



Effects of Temperature and Torrefaction Time on the Physical Characteristics of Rice Straw Pellets with Dolomite

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Abstract – This research investigated the influence of torrefaction temperature and duration on the physical characteristics of biomass pellets made from rice straw mixed with dolomite. This research examined the physical characteristics, pellet density, higher heating value, and hydrophobicity of the pellets. Dolomite was added at weight percentages of 0%, 3%, 5%, and 10%. The temperature of torrefaction process was conducted at 230°C, 250°C, and 270°C for durations at 5, 10, and 15 minutes. The experimental results indicated that increasing the temperature and residence time increased both the higher heating value (HHV) and hydrophobicity of the pellets. The results indicated that increasing both temperature and duration can significantly enhance the HHV, while the density exhibited a slight decrease. However, the pellets containing dolomite showed a decrease in HHV compared to the control samples without dolomite. Therefore, the optimum conditions were at 270°C for 15 minutes and with a dolomite addition ratio of 3%, under which the heating value of the fuel increased by up to 17.52% compared to the raw biomass.

Keywords – Dolomite, higher heating value (HHV), pellets physical properties, rice straw, torrefaction.

1. INTRODUCTION

Biomass energy has been considered an attractive renewable energy source because agricultural residues provide a clean, renewable, and sustainable energy source. Biomass fuels are widely used in power plants to replace fossil fuels. The benefits of biomass fuels include low pollution, affordability, and a wide range of available sources. Additionally, biomass energy can help reduce net carbon dioxide emissions, as well as emissions of sulfur and nitrogen oxides. [1]-[4]. As an agricultural country, Thailand has high-potential biomass sources, including rice straw, sugarcane bagasse, corn cobs, cassava rhizomes, rice husk, wood chips, and sawdust. In 2024, the average rice planting area is about 65 million rai, 20 per cent of the total area of country. Each production cycle has about 25.45 million tons of rice straw per year, and there is a remaining amount of rice stubble in the rice fields of 16.9 million tons per year. It has the highest amount of rice straw and rice stubble compared to other crop residues. Therefore, rice straw has significant potential for being converted into biomass fuel. Additionally, The Thai government aims to achieve 30% renewable energy by 2036. [5]-[7]. Biomass fuels are carbon-neutral and have a positive impact on the environment, which are alternative energy sources to fossil fuels in the future. Biomass raw materials, as a natural form for combustion, have limitations such as irregular shapes,

lower densities, higher moisture content, and hydrophilic properties, which decrease their heating value. All these parameters influence the higher costs for transportation and energy production process. In addition, the problem of slagging and fouling occurs in biomass combustion, affecting combustion efficiency. Therefore, many researchers have studied biomass conversion technology and performed it to prevent slagging [8]-[12]. One of the methods of improving fuel properties by conversion technology is pelletizing. Biomass pellets are typically cylindrical, with low moisture content and high density. The high density of biomass pellets guarantees economical transportation and storage [13]-[17]. However, biomass fuels have a lower calorific value than coal, impacting combustion efficiency. Therefore, increasing the calorific value of the fuel has received attention. One method that has focus is the torrefaction method. The torrefaction process significantly enhances the properties of biomass fuels, including high heating values and improved hydrophobicity. Moreover, this method to prevent slagging and fouling of biomass fuel combustion is the additive method. Adding additives can increase the melting temperature of ash, resulting in a reduced slagging and fouling formation tendency [18]-[24]. When using additives to reduce slag formation in biomass combustion, it is important to consider the potential decrease in calorific value. Therefore, this research aims to investigate the impact of temperature and short-term torrefaction duration affect the physical characteristics of rice straw pellets, using various amounts of dolomite as additives. The physical characteristics of biomass pellets focused on the study are moisture content, density, high heating values, and equilibrium moisture content.

