$$DR = \frac{M_{t+1} - M_t}{\Delta t} \quad (3)$$

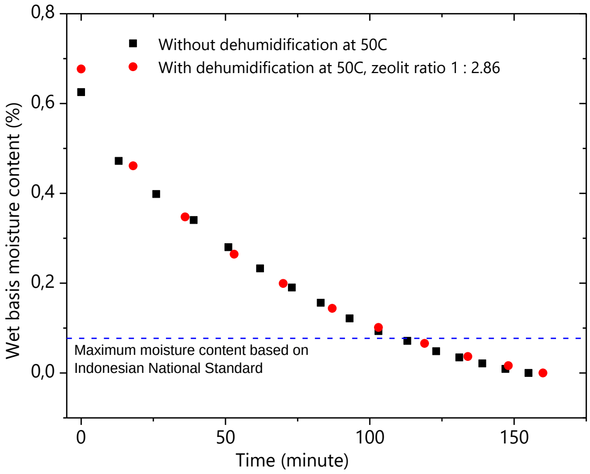
where M_t and M_{t+1} are the moisture content at t and moisture content at t+1, respectively, and t is the drying time.

RESULTS AND DISCUSSION

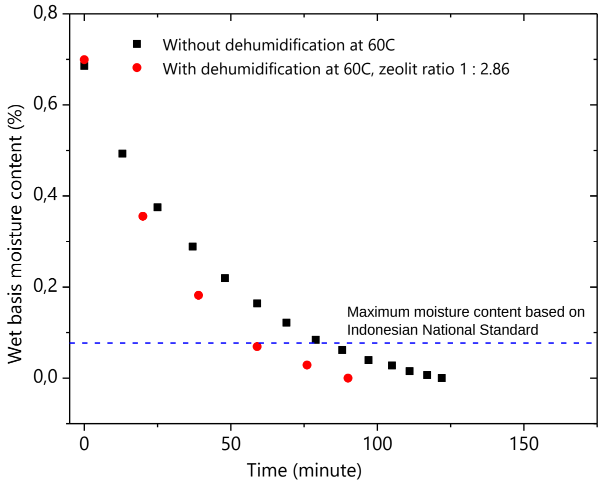
Effect of Dehumidification and Drying Temperature on Drying Time and Moisture Ratio.

Drying was carried out repeatedly until it reaches a constant weight. According to the Indonesian National Standard, the maximum permissible water content of dry tea leaves is 8%, so the drying time is determined based on the length of drying time to reach a water level below 8%. Figs. 2a, 2b, and 2c show how drying time is affected by dehumidification. Utilizing zeolite into a dehumidifier used for drying green tea, can accelerate the drying process by as much as 37% (from 122 minutes to 90 minutes) at a temperature of 60°C and a zeolite to tea leaf ratio of 1:3,3. When comparing the drying times with and without a dehumidifier (Fig. 3 and Fig. 4), at 50°C, zeolite does not influence drying time reduction (155 minutes); on the other hand, at 70°C, there is a 15% reduction in drying time (85 to 72 minute). At low temperatures, the kinetic energy of water molecules decreases, resulting in slower diffusion rates (Yang *et al.*, 2022). Zeolites rely on molecular diffusion for adsorption to occur. When temperatures are low, the adsorption rate onto the zeolite surface is sluggish, leading to decreased efficiency in dehumidification. The second reason could be that zeolites have an equilibrium moisture content, which is the moisture level they achieve after absorbing as much moisture as possible under specified conditions. At low temperatures, the equilibrium moisture content may not differ considerably from the ambient humidity level, implying that the zeolite absorbs little extra moisture from the air. Driving force is the third possible explanation for zeolite's low effectiveness at a drying temperature of 50°C. The driving force for moisture adsorption is the difference in vapor pressure between the material to be dried and the zeolite. At low temperatures, this driving force is reduced because water vapor pressure is lower, resulting in a weaker driving force for moisture transfer to the zeolite. Zeolite-based dehumidification systems are often more effective at moderate to high temperatures where adsorption kinetics are more favorable, and regeneration can be achieved efficiently.

