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Optimization of Density Variation and Contact Time Using Zeolite to Reduce Iron (Fe) Metal Content of Dug Well Water in Air Molek Indragiri Hulu

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Abstract: The limited capacity of the Regional Drinking Water Company (PDAM) to provide clean water has led many communities to rely on groundwater sources, particularly dug wells, for daily use. However, such water sources are prone to contamination by heavy metals. A preliminary analysis using Atomic Absorption Spectrophotometry (AAS) of a dug well in Air Molek, Indragiri Hulu Regency, revealed an iron (Fe) concentration of 1.029 mg/L, exceeding the acceptable limit for clean water. Prolonged use of water with high Fe content poses significant health risks, including gastrointestinal and skin disorders. This study aims to assess the effectiveness of zeolite synthesized from rice husk ash and coal ash in reducing Fe concentrations in well water. An experimental method was employed, in which 1 liter of contaminated water was treated with varying zeolite dosages (1 g, 2 g, and 3 g) and contact times (30, 60, 90, and 120 minutes). The treated water samples were analyzed using AAS to determine the remaining Fe levels. The results demonstrated that the optimal Fe removal was achieved with a zeolite dosage of 2 g/L and a contact time of 60 minutes, indicating the potential of modified zeolite as an effective adsorbent for improving groundwater quality.

Keywords: Atomic Absorption Spectrophotometry, Zeolite, iron metal.

1. Introduction

The increase in population has an impact on the increasing demand for various resources, including the need for clean water. Water sources can come from surface water such as rivers, lakes, rain, sea, and groundwater such as springs and wells [1]. If surface water is not available, groundwater becomes an alternative although it only stores less than 1% of the total water on

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earth [2]. As a universal solvent, water plays an important role in supporting the life of living things [3], and supports almost all human activities, from domestic needs to food production [4].

The increasing demand for clean water demands the provision of water with adequate quantity, safe quality, and free from contamination [5]. However, according to the World Health Organization in 2015, 663 million people still lack access to clean water, and UNESCO predicts that by 2025, nearly two-thirds of the world's population will live in water-stressed areas. In Indonesia, the National Planning and Development Agency (BAPPENAS) estimates that a clean water crisis will occur due to population growth that is not proportional to water availability [6].

Clean water that is suitable for consumption must meet physical, chemical, biological, and radioactive parameters [7]. According to the Regulation of the Minister of Health of the Republic of Indonesia Number 2 of 2023 concerning Standardized Environmental Health Quality, clean water must be odorless, tasteless, and colorless [8]. The quality standard for heavy metals according to PERMENKES NO.2 of 2023 is 0.2 mg/L for Fe and 0.1 mg/L for Mn [8]. In Indonesia, clean water services such as PDAM (Regional Drinking Water Company) have not fully met the needs of the community, especially in rural areas. In Air Molek, Pasir Penyu sub-district, Indragiri Hulu Regency, most people still rely on groundwater sources through dug wells.

Dug wells have great potential as a source of clean water, but are also vulnerable to contamination, especially if their construction does not meet standards [9]. The condition of well water in the Air Molek area is generally brown, smelly, oily, and often contains heavy metals such as iron (Fe) and manganese (Mn) [10]. Exposure to heavy metals has adverse effects on human health, including nerve damage, kidney and developmental disorders, and can threaten ecosystem balance [11]. Iron content in groundwater exceeding 1 mg/L can cause changes in water color to reddish and bad taste. Therefore, water treatment with filtration technology using materials such as zeolites is an effective solution [12]. Zeolite is a porous mineral that can adsorb heavy metals, and can be synthesized from waste materials such as rice husk ash and coal ash which are rich in silica (SiO_2) and alumina (Al_2O_3) [13]. Rice husks are one of the by-products of the rice milling process that are available in abundance. The utilization of rice husks is still limited to efforts to increase their economic value and reduce their negative impact as waste. Rice husk ash has a very high silica content, around 85–98% [14]. Rice husk ash can be used as a raw material for the production of zeolite using the hydrothermal method. The silica content in rice husk ash reaches 88.92%, making it a potential material for zeolite synthesis [15]. Coal is one of the world's primary energy sources, contributing approximately 23% of global energy. The use of coal as fuel produces solid waste in the form of ash, which contains silica (SiO_2) and alumina (Al_2O_3) at levels exceeding 85%, making it a potential raw material for zeolite production, replacing conventional materials such as sodium silicate and aluminate [16]. Zeolite is a porous material with a wide range of applications due to its ability for ion exchange, adsorption, and as a catalyst. Zeolite is a crystalline silicate material with a regular structure and high porosity. The process of producing synthetic zeolite involves several stages, namely the production of sodium silicate and sodium aluminate. Sodium silicate is obtained through the reaction of rice husk ash and coal ash with NaOH solution. Meanwhile, sodium aluminate is produced from the reaction between NaOH and Al_2O_3 [17].