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2. RESEARCH METHODOLOGY

2.1 Raw Materials Preparation

The rice straw was used as the main material. The additive as dolomite was used in pellet fuel production. The additive used in this research is dolomite, a mineral and sedimentary rock composed of calcium magnesium carbonate in powdered form, which was studied. The process utilizes the main material and dolomite, as illustrated in Figure 1.



(a) rice straw

(b) dolomite

Fig. 1. The images of rice straw and dolomite.

2.2 Biomass Pelletization Processes

Biomass pelletization processes is an efficient process consisting of four essential steps: drying, grinding, pelletizing, and cooling. Each stage is crucial in

transforming raw materials into a high-quality energy source. The initial step, the rice straw as main raw materials was passed the drying process. The particles of the rice straws were reduced to 5 mm, which were produced using a grinding machine. To prepare dolomite powder as an additive, the dolomite was dried at 105 °C for 24 hours. This research studied adding percentage of additive as dolomite at 3%, 5%, and 10%, respectively. In the preparation of pellets with additive. The flat-die pellet mill machine was utilized to produce pellet samples. The pellets diameter was 6.0mm. The pellet fuel samples were tested following the standards set by the Pellet Fuels Institute (PFI).

2.3 Torrefaction process of rice straw pellets

For the torrefaction process, a 10-gram pellet sample was introduced into a reactor cylinder made of stainless steel 304. The flow rate of nitrogen was 100 ml/min in the controlled heating furnace, as specified. This study investigated temperatures of 230, 250, and 270 °C using a temperature controller. Afterward, hot nitrogen was introduced into the torrefaction reactor, while the residence times were regulated at 5, 10, and 15 minutes, respectively. Finally, the physical properties of the pellets were tested under all conditions. The diagram for the short torrefaction process is illustrated in Figure 2. Equipment of torrefaction reactor and reactor cylinder are illustrated in Figure 3 and Figure 4.