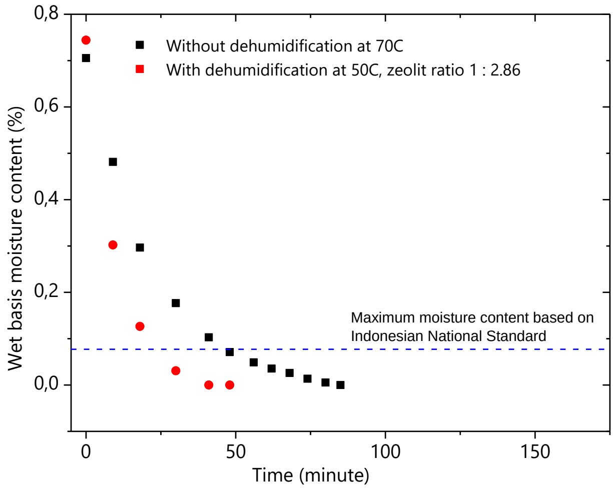
Temperature has an impact on drying times as well. The drying time decreases with increasing drying temperature, as shown in Fig. 3., due to the high heat content of the drying air. This result is in line with research conducted by Asiah *et al.* (2017) that temperature is an essential parameter in the drying process because at high temperatures, the moisture in the air is in the vapor phase so that the air content in the dried material is more easily transferred to the drying air. The difference in water content reduction is significant at high temperatures due to a decrease in relative humidity. This finding is consistent with previous research (Djaeni *et al.*, 2014), which found that increasing air temperature induces a drop in relative humidity, increasing the driving force of the drying process. The maximum temperature in this study was limited to 70°C to prevent thermal degradation from reducing the catechin content of green tea. High drying temperatures, however, can degrade green tea's catechins thermally, lowering the tea's quality. A maximum drying temperature of 90°C is required to maintain high catechin content.



a. Drying temperature 50°C



b. Drying temperature 60°C



c. Drying temperature 70°C

Fig. 2: Comparison of drying time between without dehumidification and with dehumidification at 50°C (a), 60°C (b), and 70°C (c).

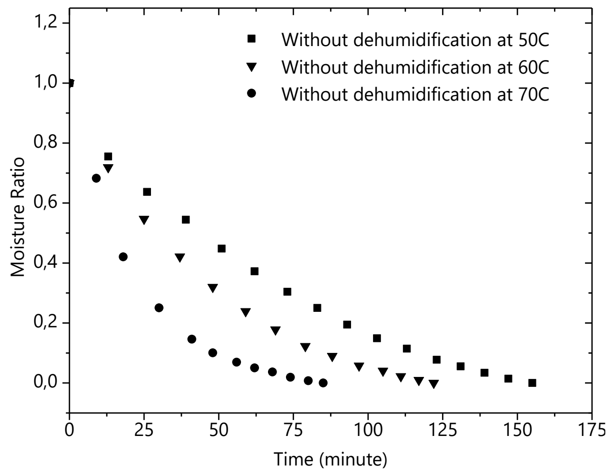


Fig. 3: Moisture ratio of green tea drying using vibro-fluidized bed dryer at various temperature

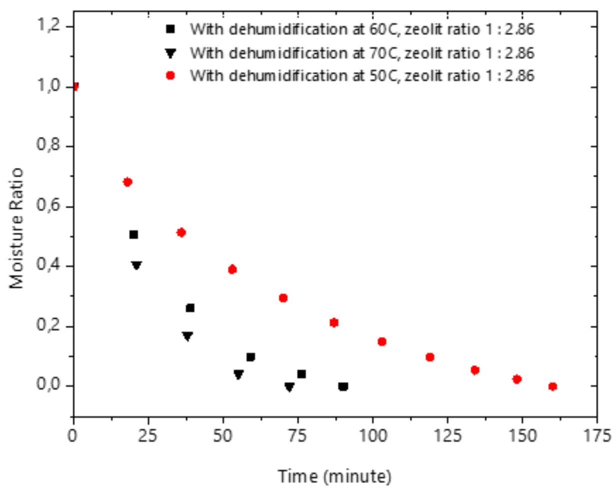


Fig. 4: Moisture ratio of green tea drying using vibro-fluidized bed dryer with dehumidification at various drying temperature.

