Comparison of Adsorption Capacity Between Pelletized and Powdered Clinoptilolite for Methylene Blue Removal

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ABSTRACT

The increasing use of dyes in industries such as textiles and printing has led to environmental concerns. Adsorption is a practical solution for removing these pollutants. This study compares the adsorption capacities of pelletized and powdered clinoptilolite for removing methylene blue. While both forms demonstrated increased adsorption with increasing mass, pellets showed significantly lower adsorption capacity than powders due to limited surface area and penetration resistance. This study suggests that reducing pellet mass and thickness could enhance performance, demonstrating potential improvements for pelletized clinoptilolite.

Keywords: adsorption, clinoptilolite, methylene blue, pellet

INTRODUCTION

Adsorption, a surface phenomenon where molecules adhere to a solid or liquid surface, is a cost-effective and widely applied method for water treatment, gas purification, and contaminant removal (Liu et al., 2020). Clinoptilolite, a natural zeolite, is often used in water treatment due to its low cost and effectiveness (Meili et al., 2019). Its ability to adsorb cationic substances like methylene blue makes it a valuable adsorbent (Ngapa & Gago, 2021).

However, most adsorption studies use adsorbents in powder form. This form, while effective, requires post-filtration and may cause issues like sedimentation, which can increase maintenance costs and lower adsorption efficiency (Putra & Lee, 2020). In response, other researchers explored microbeads, but their complex production and reduced surface area made them impractical (Dinu et al., 2017). This study explores pelletized clinoptilolite as an alternative, aiming to compare its adsorption efficiency to powdered clinoptilolite and propose improvements.

MATERIALS AND METHODS

Materials

Clinoptilolite granules were sourced from ACME Sdn Bhd, and methylene blue was obtained from Sigma Aldrich.

Preparation of Clinoptilolite Powder

Granular clinoptilolite was cleaned with tap water, rinsed with distilled water, and dried at 100°C overnight. The dried granules were ground into powder (0.42 µm) using a ball mill (Pulverisette 6, Fritsch), and particle size was confirmed with a Zetasizer Nano ZS90.

Preparation of Clinoptilolite Pellets

Pellets were made using a hydraulic press with a pressure of 1 ton. Pellet thickness was adjusted by varying the powder mass, and the pellets (6 mm in diameter) were heat-treated at 400°C for 48 hours to enhance structural integrity. Pellets produced using 50, 70, and 90 mg of powder were labeled as Pe5, Pe7, and Pe9, respectively. The corresponding powder samples were labeled as Pd5, Pd7, and Pd9, respectively. Figure 1 shows the pellet sample.

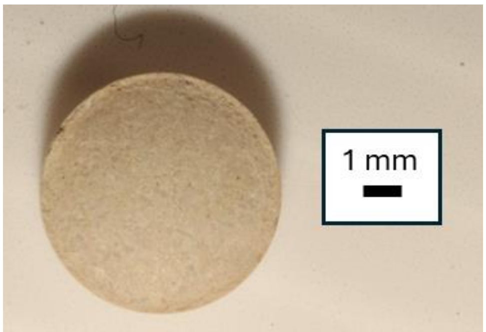


Figure 1. Pellet format produced from clinoptilolite powder

Adsorption Experiment

A stock solution of 0.5 mg/L methylene blue was prepared. Clinoptilolite samples (both pellets and powder) were added to 50 mL of 20 mg/L methylene blue solution in 100 mL flasks. The flasks were shaken at 100 rpm until the concentration reached equilibrium. The concentration of methylene blue was measured using a UV-Vis spectrophotometer, and adsorption capacity was calculated using the equation from Noori et al. (2022).

$$q_e = \frac{(C_i - C_e)}{m} \times V$$

where q_e is the adsorption capacity, C_i is the initial concentration of methylene blue, C_e is the concentration of methylene blue at equilibrium, m is the mass of clinoptilolite added to the solution, and V is the volume of the methylene blue solution.

RESULTS AND DISCUSSION

Adsorption Capacity of Powdered Clinoptilolite

As shown in Figure 2, powdered clinoptilolite exhibited a consistent increase in adsorption capacity as mass increased. This is attributed to the increased number of adsorption sites. Adsorption capacities of the powder are consistent with previous studies (Dosa et al., 2018;

Molla Mahmoudi et al., 2019).