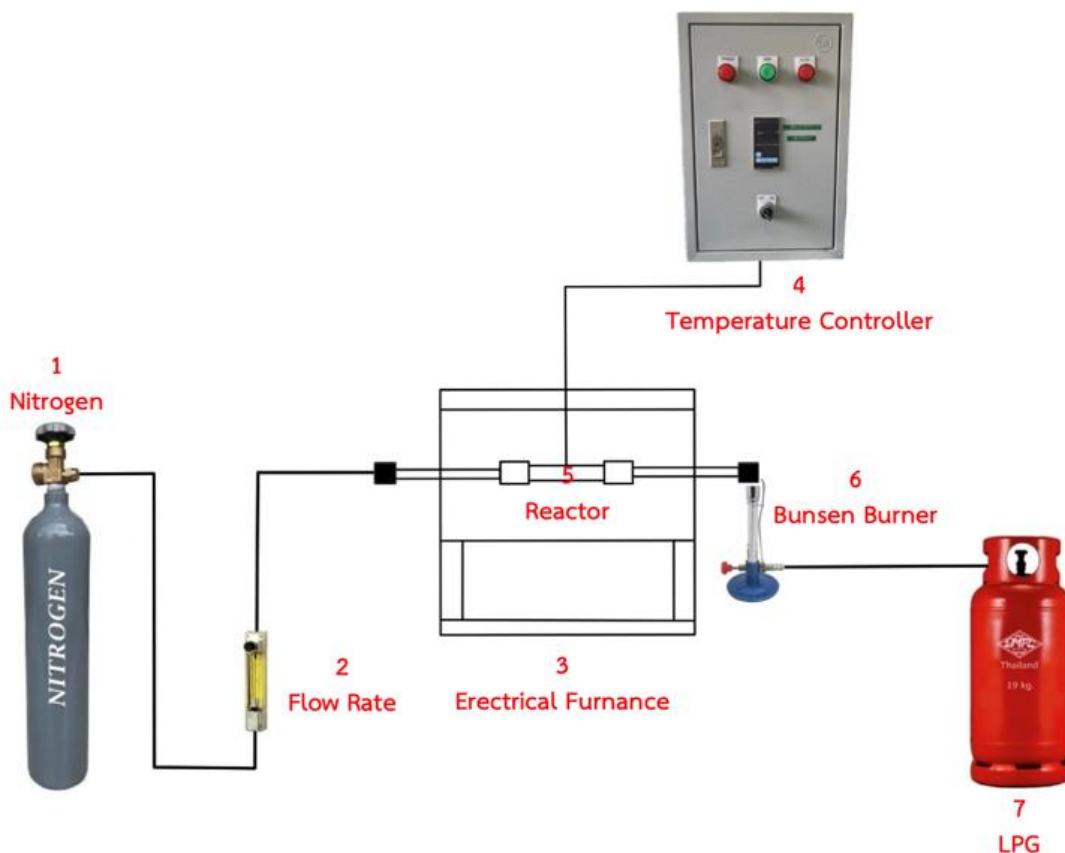


Fig. 2. Diagram for the short torrefaction process of rice straw pellets samples.



Fig. 3. Torrefaction reactor for the torrefaction process.



Fig. 4. The reactor cylinder contains a pellet sample.

2.4 Pellet Fuel Qualities Testing

Pellets physical properties include physical appearance, pellet density, higher heating value (HHV), and hydrophobic. The pellet density was tested to determine the density of the pellet. The pellet density was calculated as the mass of the pellet (m) divided by volume of the pellet (V), as shown in Equation (1).

$$\rho_{\text{pellet}} = m/v \quad (1)$$

When, ρ_{pellet} is pellets density (kg/m^3), m is pellet mass (kg) and v is pellet volume (m^3).

The HHV of the pellet sample will be tested using a bomb calorimeter model 1341, following ASTM Standard D5865-07.

The hydrophobic of pellets is the property that resists deformation due to contact with moisture or water. This physical behavior was observed through photography to monitor water absorption. Additionally, the equilibrium moisture content (EMC) of the pellet was tested using a drying method in a hot air oven. Afterward, the pellet sample was weighed, and the initial mass (m_i) was recorded. Then, the pellet sample was placed in the humidity-controlled chamber at 90% RH and a temperature of 30°C. Every 30 minute, the sample will be weighed on a precision scale until its weight stabilizes. At that point, the final mass will be recorded. The equilibrium moisture content (EMC) can be determined using the Equation (2).

$$EMC = ((m_f - m_i) \times 100 / m_i) \quad (2)$$

When, EMC is equilibrium moisture content (% db), m_f is the final mass (g) and m_i is the initial mass (g)

3. RESULTS AND DISCUSSION

3.1 Physical Characteristics of Pellets

The physical characteristics of the samples with dolomite at varying ratios of 0% (without dolomite), 3%, 5%, and 10% are illustrated in Figure 4. In this research, the biomass pellet samples with dolomite added at 0%, 3%, 5%, and 10% and which were torrefaction at 230 °C are referenced to as T230D0%, T230D3%, T230D5%, and T230D10%, respectively.

Moreover, the pellets sample at torrefaction temperatures of 250°C and 270 °C with dolomite additions of 3%, 5%, and 10%, are designated as T250D0%, T250D3%, T250D5%, T250D10%, T270D0%, T270D3%, T270D5%, and T270D10%, respectively. The physical appearance of the rice straw pellets at different residence times is illustrated in Figure 5 to Figure 7. The characteristics of pellet samples at temperatures of 230 °C and 250 °C exhibited similar trends. As the residence time increased, the physical appearance of the samples changed, with the colour and texture becoming darker and shinier. At a residence time of 5 minutes for torrefaction processes, the samples were dark brown. However, the colour at a residence time of 10 minutes was changed to black. When the residence time exceeded 10 minutes, a black colour and a drier texture were observed on the outer surface of the pellets. This dry surface indicated the decomposition of hemicellulose and cellulose, which increased the hydrophobicity of biomass pellets.

Residence Time	5 min.	10 min.	15 min.
T230D0%			
T230D3%			
T230D5%			
T230D10%			

Fig. 5. Physical characteristics of the pellets with dolomite at 230 °C.