Based on the results of testing using Atomic Absorption Spectrophotometry (SSA) in Air Molek, it was found that the Fe content in the well water reached 1.029 mg/L, exceeding the threshold set by Permenkes No. 2 of 2023, which is 0.2 mg/L. Meanwhile, the Mn content was not detected (-0.078 mg/L). Consumption of water with high Fe content risks causing digestive disorders and skin diseases [18]. The problem to be studied is the optimization of zeolite mass variations derived from rice husk ash and coal ash on the amount of fe metal reduction in dug well water in Air Molek, Indragiri Hulu district. Researching the optimization of zeolite contact time to improve the quality of dug well water to meet clean water quality standards.

2. Materials and Method

This study employed an experimental design to evaluate the effect of zeolite as a catalyst in reducing iron (Fe) concentrations in dug well water. The research was conducted from November 2024 to January 2025, with water sampling carried out in Air Molek, Indragiri Hulu Regency, and laboratory testing conducted at the LLDIKTI Region X Laboratory in Padang using an Atomic Absorption Spectrophotometer (AAS).

The independent variables in this study were zeolite mass (1 g/L, 2 g/L, and 3 g/L) and contact time (30, 60, 90, and 120 minutes). The dependent variable was the concentration of Fe in the water samples, while the controlled variables included the source of the water and the type of zeolite used. Zeolite synthesis involved the production of sodium silicate from rice husk ash and coal ash, and sodium aluminate from Al_2O_3. The rice husk ash was thoroughly washed with distilled water both before and after the combustion process to ensure material purity. The use of distilled water for both dissolution and washing highlights the importance of maintaining high purity levels during synthesis [18].

A total of 12 water samples were prepared by treating 1 liter of dug well water with varying zeolite dosages and contact times. After the designated contact time, samples were acidified with HNO_3, heated, and diluted prior to analysis. The Fe concentration in each sample was measured using AAS, and values were determined based on the calibration curve derived from standard solutions. The metal concentration was calculated using the following linear equation:

$$Abs = b \cdot x + a$$

where *Abs* is the absorbance of the sample, *b* is the slope (gradient), *a* is the intercept of the calibration curve, and *x* is the metal concentration. The efficiency of iron adsorption was calculated using the following formula:

$$Efisiensi\ Adsorpsi\ (\%) = \frac{C_0 - C_1}{C_0} \times 100\%$$

where C_0 represents the initial Fe concentration and C_1 is the Fe concentration after treatment.

