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Suitability of pressmud as an adsorption material in wastewater treatment and as a booster in soil fertility and productivity

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Abstract. Pressmud is one of the most abundant wastes produced by the sugarcane industry. However, it has received far too little attention as a reactive material for pollutant removal, although its beneficial effect on soil fertility and crop productivity is well established. This paper investigates the potential of pressmud to minimize heavy metal migration while boosting soil fertility and productivity. Firstly, the adsorbent was characterized by Fourier Transform Infrared Spectroscopy (FTIR) and Field-Emission Scanning Electron Microscopy (FESEM) analyses, which showed the presence of functional groups such as carbonyl, hydroxyl, and silica capable of adsorbing metal ions. The cation exchange capacity (CEC) of pressmud is very high, ranging between 44.9 and 45.2 meq/100 g. Along with removal efficiency testing and evaluating breakthrough curves, characterization and adsorption analyses (batch equilibrium and column test) were carried out. The pressmud reveals promising adsorption characteristics, including a high organic content (17.62%) and the presence of carbon, which significantly affects its excellent removal effectiveness. Based on the removal efficiency test, pressmud successfully removes metal ions at the highest value, such as zinc (Zn), at 99.7%. Meanwhile, its breakthrough curve reveals that it efficiently retained all heavy metals, as these metals do not reach 1 to 10 pore volumes (p.v.), indicating that pressmud is a good material for heavy metal adsorption and soil productivity. This possible use establishes a new cyclical flow for the material and contributes to its minimization and reuse, adhering to circular economy ideas. However, pressmud must be disposed of properly to avoid adverse effects on humans and the environment.

1. Introduction

Malaysia has four sugarcane processing facilities, three in the northern peninsula (Perlis, Kedah, and Penang), and another in Selangor. Two northern facilities, namely Gula Padang (Kedah) and Perlis Plantations (Perlis), are integrated sugar mills that can refine imported raw sugarcane. Meanwhile, the remaining two refinery facilities handle imported raw sugar. The Malayan Sugar Manufacturing Company (MSM) owns one of them, a port-side refinery across Penang Island [1].

The four main by-products of the sugarcane industry are cane tops, bagasse, filter mud (pressmud), and molasses. Commonly, 100 tons of crushed sugarcane generate approximately 3% pressmud cake. Composting this by-product produces highly nutritious organic manure. In addition, this process makes organic solid waste biodegradable and suitable as a fertilizing agent rich in micro and macronutrients and organic carbon or soil conditioner for agricultural fields. It also enriches the microbial population, prepares helpful microbial communities, improves microbiological standards, and creates a manageable and storable substance that can convert and generate various crucial enzymes for field application without harming the environment. Additionally, it can protect plants from diverse soil-borne diseases while preserving soil fertility, as well as promoting crop production sustainability on degraded lands caused by the extreme utilization of chemical fertilizers and pesticides continuously [2].

Pressmud regularly appears to be a blackish-brown, amorphous, and spongy solid and contains sufficient fiber. It is rich in organic matter, which can improve soil productivity [3]. This study evaluates the physicochemical characteristics, removal efficiency, and column test for pressmud to demonstrate its suitability as a potential material for increasing soil productivity and treating wastewater and leachate in landfills.

2. Methodology

The preparation of the pressmud sample was adapted directly from Dominic et al. [4] and Azme and Murshed [5], obtained from Malayan Sugar Manufacturing Co. Bhd. in Perai, Penang, Malaysia. Pressmud was dried for 24 hours at 105°C in an oven until the weight was constant for moisture removal. The particle size of the dried pressmud was reduced to less than 1000 μm through grinding and sieving and stored at a room temperature of 28±2ºC. The samples were characterized and evaluated for their basic characteristics and physicochemical properties using standard methods [6, 7].

Analyses on the basic properties of pressmud were also conducted through several tests, namely natural moisture content, pH, organic content, and carbon content determination. The physicochemical properties analysis, including surface physical morphology and cation exchange capacity testing, was performed according to ASTM D4319 [8]. Meanwhile, the surface functional group determination was conducted according to ASTM E1252-98 (2013) Standard Practice for General Techniques for Obtaining Infrared Spectra for Qualitative Analysis [9]. For the removal efficiency test, 10 mL of each solution at 10 mg/L initial concentration and 1 g of sample were thoroughly mixed at a 10:1 ratio [10, 11]. Finally, pressmud was observed in a column test to measure the capability of heavy metal migration using spiked solutions to get the breakthrough curve as specified by ASTM D4874-95 [12].

