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Addressing the Environmental Concerns: Statistical Approach for Mg^{2+} and Mn^{2+} Mitigation in Water System Sustainability in Indonesia

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ABSTRACT: This research aimed to determine the most effective adsorbent for reducing Mg^{2+} and Mn^{2+} levels in residential water near the oil and gas industry in the Tambun area, Bekasi, Indonesia. Bentonite was tested with varying temperature conditions. The study further compared activated charcoal and bentonite as potential adsorbents, examining their efficacy under different contact times (10, 20, and 30 minutes). Thus, sampling followed the SNI 6989.57:2008 method for surface water sampling, with bentonite conditioning and activation as initial steps. Next, the adsorption experiments utilized a separating funnel, varying the contact time between adsorbent and sample. Hence, the filtrates were analyzed quantitatively for Mn2+ using atomic absorption spectroscopy and for Mg^{2+} through complexometric titration.

KEYWORDS: Adsorbent, Adsorption, Adsorption Process, Bentonite, Regression Analysis.

INTRODUCTION

Effective mitigation strategies are essential to ensure the safety and quality of residential water supplies. Thus, identifying the optimal adsorbent is paramount for successful water treatment initiatives in areas proximal to industrial operations. The Tambun region, located in Bekasi, Indonesia, serves as a pertinent case study due to its significant industrial presence and potential water contamination risks.(Elkhalek, 2022; Salikhanova and Usmonova, 2022)(Durán et al., 2019; Hamid et al., 2017a; Pawar et al., 2016)

Bentonite, a naturally occurring clay mineral known for its adsorption capabilities, was selected as a primary adsorbent in this study(Hamid et al., 2017b). The research aimed to evaluate its performance under different temperature conditions, considering the potential influence of temperature on adsorption efficiency. Additionally, activated charcoal, another commonly used adsorbent, was included for comparative analysis to assess its efficacy alongside bentonite in removing Mg2+ and Mn2+ from water samples.(Durán et al., 2019)

The study's experimental design involved introducing activated charcoal and bentonite into water samples collected from residential areas around the oil and gas industry in Tambun(Maulani et al., 2021; Prima et al., 2022, 2021, 2020; Samura et al., 2021; Wijayanti et al., 2021). Different contact times were tested to determine the optimal duration for adsorption processes. The research methodology adhered to standardized protocols for water sampling and analysis, ensuring reliability and comparability of results.

Through systematic experimentation and analysis, this research aims to contribute valuable insights into effective water treatment strategies for mitigating Mg2+ and Mn2+ contamination in residential areas near industrial sites. The findings hold significant implications for environmental management and public health, offering potential solutions to address water quality challenges in similar contexts worldwide.(Yu and Lin, 2016)

The compounds Mg^{2+} and Mn^{2+} are metal ion compounds commonly found in their salt forms ($MgSO_4$ and $MnSO_4$), in the form of their metal oxides (MgO and MnO), or as part of naturally occurring mineral compounds. Magnesium (Mg^{2+}) is a silvery-white metal that is insoluble in cold water (Kheibarian et al., 2022), while manganese (Mn^{2+}) is a white-grayish metal classified as a heavy metal (atomic mass = 54.94 g/mol)

Each of these metals undoubtedly has benefits for living organisms. For example, magnesium metal ions in the human body play a role in converting food nutrients into energy, and in the field of medicine, magnesium is used as an antacid for treating stomach acidity. On the other hand, manganese metal ions are useful as raw materials in textiles or printing due to their coloring properties. However, excessive utilization of these metals can lead to environmental damage and pose a threat to surrounding living organisms. An excess of Mg^{2+} ions (in its oxide form) can cause irritation to the eyes and nose and may result in flu-like symptoms (Hazardous

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Substance Fact Sheet, 2007). In contrast to Mg^{2+} ions, manganese compounds in low concentrations are highly toxic (Gomaa et al., 2017) and belong to the most dangerous environmental pollutants that can cause pneumonia.

An absorber is needed to reduce the levels of Mg^{2+} and Mn^{2+}, and three common types of absorbers found in the market are activated charcoal, bentonite, and zeolite. For this research, one type of absorber, namely bentonite, was chosen. Bentonite (clay) is a mineral that has the ability to exchange ions and is commonly used to bind sand in metal casting. The alkali metal ions (Na^{+}) on activated bentonite undergo ion exchange with Mg2+. Similarly, this research aims to test the ability of bentonite to absorb excess Mn^{2+} ions, considering that both ions have similar chemical and physical properties.