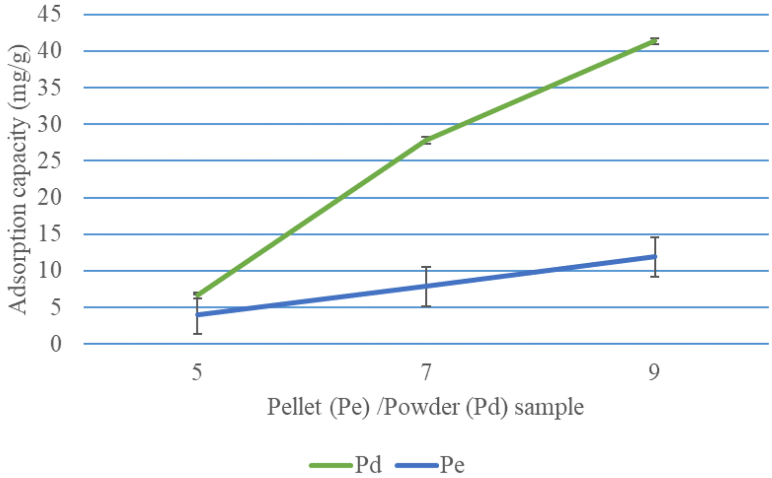


Figure 2. Adsorption capacity of pellet and powder

Adsorption Capacity of Pelletized Clinoptilolite

Pellets followed a similar trend, with adsorption capacity increasing as mass increased (Figure 2). However, the increase was less significant compared to powder. This is likely due to the limited surface area and internal structure, which restrict methylene blue from fully penetrating the pellet. Error bars indicate variability in adsorption capacity, which may result from inconsistencies in pellet formation (e.g., uneven pressure distribution during pressing). The value of adsorption capacity is comparable to previous works.

Comparison of Adsorption Capacities

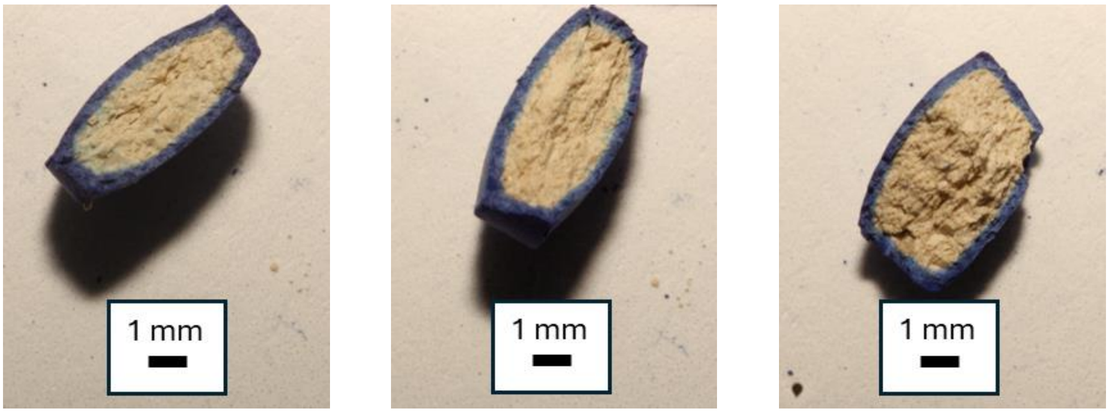
As illustrated in Table 1, the difference in adsorption capacity between pellets and powder becomes more pronounced with increasing mass. For instance, the adsorption capacity of Pe5 was 64% lower than Pd5, and for Pe9, it was 247% lower than Pd9. This can be attributed to the reduced effective surface area of the pellets, particularly at higher masses, where the thicker pellet structure inhibits full access to adsorption sites.

Table 1. Comparison between the pellet and powder adsorption capacity of clinoptilolite on methylene blue pellet

Pellet	Adsorption capacity compared to its powder counterpart
Pe5	64% smaller than Pd5
Pe7	253% smaller than Pd7
Pe9	247% smaller Pd9

Penetration Resistance

One of the key issues with pelletized clinoptilolite is penetration resistance. As shown in Figure 3, methylene blue only penetrated 0.32–0.37 mm into the pellet, leaving much of the internal structure unutilized. In contrast, powdered clinoptilolite, with its smaller particle size, achieves near full utilization of surface area. Our findings suggest that pellet thickness should be reduced to 0.64–0.74 mm to improve adsorption efficiency.



(a) (b) (c)

Figure 3. Cross-sectional views of pellets following methylene blue adsorption for (a) Pe5, (b) Pe7, and (c) Pe9.

CONCLUSION

This study compared the adsorption capacities of pelletized and powdered clinoptilolite for methylene blue removal. Both formats showed increased adsorption with mass, but pellets exhibited lower adsorption capacity due to limited surface area and penetration resistance. Reducing pellet thickness and improving porosity could help enhance their performance to match that of the powder format. Future research should focus on optimizing the pellet structure to improve porosity and facilitate better penetration of adsorbates. Additionally, reducing pellet thickness to below 1 mm could help increase surface area utilization, improving overall adsorption capacity.

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