3. Results and Discussions

The properties of the pressmud were measured to determine its potential for improving soil properties. Table 1 summarizes the results of the pressmud properties. Pressmud is a hydrophilic organic material that may store more water than other soils. It has a 34.53% water content due to its amorphous form. Moreover, it also has a slightly alkaline pH of 8.54. The organic content of pressmud was 17.62%, indicating a significant concentration of macro- and micronutrients [13]. Pressmud contains a variety of macro- and microelements that plants need, frequently combined with other organic fertilizer sources in numerous techniques [3]. As a result, pressmud with a high organic carbon and nutrient content can aid in heavy metal adsorption. Furthermore, this result indicates that pressmud consists of 14.57% carbon.

Table 1. Basic characterizations of Pressmud.

Properties	Value
Moisture content	34.53
pH	8.54
Organic content (%)	17.62
Carbon content (%)	14.57

The surface physical morphology was analyzed using Field-Emission Scanning Electron Microscopy (FESEM). Figure 1 shows the pressmud layer at a magnification of 10,000 times with a dimension of 1 µm. More pores are expected to be present on its surface. The average pressmud pore diameter is 28.79 nm. Pressmud has granular textures, while soil exhibits a less granular texture. The texture and surface became uneven and pore-filled, as shown in Figure 1.

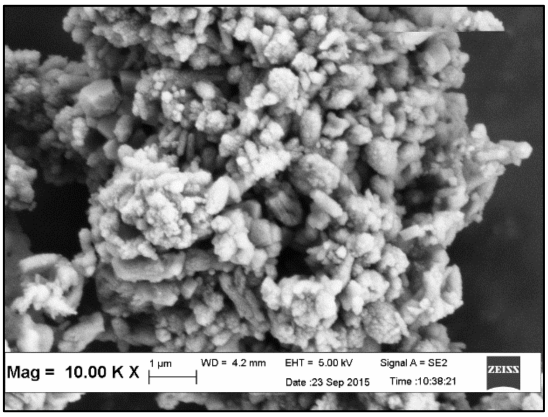

Figure 1. Surface morphology of pressmud.

Cation exchange capacity (CEC) measures the ability of soil to retain positively charged ions. It is a crucial soil property that affects soil structure stability, nutrient availability, pH, and reactions to fertilizers and other ameliorants [14]. Pressmud exhibits extreme CEC values of 44.9 – 45.2 meq/100 g, indicating that this material can increase soil productivity. Low CEC soil has a greater tendency to have low K, Mg, and other cations. Meanwhile, high CEC soil can surpass these constraints. Although there is a lack of research on how nutrients directly affect soil CEC, the effect presumably exists since nutrient addition influences pH, particularly in variably charged soils. Lesser soil CEC indicates rapid pH changes over time [15].

Functional group components in pressmud were predicted using Fourier transform infrared spectroscopy (FTIR) analysis. Figure 2 presents the FTIR spectra of pressmud in this study. The presence of metal ion-adsorbing surface functional groups, such as carbonyl, hydroxyl, and silica, is indicated by absorption bands and peaks. A broad, declining band at 3692 – 3416 cm^{-1} is the hydroxyl group, most likely present in adsorbing water. On the other hand, the stretching vibration of C=H is 2959 – 2515 cm^{-1}. The band that is wide and strong in the 1084 – 1141 cm^{-1} range is identified as being part of the silica group, specifically the Si-O-C or Si-O-Si structure, which is associated with the high presence of silicon in the materials [6]. The carbonyl group presented on the surface is indicated by the wave number at 1797 cm^{-1}. The trough observed at 713 cm^{-1} indicates C-H groups. High organic carbon content in pressmud may further boost its metal ions absorption capability.