The samples used are water sources utilized by residents for daily purposes, collected in the Tambun area, Bekasi, as it is close to the oil and gas industry. The water samples undergo several filtration and absorption processes, followed by the analysis of Mg2+ and Mn2+ levels using complexometric titration and atomic absorption spectroscopy, respectively. The results from both methods are compared to determine which method has higher accuracy and precision, thereby ensuring representative and valid results.

OBJECTIVES OF THE STUDY

This research aimed to determine the most effective adsorbent for reducing Mg^{2+} and Mn^{2+} levels in residential water near the oil and gas industry in the Tambun area, Bekasi, Indonesia. The selection of adsorbents is crucial due to the potential health hazards posed by elevated concentrations of these metal ions in drinking water. Mg^{2+} and Mn^{2+} contamination in water sources can result from various industrial activities, including oil and gas exploration and production, which often release metal ions into nearby water bodies.

METHODOLOGY

The methodology for the study on reducing Mg^{2+} and Mn^{2+} levels in residential water near the oil and gas industry in the Tambun, Bekasi. Indonesia involves several key steps:(Ajenifuja et al., 2016)

Sampling: Water samples are collected from residential areas surrounding the oil and gas industry in the Tambun region of Bekasi, Indonesia. Sampling follows the SNI 6989.57: 2008 method for surface water sampling to ensure consistency and reliability. The following figure.1 explain the adsorption process.(Alexandre Poirier, Patrick Le Griel, Javier Perez, Daniel Hermida-Merino, Petra Pernot, 2022; Priprem and Wankao, 2015)

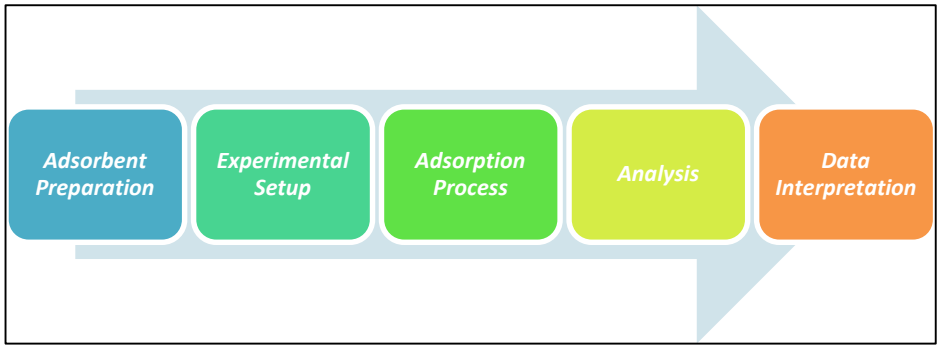

Figure 1. The Adsorption Process

1. ***Adsorbent Preparation***: Bentonite, chosen as the primary adsorbent, undergoes conditioning and activation processes to enhance its adsorption capacity. Activated charcoal, another adsorbent, is also prepared for comparative analysis.
2. ***Experimental Setup***: Different temperature variations are applied to the bentonite to assess the impact of temperature on its adsorption efficiency. The activated charcoal and bentonite are introduced into separate water samples with varying contact times (e.g., 10, 20, and 30 minutes).(Poirier et al., 2022)
3. ***Adsorption Process***: Adsorption experiments are conducted using a separating funnel to facilitate the interaction between the adsorbents and water samples. The contact time between the adsorbents and water is controlled to investigate the optimal duration for effective adsorption.(Gitari et al., 2019)

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4. ***Analysis***: After the adsorption process, the filtrate is collected and subjected to quantitative analysis. Mn^{2+} metal analysis is performed using atomic absorption spectroscopy, while Mg^{2+} metal analysis is conducted through complexometric titration.(Adibmehr and H Faghihian, 2018; Y. S. Guang et al., 2018; Nkele et al., 2022)
5. ***Data Interpretation***: The data collected from the analysis are interpreted to evaluate the efficacy of the adsorbents in reducing Mg2+ and Mn2+ levels in the water samples. Statistical analysis may be employed to compare the performance of bentonite and activated charcoal under different conditions.(Nie et al., 2021)