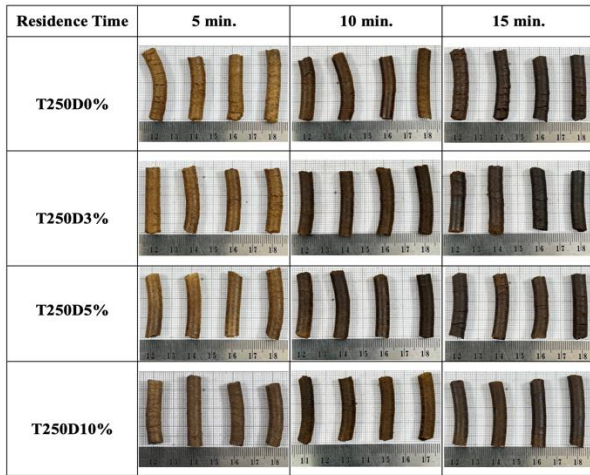


Fig. 6. Physical characteristics of the pellets with dolomite at 250 °C.

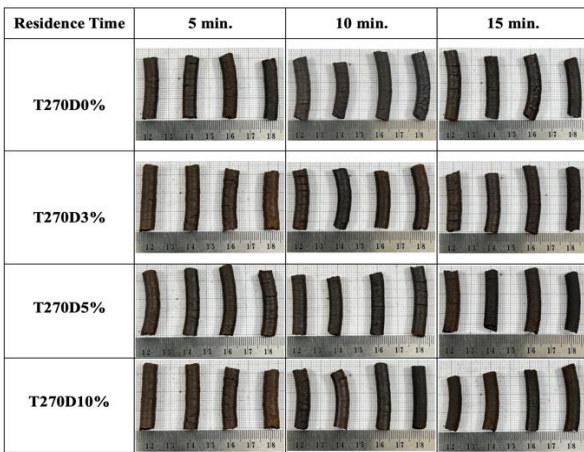


Fig. 7. Physical characteristics of the pellets with dolomite at 270 °C.

Furthermore, at a torrefaction temperature of 270°C, all dolomite addition ratios and residence time resulted in a darker and drier texture on the surface of the pellets. Thus, the results demonstrated that increasing the residence time at all tested conditions led to a deeper dark colour and a drier texture on the surface of the pellets.

3.2 Effect of Dolomite Addition on Pellets Properties

The impact of dolomite addition on pellet properties was examined with addition ratios of 0%, 3%, 5%, and 10%, as shown in Figure 8. The results obtained from the addition of non-torrefied served as a reference for torrefied pellets samples. The study results showed that adding more dolomite decreases pellet density. The pellet samples with dolomite addition ratios at 0%, 3%, 5%, and 10% were measured with densities recorded as $1008 \pm 66.54 \text{ kg/m}^3$, $1038 \pm 83.13 \text{ kg/m}^3$, $1062 \pm 52.43 \text{ kg/m}^3$, and $1062 \pm 23.06 \text{ kg/m}^3$, respectively. It was indicated that higher levels of dolomite addition correlate with reduced pellet density. In addition, the addition of dolomite as an additive has an impact on the HHV of rice straw pellets. The pellets with dolomite addition ratios of 0%, 3%, 5%, and 10%

were $18 \pm 0.27 \text{ MJ/kg}$, $16 \pm 0.30 \text{ MJ/kg}$, $15 \pm 0.28 \text{ MJ/kg}$, and $14 \pm 0.35 \text{ MJ/kg}$. It was illustrated that adding dolomite reduced the HHV.