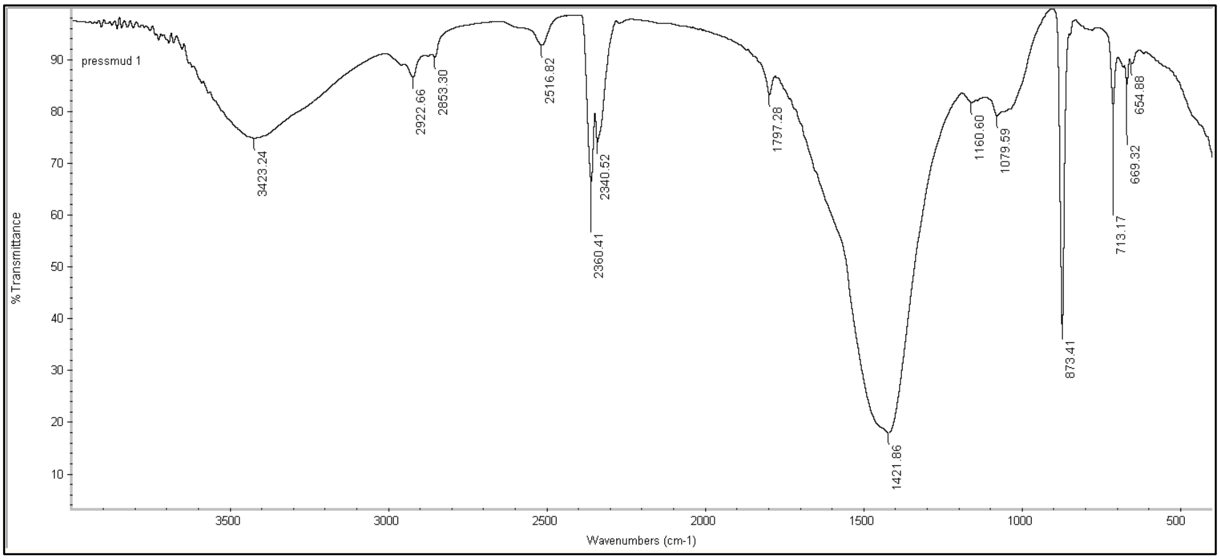

Figure 2. FTIR spectrum of pressmud.

Batch equilibrium tests evaluate the heavy metal removal efficiency using EPA [10] and USEPA [11] methods. The current study determines the adsorption effectiveness of pressmud using different heavy metals, including Cadmium (Cd), Chromium (Cr), Copper (Cu), Iron (Fe), Manganese (Mn), Nickel (Ni) and Zinc (Zn), at an initial concentration of 10 mg/L. Figure 3 depicts the percentage removal of metal ions from the solution, in which pressmud removes 98.4% of Cd but only 97.1% of Cr. The pressmud removes 92.7% of Cu while excellently removing 99.2% of Fe. Lastly, pressmud also removes 87.9%, 91.7%, and 99.7% of Mn, Ni, and Zn, respectively. The analysis of variance (ANOVA) reveals a considerable improvement ($p<0.05$) for removing seven metal ions from the solution. It is suggested that pressmud significantly reduced the heavy metal concentration in the solution filtrate. In summary, pressmud has high potential as a soil amendment material due to the combinations that help improve wastewater and leachate quality while minimizing heavy metal mobility.

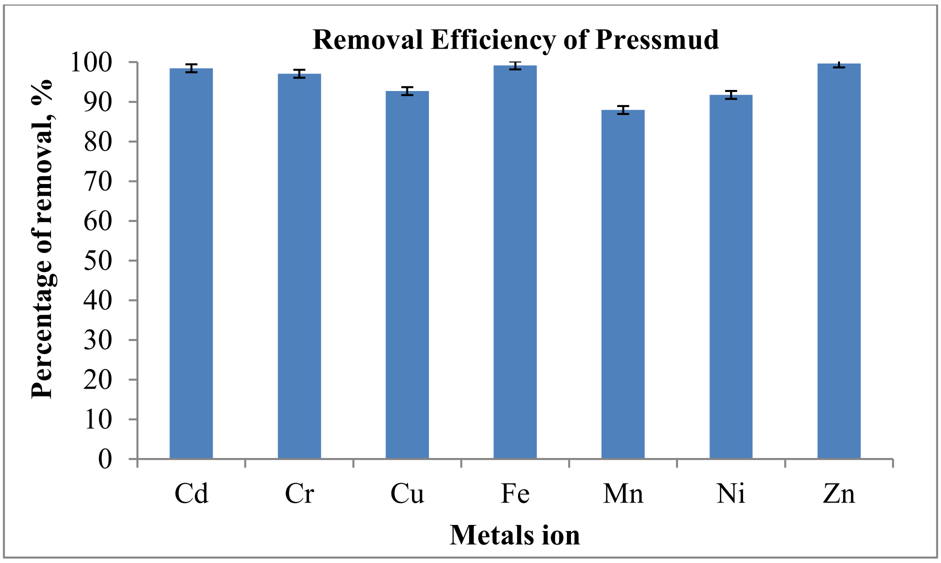

Figure 3. Removal percentage of metals ion from the solution.