RESULTS AND DISCUSSIONS

The results of the study underscore the importance of considering the specific adsorption capacities of different materials when designing water treatment strategies for metal ion removal. While activated bentonite demonstrates effectiveness in reducing Mg^{2+} concentrations, its limited adsorption capacity for Mn2+ highlights the need for tailored approaches to address specific metal ion contaminants.(Y. Guang et al., 2018; Mohammad Hadi Dehghani, Sahar Afsari Sardari, Mojtaba Afsharnia, 2023; M. Shenashen et al., 2017; Shizong Wang, 2022)

The ion exchange mechanism of activated bentonite offers a promising avenue for Mg^{2+} removal, particularly in environments where high Mg2+ concentrations pose health and environmental risks. By replacing Na^{+} ions in the bentonite matrix with Mg^{2+} ions from the water solution, activated bentonite effectively reduces Mg^{2+} levels in water solutions.(Alexander et al., 2019a; Innowacje. and 2023, 2023; Mohammad Hadi Dehghani, Sahar Afsari Sardari, Mojtaba Afsharnia, 2023; M. A. Shenashen et al., 2017)

However, the ineffectiveness of activated bentonite in reducing Mn^{2+} concentrations underscore the complexity of metal ion removal processes. Mn2+ ions may exhibit different chemical properties and interactions with adsorbents compared to Mg^{2+} ions, necessitating alternative approaches for effective removal.(Alexander et al., 2019b; Durán et al., 2019; Kuncoro et al., 2018; Mohammad, S and Suzylawati, 2020; F. Nwosu et al., 2018; F. O. Nwosu et al., 2018)

Bentonite activation is carried out through a physical activation method. Bentonite is heated in a furnace at a temperature of 350°C for three hours, then cooled and weighed until a constant weight is achieved. The required weight of activated bentonite is approximately 100 grams, which will be used as an adsorbent.

Activated bentonite is stored in a desiccator to prevent moisture or other contaminants. For the analysis, 20 grams of physically activated bentonite is used for 100 ml of the water sample (the ratio of bentonite to water sample is 1:5). The setup for the adsorption process involves using an extraction flask containing a sterile cotton arrangement and 20 grams of activated bentonite, as shown in Figure 2.

Figure 2. Arrangement of the Adsorption Process

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Adsorption is carried out with varying contact times, namely 10, 20, and 30 minutes. For each research sample, a new adsorbent is used, replaced for each different sample. After adsorption, the resulting filtrate will be analyzed for Mn and Mg metals using complexometric titration and Atomic Absorption Spectrophotometry (AAS). Titrations and adsorption, along with their preparations, are conducted in the Fluid Reservoir Analysis Laboratory (AFR), while AAS is performed in the Environmental Engineering Laboratory of Trisakti University. Titration is conducted using Na2EDTA 0.1N. However, due to limitations in materials and time, titration is only performed to determine the Mg content. For the AAS method, due to equipment conditions, the analysis is conducted only for Mn content. The titration is carried out in a basic environment using a pH 10 buffer with the assistance of EBT indicator under warm conditions. The initial colour of the titration is wine red, and the titration is stopped when it turns blue, as shown in Figure 3.

(a) (b)

Figure 3. (a) Before Titration; (b) After Titration

Theoretically, the Mg content is expected to decrease with the increasing duration of contact with adsorption. This is substantiated by calculations obtained from the titration results presented in Table 1 below. The titration results indicate that with a longer contact time, there is a greater reduction in the Mg metal content. This is consistent with the explanation provided in the background of this experiment.

Table 1. The Results of Mg Metal Titration

Sample	Time	Content Mg (%)
Ground water	0	19,44
	10	17,04
	20	14,64
	30	12,24
Irrigation	0	18,84
	10	16,44
	20	15,00
	30	12,00

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Surface water/x	0	21,24
	10	16,44
	20	12,00
	30	11,64

* The Standardization Results of Na2EDTA Using Secondary Data

For the Mn metal content analyzed in the Environmental Engineering Laboratory of Universitas Trisakti, the results show the opposite trend. The Mn metal content obtained (mg/L) does not indicate a decrease in Mn metal. The data reveals an increase in Mn metal from the original sample. A plausible explanation for this occurrence could be the leakage of bentonite during filtration. The leaked bentonite is likely to have been drawn into the AAS, leading to its detection as an additional Mn metal by the detector, causing the Mn metal content to appear higher than it should or not significantly different from the original sample. Below are the Mn Metal levels obtained from the AAS readings in the Environmental Engineering Laboratory of Universitas Trisakti.