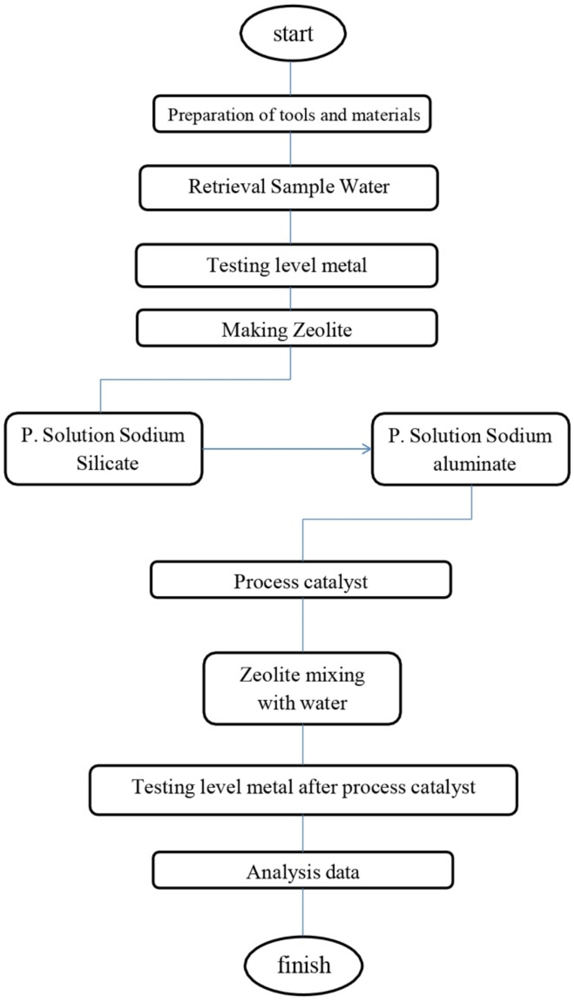
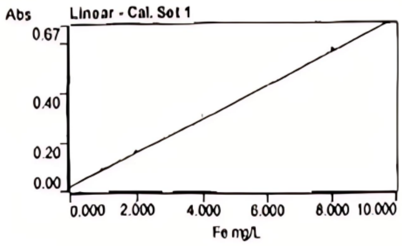


Figure 1. Flowchart of Research Procedure.

3. Results and Discussion

This study aims to determine the levels of Fe and Mn metals in dug well water before and after treatment using zeolite. Initial analysis using the Atomic Absorption Spectroscopy (AAS) method showed that the Fe metal level was 1.029 mg/L, while Mn was - 0.078 mg/L. This Fe level far exceeds the quality standard set in Permenkes RI No. 2 Year 2023, which is 0.2 mg/L, while Mn metal was not detected and is still within safe limits. This shows that the well water has the potential to endanger health if consumed without further treatment, so an effective method is needed to reduce Fe metal levels, one of which is through adsorption using zeolite. After testing Fe metal in the sample before contacting with zeolite. The following results were obtained:

SpectrAA Report.	3:47 PM 1/6/2025		Pago 2 of 2
	0.0001	0.0001	0.0000
STANDARD 1	2.000	0.4	0.1558
	Readings		
	0.1551	0.1565	0.1559
STANDARD 2	4.000	0.3	0.3008
	Readings		
	0.3011	0.2999	0.3014
STANDARD 3	6.000	0.4	0.4342
	Readings		
	0.4322	0.4354	0.4350
STANDARD 4	8.000	0.4	0.5601
	Readings		
	0.5589	0.5586	0.5628
STANDARD 5	10.000	0.5	0.6689
	Readings		
	0.6715	0.6698	0.6656



Curve Fit = Linear
Characteristic Conc = -0.207 mg/L
r = 0.9982
Calculated Conc = -0.272 2.053 4.216 6.207 8.086 9.710
Residuals = 0.272 -0.053 -0.216 -0.207 -0.086 0.290

Abs = 0.06701 x C + 0.01323

Air Sumur	1.029m	0.4	0.0872
	Readings		
	0.0877	0.0870	0.0871

Figure 2. Fe metal test results in dug well water

After testing for Mn metal in the sample before contact with zeolite. The following results were obtained :