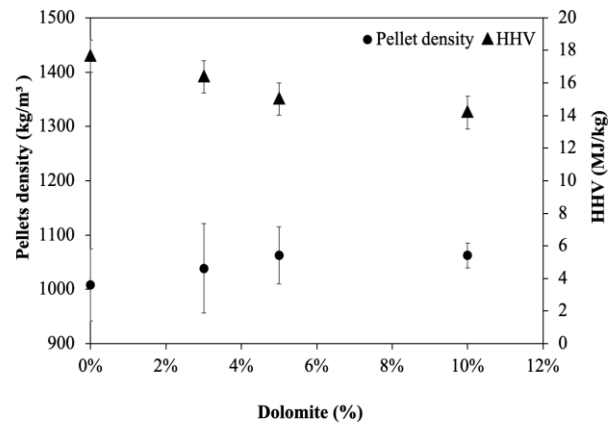


Fig. 8. The relationship between dolomite addition and pellets density and higher heating value (HHV).

3.3 Density of Torrefied Pellets

The density of rice straw pellet was tested with different proportions of dolomite: 0%, 3%, 5%, and 10%. These were evaluated during a short torrefaction process with residence times of 5, 10, and 15 minutes, respectively. The result of pellet density of rice straw with addition ratios of 0%, 3%, 5%, and 10%, as illustrated in Figure 9 to Figure 12. The experimental results indicated that the density of non-torrefied pellets was higher than that of torrefied pellets. Additionally, it was noted that increasing the torrefaction temperature led to a reduction in pellet density for the same amount of dolomite added. Additionally, longer residence times led to a decreased density of rice straw pellets containing dolomite at the same torrefaction temperature. Both the torrefaction temperature and residence time significantly affect the density of rice straw pellets containing dolomite.

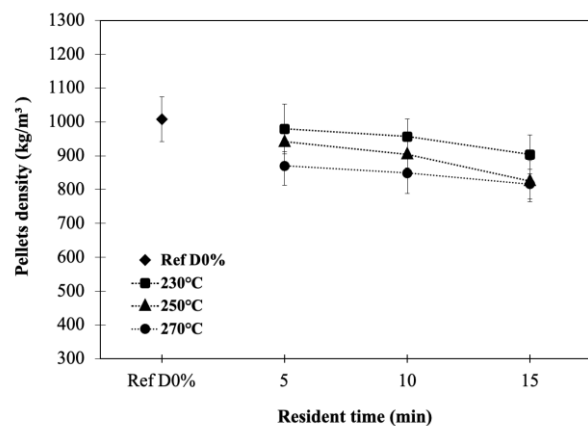


Fig. 9. The effect of the time on density of the pellets without additives at 0%.

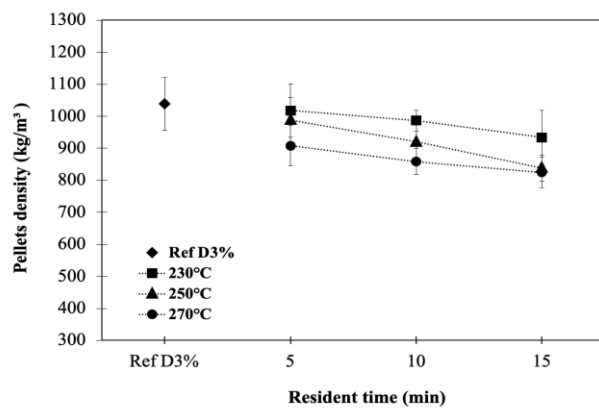


Fig. 10. The effect of the time on density of the pellets without additives at 3%.

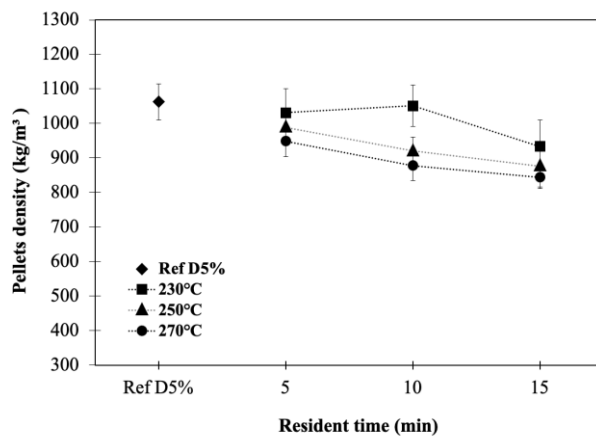


Fig. 11. The effect of the time on density of the pellets without additives at 5%.

