

## Literature Review: Effects of Palm Oil Fuel Ash Adsorbent Mass Variation on Adsorption Process Efficiency in Water Treatment

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### ABSTRACT

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Palm Oil Fuel Ash (POFA) has excellent potential as an adsorbent for heavy metals, especially zinc (Zn), because it is able to provide a high absorption percentage. The purpose of this literature study is to systematically examine the effect of variations in the mass of Palm Oil Fuel Ash (POFA) adsorbent on the efficiency of the heavy metal adsorption process in water treatment, as well as to identify the most effective activator for POFA-based adsorbents based on the results of previous studies. The literature study method was carried out by reviewing and comparing relevant national and international scientific articles through Google Scholar, Garuda, and SINTA-accredited journal databases, with a focus on the relationship between POFA adsorbent mass and adsorption efficiency. Commonly used activators include  $\text{NH}_4\text{Cl}$ , HCl, NaOH, and KOH, with the best results varying for each type of POFA modification. Unmodified POFA showed optimum performance when activated using  $\text{NH}_4\text{Cl}$ , with an adsorption percentage reaching 98.65% at a mass of 10 grams, while zeolite POFA gave the highest results with HCl activator, namely 98.77% with a mass of only 2 grams. In contrast, silica POFA showed a lower adsorption capacity, with an adsorption percentage of 44.50% at a mass of 25 grams. Overall, these results indicate that POFA zeolite is the most effective adsorbent in the adsorption of zinc metal compared to unmodified POFA and silica POFA because it is able to achieve high efficiency with the use of less adsorbent mass.

**Keywords:** Palm oil fuel ash, POFA, Adsorbent, Adsorption, Removal efficiency

### 1. INTRODUCTION

Water pollution occurs when a water body is contaminated by foreign pollutants, which can be in the form of gas, suspended, or dissolved materials. Pollution diminishes the quality of water to the extent that the water can no longer serve its inherent functions or be utilized for its intended purposes, such as for household, agricultural, or industrial uses, or to sustain the life of water systems or aquatic ecosystems [1]. Water pollution occurs when pollutants are discharged directly or indirectly into water bodies without adequate treatment [2]. The treatment and disposal of domestic and

industrial wastewater is a serious issue that must be addressed to prevent environmental degradation [3]. The quality of generated wastewater is expected to comply with the quality standards stipulated in the Regulation of the Minister of Environment and Forestry (PERMEN LHK) No. 68 of 2016 concerning domestic wastewater quality standards, which include four parameters: pH, BOD, COD, and TSS [4].

In urban areas, water pollution caused by waste and garbage generally occurs in river regions. River water experiences pollution due to the accumulation of domestic, industrial, and

agricultural waste [5]. In addition to river water, there is also domestic wastewater. Domestic wastewater is water originating from residential activities, restaurants, offices, commercial facilities, apartments, and housing areas [6]. Forms of this wastewater include feces, urine, bathroom wastewater, and residues from household kitchen activities [7]. According to Government Regulation of the Republic of Indonesia No. 22 of 2021 concerning the Implementation of Environmental Protection and Management, liquid waste is water originating from a process within an activity. Therefore, industrial liquid waste is water generated from industrial activities, such as residual dyeing water from textile industries, wastewater from food industries, and washing residues from meat or vegetables [8].

Water pollution generally consists of heavy metal ions, pesticides, pharmaceuticals, hydrocarbons, and organic dyes. Heavy metals are materials that are not easily degraded naturally and can accumulate in ecosystems before eventually entering the human body through the food chain [9]. Generally, heavy metals cannot decompose in water; increasing activities related to heavy metals, such as industrial operations, lead to water contamination and metal accumulation in aquatic environments [10]. In addition, high levels of BOD or COD in waters can reduce dissolved oxygen concentrations, thereby decreasing water quality and aquatic resource productivity [11]. The presence of heavy metals in the human body can result in serious conditions that include vomiting, stunted growth, paralysis, abdominal pain, and anemia [12]. There is a concerning presence of toxic metals Cu, Zn, Cr, Cd, Ni, and Pb in industrial wastewater, all of which are dangerous to human health and the ecosystem. Unregulated discharging of industrial wastewater can have devastating consequences on the immediate environment [13].