Table 2. The Results of Mn Metal Reading using AAS

Metal Mn		
Sample	Time	Content Mn (mg/L)
Ground water	0	0,3316
	10	5,564
	20	2,745
	30	6,628
Irrigation	0	2,277
	10	2,804
	20	3,501
	30	5,135
Surface water/x	0	0,708
	10	2,446
	20	3,079
	30	1,847

The experimental results clearly demonstrate that activated bentonite effectively lowers the concentration of Mg+ ions in the solution. This reduction is directly linked to the ion exchange process, where Mg2+ ions are swapped with Na+ ions present in the bentonite matrix.

Our findings reveal that activated bentonite exhibits remarkable efficacy in reducing the concentration of Mg+ ions. This phenomenon arises from the exchange of ions, specifically Mg2+, facilitated by the Na+ ions naturally occurring in the bentonite material.

The data obtained from our study unequivocally supports the role of activated bentonite in mitigating the concentration of Mg+ ions. This reduction is attributed to the ion exchange mechanism, wherein Mg2+ ions interact with Na+ ions within the bentonite lattice.

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From the obtained data, activated bentonite is effective in reducing the concentration of Mg+ in the solution, reflecting the ability of bentonite to exchange ions with Mg2+ due to the presence of Na+ ions in bentonite. In the adsorption activity of Mg2+ ions, there is a significant decrease in concentration, as illustrated in Figure 4.

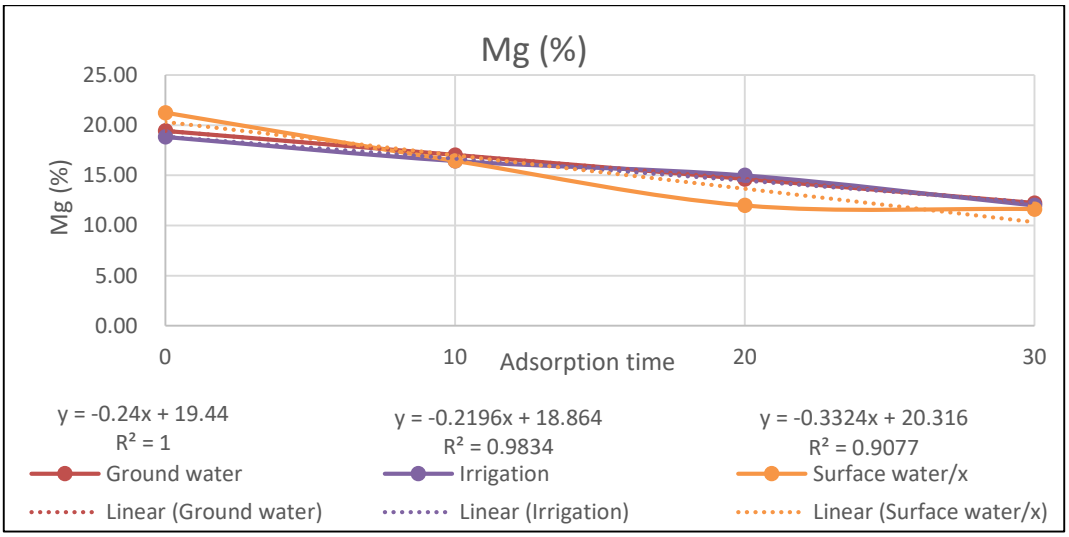

Figure 4. The Graph of Decrease in Mg Content

From the graph showing the reduction in the concentration of Mg^{2+} metal ions in well water, rice field water, and lake/river water samples, the regression approaches almost 1.00. This indicates that activated bentonite is successful in reducing the concentration of Mg2+ metal ions by cation exchange (Na+ in bentonite) with Mg^{2+} ions in the water samples. However, for the lake/river water sample, the regression does not quite meet the criteria (1>r>0.98), which could be caused by the leakage of bentonite during the adsorption process at the 30-minute mark, resulting in a reduced amount of active bentonite in contact with the sample. Nevertheless, considering the amount of Mg^{2+} ions obtained before adsorption, a decrease still occurs, indicating that activated bentonite is capable of reducing the concentration of Mg^{2+} metal ions in water samples. As for Mn metal, bentonite does not show signs of the ability to adsorb Mn metal, as shown in Figure 5.