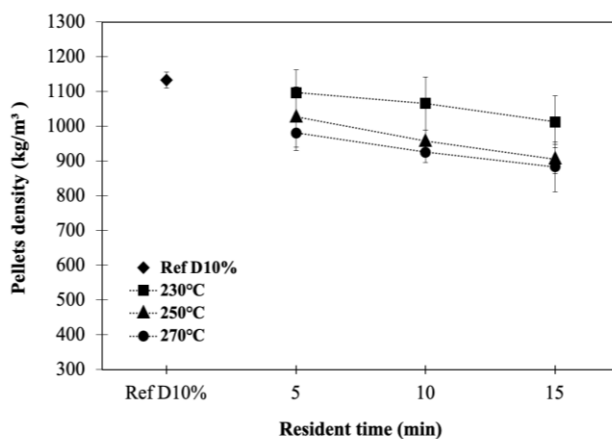


Fig. 12. The effect of the time on density of the pellets without additives at 10%.

3.4 Higher Heating Values (HHV) of Torrefied Pellets

The HHV of rice straw was assessed after the addition of dolomite at ratios of 0%, 3%, 5%, and 10% through the torrefaction process. For each dolomite addition ratio, the torrefaction temperatures were set at 230°C, 250°C, and 270°C. Additionally, the residence time for each dolomite

ratio was varied to 5, 10, and 15 minutes, respectively. The results for the HHV of rice straw with the different dolomite at 0%, 3%, 5%, and 10% are illustrated in Figure 13 to Figure 16. The experimental results indicated that the HHV of the non-torrefied sample was the lowest among all case studies. Thus, torrefaction significantly enhances the HHV. Increasing the torrefaction temperature significantly raised the HHV. However, there was no significant difference in HHV between the temperatures of 230°C and 250°C. In this study, the maximum of HHV was illustrated at 270°C across all ratios of dolomite addition. Additionally, extending the residence time also contributed to an increase in HHV due to this longer residence time impacts the processes of dehydroxylation, decarboxylation, and decaronylation [19]-[21]. Moreover, extending the residence time during torrefaction increases the carbon content in relation to the fuel, leading to a higher calorific value.

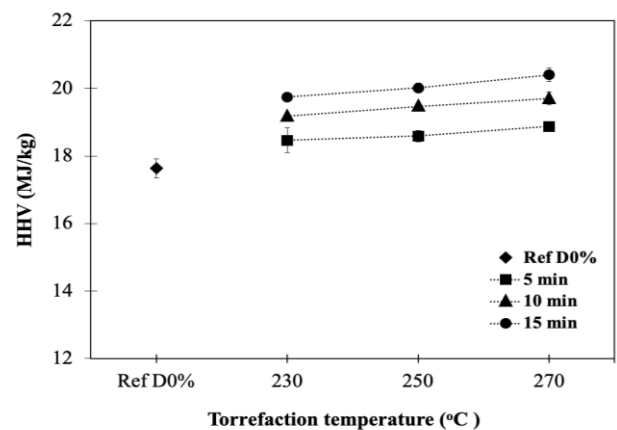


Fig. 13. The effect of the temperature on HHV for pellets without the additive (for 0%).