Water bodies may receive chemical contaminants in various forms, dissolved in a liquid as a solution, as a liquid, as gas bubbles, as floating particles, or as settled-out particulates in the water column. The

pollutants may include such hazardous characteristics as being flammable, explosive, or, if one is unfortunate enough to come into contact with these, may have carcinogenic or poisonous properties [14]. The consequences of heavy metal pollution on as yet unexposed organisms include the death of the fish, the damage of certain organs like the liver, the gills, and other internal organs [15]. In addition, the sublethal exposure to heavy metals can lead to, and in many cases have been the cause of, various diseases and disorders especially of the closed circulatory and respiratory systems, the central nervous system, the urinary and reproductive systems, the endocrine system, the skeletal system, as well as other systems and, in many cases, serve as a precursor to cancer [16].

Adsorption is a process in which molecules or ions are absorbed from a liquid phase onto a solid surface due to physical or chemical forces. Adsorption is a result of variations in surface energy, leading to attractive forces between molecules of the substance being adsorbed and the surface of the adsorbent [17]. During adsorption, the choice of adsorbent is a critical parameter. Activated carbon has been employed in wastewater treatment as an adsorbent because of its advantages, such as a large surface area and a higher adsorption capacity [18]. Adsorption is applied in the treatment of wastewater for diminishing organic compounds in wastewater [19].

Adsorbents are substances with the ability to remove pollutant particles in liquid form through their surface pores. The efficiency of the adsorbent is largely dependent on its surface area, pore size, particle size, and pore density. The rate of the adsorption activity may be dependent on the concentration of the adsorbent [20]. The quantity of the adsorbent used as well as the temperature, surface area of the adsorbent, pH, and the concentration of the adsorbate substance are some of the variables that affect the adsorption activity [21]. In general, adsorbents are known to have large surface areas and porous structures. Therefore, they are highly effective in the purification or separation of compounds and in waste treatments [22]. The commonly

employed adsorbents comprise activated carbon, silica gel, alumina, zeolite, and natural materials or activated agricultural wastes [23].

The magnitude of variation of the adsorbent mass is another factor to which specific study to be conducted because the mass of the adsorbent is directly related to the quantity of pores and sites that are available for heavy metal adsorption in water treatment processes, and to what extent the efficiency of heavy metal adsorption is achieved in water treatment processes [21]. Thus, in this literature study, the aim is to investigate the influence of variations in unmodified and modified POFA adsorbent mass and its corresponding impact on the heavy metal adsorption efficiency. The findings from this literature study are linked to the discourse regarding the measurement of optimal conditions of adsorption for different types of POFA and to provide a scientific perspective of effective and efficient water treatment adsorbent mass magnitude [20].

## **2. RESEARCH METHODS**

This section is supposed to be written briefly and clearly, but fully to enable replication and development of the published findings. In this section, an account of the methodology of research, research participants, research process implementation, material and instrument utilization, data gathering, and methods of data analysis will be found. They are not theories. Through this description, readers can judge the appropriateness of research methods, and data reliability and validity can be judged.

In conducting this research, a literature review was used to investigate the impact of Palm Oil Fuel Ash (POFA) adsorbent material variation on the efficiency of adsorption of heavy metals in water treatment. For the literature review research methodology, a comprehensive understanding of the process of adsorption efficiency and its effects or variations was achieved. Sources of articles included national and international journals

that used Google Scholar, Garuda, and SINTA-accredited journals through keywords that included Palm Oil Fuel Ash (POFA), adsorption of heavy metals, water treatment, variation of adsorbent materials, and adsorption efficiency. Since experimental research is mainly comprised of articles that utilized or researched POFA modified or unmodified as adsorbents in removing heavy metals, most of the articles used in this research will likely come from this category.

The identified journal articles were filtered based on their connection with the study objectives, especially those that contained quantitative information on the relationship between the mass of the adsorbent and the efficiency of the adsorption. The study used descriptive as well as comparative analyses to examine the data collected. The data variables involved the type of water as well as the type of metal used in the study, the procedures for activating the POFA material adsorbents, the variations in mass of the adsorbent materials, the contact time involved in the study procedures, as well as the level of efficiency in the adsorption.

Despite several variables that may interact in the adsorption procedure, like pH, particle size, initial metal solution concentration, contact time, type of activator, and stirring rate, this literature analysis concentrated narrowly on the specific variable of the adsorbent mass. The reason for this particular and direct analysis is to give a more in-depth assessment of the specific function of POFA mass in improving the efficiency of adsorption. In conclusion, the results of previous research were gathered to formulate a general conclusion about using POFA as a highly economical and eco-friendly adsorbent for heavy metals in water treatment processes.