Figure 4 exhibits the variation of effluent (C_e) to the initial concentration (C_o) ratio over the solution pore volume using a pressmud medium. It shows that the column is not exhausted for all heavy metals until 10 pore volumes (p.v.) of the experiment. The results show that Cr, Ni, Cu, and Mn have a breakthrough of 3.2 – 9.0 p.v. Meanwhile, Cd, Zn, and Fe have values lower than 0.5 at 10 p.v., indicating strong sorption capability. The relative mobility sequence of heavy metals for this medium is Cr>Fe>Cu>Ni>Mn>Zn>Cd. Pressmud retains all heavy metals efficiently since these metals did not reach 1 until 10 p.v., establishing pressmud as an effective mixture material for assisting heavy metal adsorption. Pressmud exhibits acceptable attenuation and retention capability concerning heavy metal mobility. The findings show that pressmud can stand alone since no heavy metals reach saturation points. Natural characteristics of pressmud having high sugar content cause it to be sticky when wet. This circumstance enhances the ability of the medium to retain heavy metals when leachate flows into it. The study determined that pressmud, a by-product of the sugarcane industry, has excellent potential as a reactive material to remove metal ions, similar to a previous study [16] that used pressmud as a reactive material for Cd^{2+} removal for equilibrium, kinetics, desorption, and bioaccessibility.

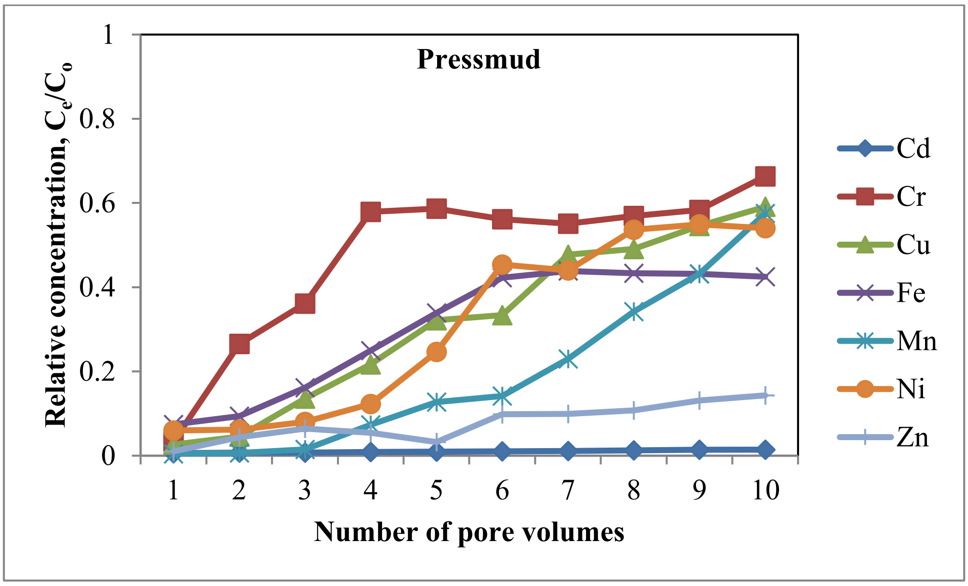

Figure 4. The breakthrough curve of heavy metals for pressmud.

4. Conclusion

Due to its basic and physicochemical characteristics, pressmud can be used as an organic mixture in soil and as an adsorbent material in wastewater treatment. It has a high metal ion removal efficiency (between 87.9 and 99.7% depending on the initial concentration of 10 mg/L) and other characteristics such as the CEC (44.9 – 45.2 meq/100 g) and organic content (17.62%). Furthermore, the findings from FTIR show the presence of various functional groups (hydroxyl, carbonyl, and silica), which support pressmud as a future potential material for soil productivity enhancement, heavy metals sorption, and other potentially toxic metal sorption. This research ushered in a new era and revealed the potential of pressmud as a low-cost medium for soil stabilization and solidification to minimize wastewater and leachate migration from waste disposal sites. Implementing pressmud at a small scale is recommended to simulate their functions in the actual situation for future investigation.

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