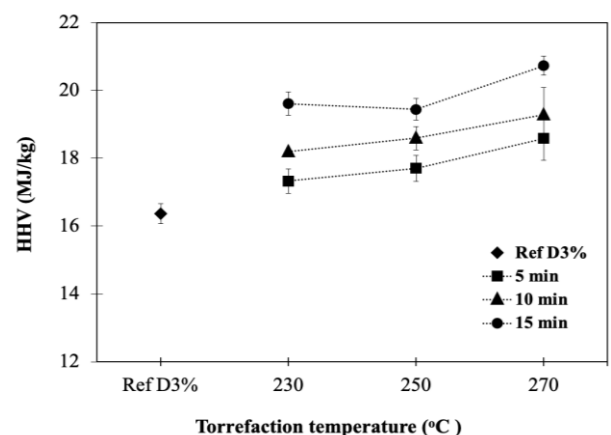


Fig. 14. The effect of the temperature on HHV for the pellets with the additive of dolomite at 3%

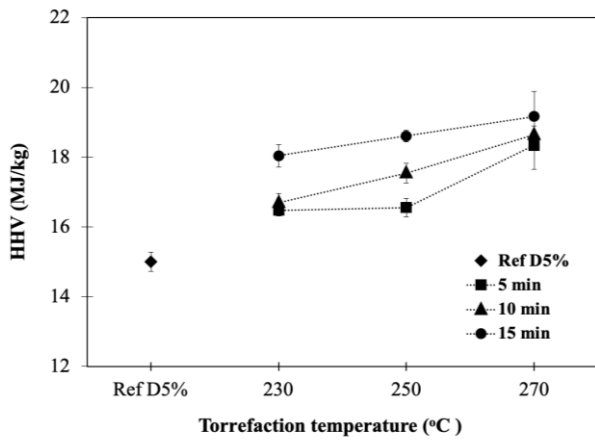


Fig. 15. The effect of the temperature on HHV for the pellets with the additive of dolomite at 5%.

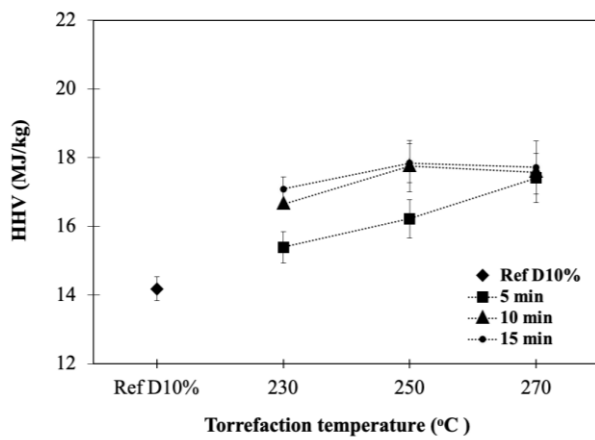


Fig. 16. The effect of the temperature on HHV for the pellets with the additive of dolomite at 10%.

3.5 Equilibrium Moisture Content of Torrefied Pellets

The effects of temperatures and residence time of rice straw pellets with dolomite on equilibrium moisture content (EMC) are examined in this study. The torrefaction temperatures were established at 230°C, 250°C, and 270°C. Additionally, the residence time for each dolomite ratio was tested for 5, 10, and 15 minutes. The results for the EMC of pellet with the different dolomite addition ratios of 0%, 3%, 5%, and 10% are illustrated in Figure 17 to Figure 20. The results of the EMC for pellets with varying dolomite addition ratios showed that increasing the time and temperature resulted in a decrease in EMC.

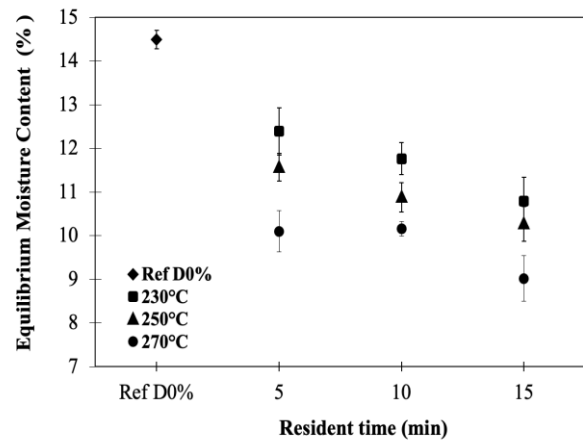


Fig. 17. The effect of the temperature on EMC for the pellets without the additive (for 0%).