### 3. RESULTS AND DISCUSSION

This literature review has been carried out in order to gain an understanding of the adsorption process in removing substances found in water and learn more about the benefits and weaknesses in the adsorption process of heavy metals. The analyses carried out by various researchers on natural water samples contaminated with metals include industrial wastewater, peat water, acid mine drainage water, and others. A very simple solution in order to decrease the level of metal found in nature in general is the adsorption method by adsorbent media, such as adsorbents. In relation to the current study being carried out, the adsorbent material used will be Palm Oil Fuel Ash (POFA), which is known to have somewhat better adsorbing properties in relation to various metals. The choice made in relation to the adsorbent will be supported

by its almost free availability in the market and relatively low cost to be produced.

From literature reviews of previous researchers, metals that can be adsorbed using adsorbent media include but are not limited to Fe, Cd, Zn, and Hg. In general, several variables significantly influence the adsorption process, such as pH, adsorbent particle size, metal concentration, adsorbent mass, contact time, type of activator, stirring speed, and the type of metal being absorbed. However, in this literature review, the focus is on the adsorbent mass variable to analyze its effect on the effectiveness of the adsorption process.

The results of the literature review from previous studies indicate that the optimum conditions for metal adsorption by adsorbents can be systematically summarized, as presented in Table 1.

**Table 1.** Summary of literature review data with the best adsorption performance

Adsorbent Type	Activator	Adsorption Target	Best Result	Reference
Unmodified POFA	NH <sub>4</sub> Cl	Fe	- Water type: Acid mine drainage - Contact time: 180 minutes - POFA mass: 10 g - Adsorption efficiency: 98.65%	[24]
Unmodified POFA	HCl	Hg	- Water type: Peat water - Contact time: 240 minutes - POFA mass: 0.25 g - Adsorption efficiency: 98.03%	[25]
Zeolite-Modified POFA	HCl	Zn	- Water type: Industrial wastewater - Contact time: 60 minutes - POFA mass: 2 g - Adsorption efficiency: 98.77%	[26]
Zeolite-Modified POFA	HCl	Cd	- Water type: Industrial wastewater - Contact time: 120 minutes - POFA mass: 10 g - Adsorption efficiency: 97.00%	[27]
Silica-Modified POFA	NaOH	Fe	- Water type: Peat water - Contact time: 120 minutes - POFA mass: 25 g - Adsorption efficiency: 44.50%	[28]

Silica-Modified POFA	KOH	Fe	- Water type: Peat water - Contact time: 210 minutes - POFA mass: 18.35 g - Adsorption efficiency: 98.65%	[29]
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**Adsorbent Composition**

The chemical composition of POFA before being applied in the adsorption process is shown in Table 2 by [30].

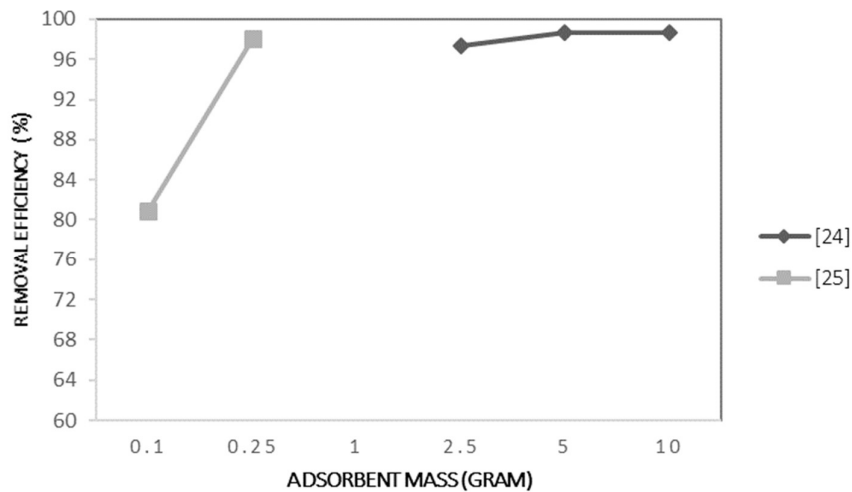
**Table 2.** POFA composition

Oxide	Percent (%)
SiO <sub>2</sub>	73.85
Na <sub>2</sub> O	0.07
K <sub>2</sub> O	2.78
CaO	0.61
MgO	0.64
Fe <sub>2</sub> O <sub>3</sub>	0.40
Cl	0.29

**3.1 Heavy metal adsorption by unmodified POFA**

One of the factors influencing the percentage of heavy metal adsorption is the mass of POFA used as an adsorbent. An

increase in the mass of POFA provides a larger available surface area for metal adsorption, resulting in a higher adsorption percentage. Figure 1 shows the link between the mass of unmodified POFA and the proportion of heavy metal adsorption.