Effect of Zeolite to Tea Ratio on Drying Time and Moisture Ratio

A series of experiments were conducted to examine the effects of varying zeolite weights on the drying duration and the moisture ratio. The correlation between the duration of drying and the weight of zeolite shown in Fig.5, while the moisture ratio of green tea at various zeolite to green tea ratio shown in Fig.6. The findings indicated that an increase in the weight of the zeolite resulted in a decrease in the drying time up to a specific weight limit. Further, adding of zeolite weight will result in an extension of the drying duration. This finding diverges from the study conducted by Djaeni et al., which found that increasing the mass of zeolite may accelerate the drying process.

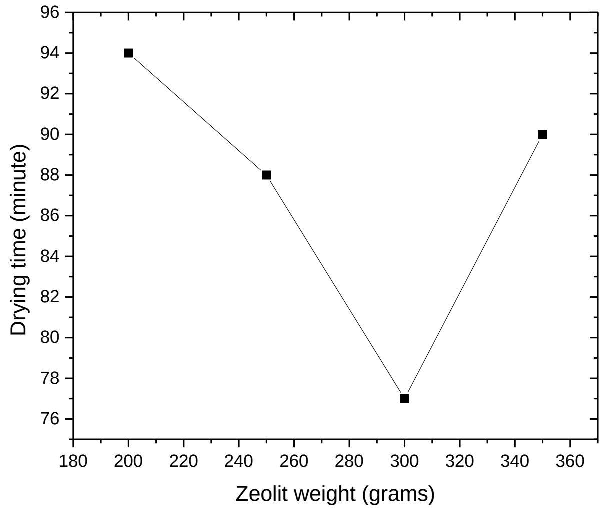


Fig. 5: Correlation between the duration of drying and the weight of zeolite

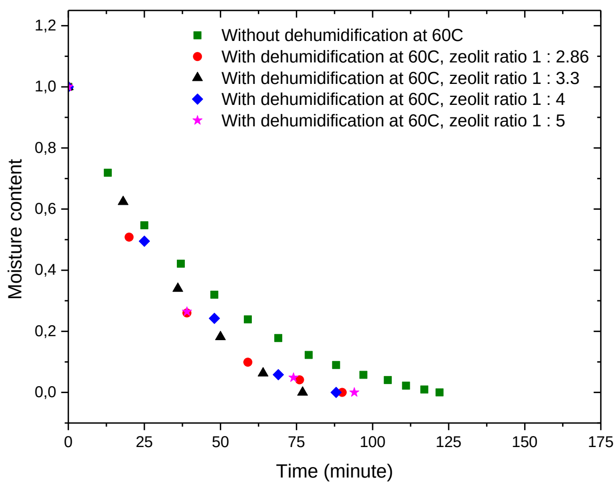
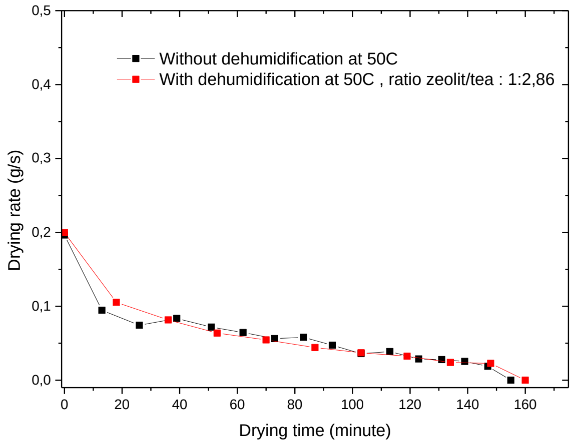
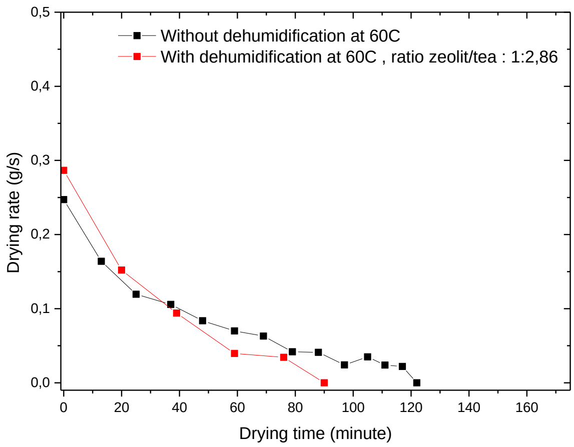