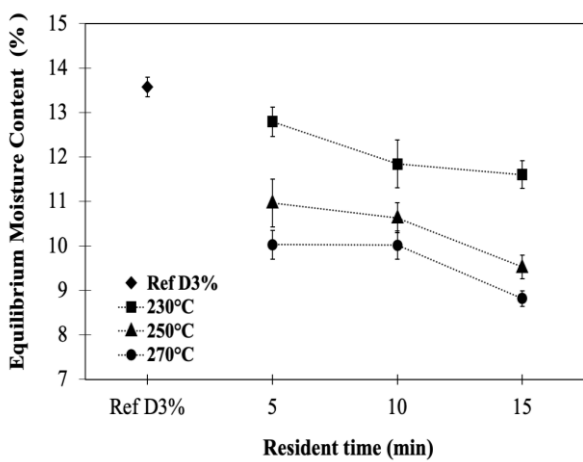


Fig. 18. The effect of the temperature on EMC for the pellets with dolomite at 3%.

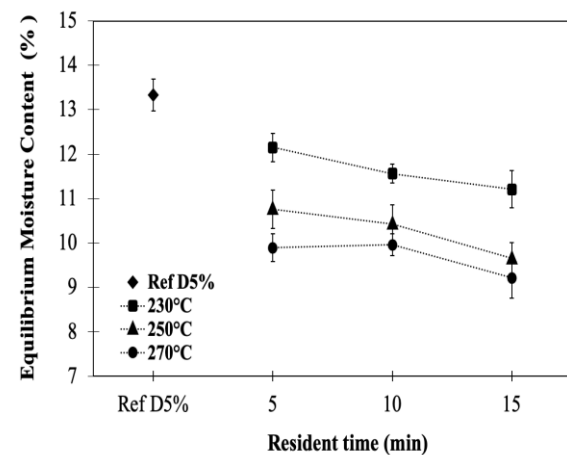


Fig. 19. The effect of the temperature on EMC for the pellets with dolomite at 5%.

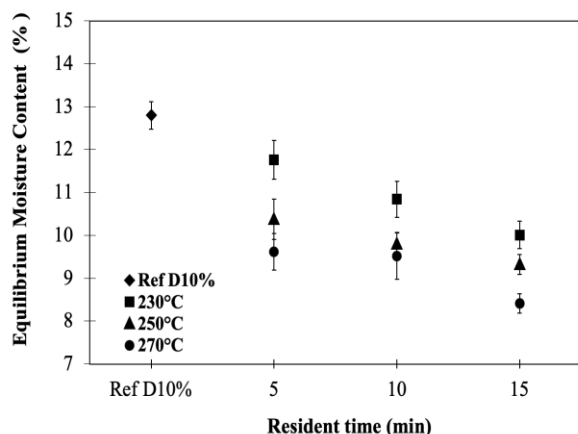


Fig. 20. The effect of the temperature on EMC for the pellets with dolomite at 10%.

4. CONCLUSIONS

Research results showed that higher temperatures and longer residence times resulted in a darker colour and a drier texture on the pellet surface. Furthermore, raising the torrefaction temperature decreased pellet density for the same dolomite ratio. Moreover, a longer residence time resulted in a reduced density of rice straw pellets that contained dolomite at the same torrefaction temperature. It is evident that both the torrefaction temperature and residence time have a significant impact on the density of rice straw pellets containing dolomite. In this study, the maximum of HHV was illustrated at a torrefaction temperature of 270 °C. In addition, increasing the residence time also resulted in a higher of HHV. In summary, both higher temperatures and longer residence times can enhance the HHV. Additionally, it was observed that as the ratio of dolomite added increased, the HHV decreased in all cases. Furthermore, the results regarding the EMC of rice straw pellets with varying dolomite addition ratios indicated that higher torrefaction temperatures and longer residence times significantly reduced the EMC.

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