**Figure 1.** Relationship between unmodified POFA mass (g) and removal efficiency (%)

From Figure 1, it is apparent that the percentage of heavy metal adsorption varies

with the mass of unmodified POFA used in both studies conducted by [24] and [25]. By

increasing the POFA mass from 0.1 g to 0.25 g in their experiments, [25] found that there was a marked increase in adsorption percentage from 80.93% to 98.03%. This suggested that within this range, adding the mass of POFA increased pores and active sites, thereby increasing the efficiency at which the POFA could adsorb heavy metal ions from the solution.

In the study conducted by [24], the adsorption efficiency was already quite high at a POFA mass of 2.5 g, achieving 97.30%, and it increased a little more to reach a peak of 98.65% at a POFA mass of 5 g. When the POFA mass was increased further up to 10 g, there was no considerable improvement in the

adsorption percentage. This indicates that the system had reached a point of adsorption equilibrium. It implies that once enough active sites are available for binding heavy metal ions, adding more POFA does not significantly enhance the adsorption efficiency.

### 3.2 Heavy metal adsorption by zeolite-modified POFA

For the analysis of the influence of the mass of zeolite-modified POFA on the adsorption efficiency of heavy metals in the adsorption process, an analysis of the relationship between the mass of zeolite-modified POFA and the adsorption percentage was conducted. The outcome of this analysis is represented in the figure 2 that follows.

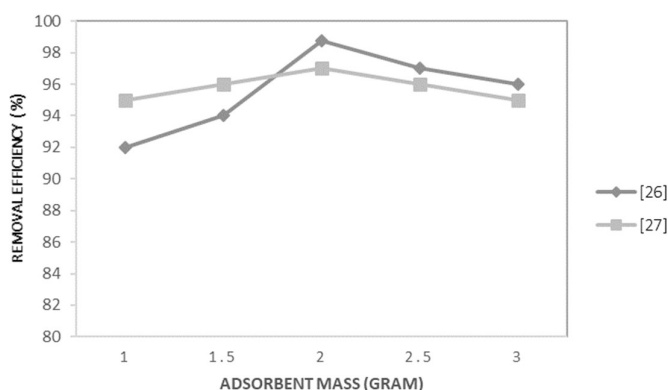


Figure 2. Relationship between zeolite-modified POFA mass (g) and removal efficiency (%)

Figure 2 shows the relationship between the mass of zeolite-treated POFA and the adsorption percentage of heavy metals in the water adsorption process based on two research studies from [26] and [27]. Generally speaking, the graph shows a similar pattern for both research studies, that is, the adsorption percentage increases along with the increase in the mass of the adsorbent until it reaches a point beyond which the adsorption percentage decreases when more adsorbent mass is added. This indicates that adsorption ability depends largely on the adsorbent mass used in relation to its pore and active site properties in the adsorption process.

The study carried out by [27] showed that the maximum percentage adsorption was

attained when the mass of the adsorbent was 2 g, with an efficiency of around 97%. In the study conducted by [26], it was seen that the maximum percentage adsorption was also attained when the mass of the adsorbent was 2 g, with a greater efficiency of around 98.77%. The similarity between the results indicates that a mass of 2 g is the most effective mass of the adsorbent to create a proper amount of pores and active surfaces for the adsorption of heavy metal ions from water.

The rise in the adsorption percentage with the increase in mass up to 2g can be ascribed to the rise in the number of pores as well as active surface sites on the adsorbent. As the mass of the adsorbent increases, a larger effective surface area is developed for the adsorption

reaction. Consequently, the efficiency of the adsorption increases. After the optimum mass is attained, the increase in the mass of the adsorbent causes a decrease in the adsorption percentage.

### 3.3 Heavy metal adsorption by silica-modified POFA

The quantity of POFA modified with silica used as an adsorbent during the adsorption process also affects active site availability and the surface area of POFA. Figure 3 illustrates the relationship between different masses of modified POFA with silica and variation in the percentage of heavy metals adsorbed during water treatment.