Fig. 6: Moisture ratio of green tea at various zeolite to green tea ratio

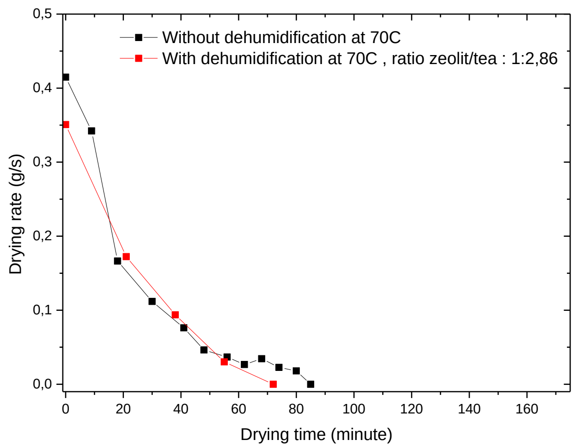
According to Handayani et al., drying tea with a batch type fluidized bed drier with zeolite dehumidification and increasing the zeolite ratio to 3:1 can reduce drying time (Handayani *et al.*, , 2015). The discrepancy



a. Drying temperature 50°C



b. Drying temperature 60°C



c. Drying temperature 70°C

Fig. 7: Effect of dehumidification on drying rate at various temperatures of 50°C (a), 60°C (b), and 70°C (c)

that has been noticed can be related to the arrangement of zeolite within dehumidifiers. The increase of zeolite content within the dehumidifier rack will lead to a higher pressure drop due to the zeolite's tendency to block airflow, hence causing an inevitable reduction of the contact area between the zeolite and the drying air. Consequently, the increase in zeolite content does not lead to a reduction in the drying time.

Drying Rate

The drying rate refers to the speed at which moisture is removed from a material during drying. The effect of dehumidification on drying rate at various temperatures can be seen in Fig. 7. Dehumidification using zeolite can effectively enhance the drying rate of green tea leaves by reducing the humidity of the surrounding air, increasing the driving force for moisture transfer. Zeolites are microporous, aluminosilicate minerals commonly used as adsorbents for water and other molecules. When zeolites adsorb water vapor, they can effectively lower the humidity of the surrounding air, accelerating the drying process. Fig. 7a shows that the effect of dehumidification at 50°C is negligible since it does not differ significantly from drying without zeolite. An explanation of this condition can be found in the section on drying time.

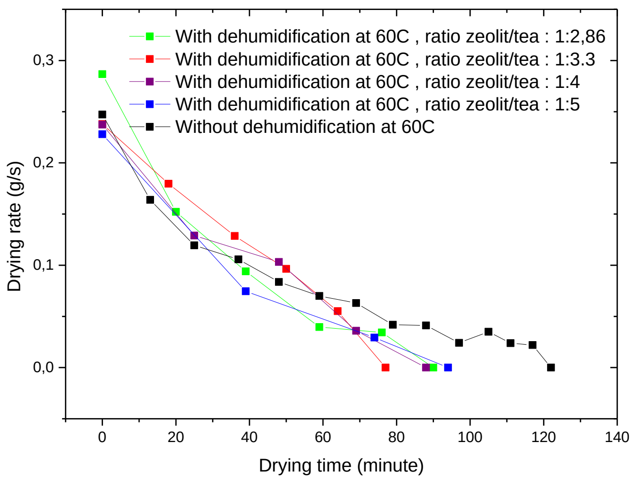


Fig. 8: Effect of dehumidification on drying rate at various zeolite to tea ratio

Fig. 8 shows the drying rate for different zeolite weight variations. Dehumidification shortens the period and boosts the drying rate during the falling rate period. This is due to the zeolite's persistent capacity to hold a lot of water vapor in its initial condition.

CONCLUSIONS

Research on using zeolite for air dehumidification in a closed cycle vibro fluidized bed dryer has been carried out. An effective impact on drying processes is seen using zeolite at a specific temperature of 60°C. The relationship between the weight of zeolite in the dehumidifier and the reduction in drying time is not perennially linear. Once the optimal value is reached, increasing the zeolite quantity will block the airflow, increasing the pressure drop and drying time. Utilizing zeolite for dehumidification can enhance the rate of drying during the falling rate period.

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