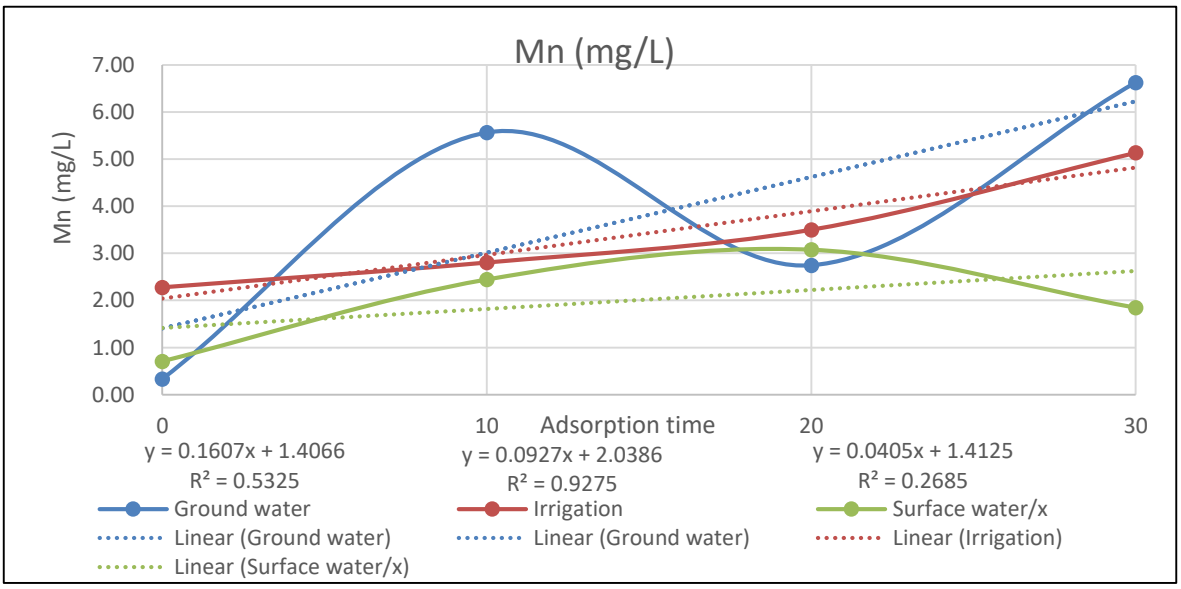

Figure 5. The Graph of Changes in Mn Metal Content

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The regression analysis conducted for each sample concerning Mn^{2+} metal ions reveal a correlation coefficient (r) of less than 0.98. A suboptimal regression outcome suggests that the concentration of Mn^{2+} metal ions either remains constant or increases. This phenomenon may arise due to the activated bentonite's limited capacity to adsorb Mn^{2+} metal ions, resulting in no discernible reduction in their concentration post-adsorption, unlike the behavior observed with Mg^{2+} metal ions. Our data further indicates an increase in the concentration of Mn^{2+} metal ions, which could potentially be attributed to bentonite leakage during the adsorption process. Such leakage might introduce errors in instrument readings, impacting the accuracy of our measurements.

CONCLUSION

In conclusion, the research findings demonstrate that activated bentonite effectively reduces the concentration of Mg^{2+} metal ions in water solutions. This efficacy can be attributed to activated bentonite's ion exchange capability, whereby Na^{+} ions in the bentonite are replaced by Mg^{2+} ions from the water solution. However, it is evident that activated bentonite is less effective in reducing the concentration of Mn^{2+} metal ions in water solutions. This inefficacy stems from the limited capacity of activated bentonite to adsorb Mn^{2+} metal ions. These conclusions highlight the importance of considering the specific adsorption capacities of different materials when designing water treatment strategies aimed at reducing metal ion concentrations. Further research may explore alternative adsorbents or modification techniques to enhance the effectiveness of activated bentonite for Mn^{2+} removal in water solutions.

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