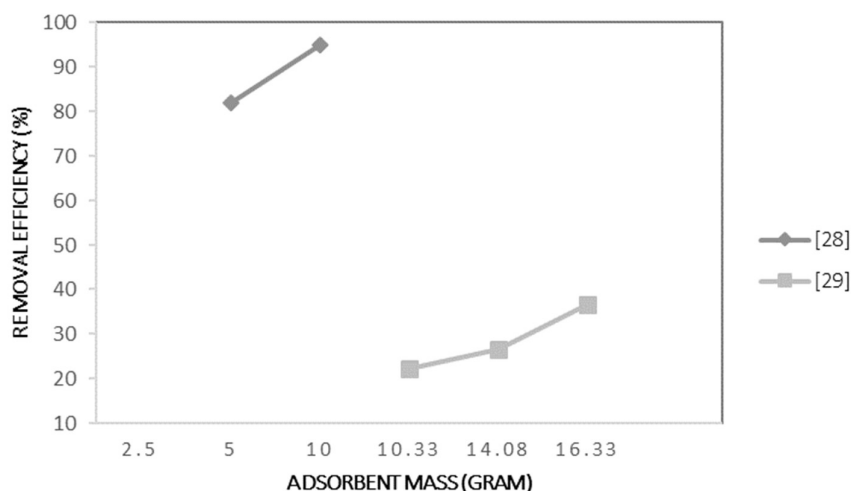


Figure 3. Relationship between silica-modified POFA mass (g) and removal efficiency (%)

Figure 3 illustrates that a higher mass of silica-modified POFA influenced the contaminant adsorption percentage in water for the two examined articles. In the article produced by [28], the greatest contaminant adsorption percentage of 95.00% was attained when the mass of POFA was 10 g. The major reason for the higher contaminant adsorption percentage at this mass was the higher number of pores and active sites on POFA as the mass of the adsorbent increased, because more contaminant molecules could easily bind to POFA molecules at higher masses of POFA. In addition, at this mass, there were adequate POFA molecules available for optimal interaction with the contaminant concentration within the solution.

On the other hand, in the study conducted by [29], the maximum adsorption percentage achieved was 36.50%, which was attained with the mass of POFA as 16.33 g. Even as the POFA mass was increased in the study, the low

efficiency attained indicates that the conditions for the adsorption process were not yet optimum. This might be due to limitations in the POFA with regard to its specific surface area or effective pore distributions, as well as the diffusion of contaminants within the POFA pores.

### 4. CONCLUSION

On performing a literature review of different studies, it can be stated that the type of activator and mass of the adsorbent Palm Oil Fuel Ash (POFA) play a significant role in the efficiency of the adsorption process. The common activators employed for POFA activation are  $\text{NH}_4\text{Cl}$ ,  $\text{HCl}$ ,  $\text{NaOH}$ , and  $\text{KOH}$  solutions. The outcome of the literature review shows that different activators are required for different modifications of POFA for optimal achievement of POFA. The performance of unmodified POFA can be optimized with activation with an  $\text{NH}_4\text{Cl}$  solution, optimum

activation for zeolite-modified POFA can be achieved with HCl activation, and activation with a NaOH solution provides optimal performance for the silica-modified POFA with maximum adsorption capacity.

Activation using  $\text{NH}_4\text{Cl}$  is more effective on unmodified POFA because  $\text{NH}_4\text{Cl}$  can increase the number of active sites and open the pores of the adsorbent moderately without damaging its natural mineral structure, so that the adsorption process takes place more optimally compared to HCl which is a strong acid and can dissolve some of the components of POFA. Meanwhile, on silica-modified POFA, NaOH is more effective than KOH because NaOH is able to dissolve amorphous silica and increase the formation of silanol groups (Si-OH) which function as active sites for adsorption, so that the surface area and adsorption capacity of the adsorbent become higher.

Besides the type of the activator used, the weight of the adsorbent material is also a major consideration that influences the adsorption phenomenon. The general trend suggests that higher amounts of POFA generate higher percentages of adsorption owing to the higher number of adsorption sites that attract metal ions. From the literature study, the optimized weight of the POFA adsorbent without modification was found to be 10 g for the removal of iron ions at a purity of 98.65%, while the optimized weight of the modified zeolite POFA adsorbent was found to be 2 g for the removal of zinc ions at a purity of 98.77%, and the optimized weight of the silica-modified POFA adsorbent was found to be 25 g for the removal of iron ions at a purity of 44.50%.

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#### CONFLICT OF INTEREST

The authors have not reported any possible conflicts of interest.

#### CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

All authors read and agree to the content of the finalized manuscript and are collectively, as the authors, responsible for the integrity of the work, as well as the accuracy of the work, as represented.

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