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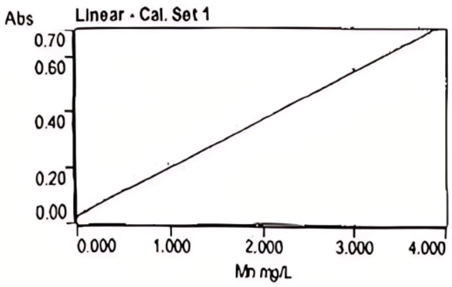
	-0.0005	-0.0011	0.0002
STANDARD 1	0.500	0.4	0.1117
	Readings		
	0.1115	0.1122	0.1114
STANDARD 2	1.000	0.3	0.2074
	Readings		
	0.2068	0.2081	0.2071
STANDARD 3	2.000	0.9	0.3887
	Readings		
	0.3872	0.3863	0.3927
STANDARD 4	3.000	0.5	0.5483
	Readings		
	0.5453	0.5502	0.5496
STANDARD 5	4.000	0.5	0.6957
	Readings		
	0.6952	0.6925	0.6995



Curve Fit = Linear
Characteristic Conc = -0.105 mg/L
r = 0.9979
Calculated Conc = -0.133 0.515 1.068 2.117 3 040 3.892
Residuals = 0.133 -0.015 -0.068 -0.117 -0 040 0.108

Abs = 0.17295 x C + 0.02257

Air Sumur	-0.078m	13.4	0.0090
	Readings		
	0.0095	0.0077	0.0100

Figure 3. Mn metal test results in dug well water

From the test results above, it can be seen that Mn metal was not detected in the samples, while the Fe metal content contained in the samples was very high and did not meet the clean water quality standards. The Fe standard calibration curve shows a strong linear relationship with the regression equation $y = 0.067x + 0.0182$ and a correlation value of $R = 0.9982$.

Table 1. Test results of metal content before contact with zeolite

No.	Metal levels in well water	Quality standard (maximum level) Permenkes RI No.2, 2023
1	1.029 mg/L	0.2 mg/L
2	-0.078 mg/L	0.1 mg/L

The Zeolites used in this study are natural zeolites made from rice husks and coal. The test results of Fe content after the adsorption process showed that the greater the mass of zeolite and the longer the contact time, the Fe concentration in dug well water decreased.

Table 2. Fe test results in well water after contact with zeolite

No.	Zeolite mass/ liter	Contact time			
		30 minutes	60 minutes	90 minutes	120 minutes
1	1 gram/L	0.774 mg/L	0.626 mg/L	0.298 mg/L	-0.054 mg/L
2	2 grams/L	0.687 mg/L	-0.046 mg/L	-0.071 mg/L	-0.015 mg/L
3	3 grams/L	0.676 mg/L	0.566 mg/L	0.098 mg/L	-0.579 mg/L

After the well water was contacted with zeolite, it was found that the Fe concentration decreased significantly as the contact time increased and the mass of zeolite increased. The Fe metal level before contacting with zeolite was 1.029 mg/L. The following is a graph of Fe metal testing in well water that has been contacted with zeolite.

Graph of zeolite mass 1 gram/liter

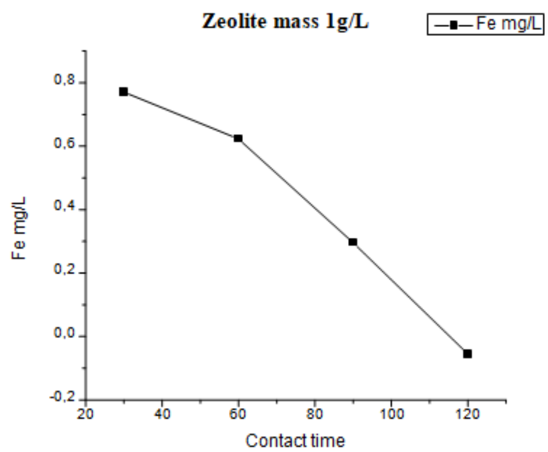


Figure 4. Graph of test results with zeolite mass 1g/L

In the use of 1 gram of zeolite, the test results show that if the longer the contact time between zeolite and water, the lower the remaining Fe concentration. At 30 minutes, the Fe concentration was still quite high at 0.774 mg/L. As the contact time increased, the Fe concentration continued to decrease until it reached -0.054 mg/L at 120 minutes contact time.

This shows that the adsorption process was effective, with the zeolite being able to adsorb all the Fe ions present in the solution within 120 minutes. At 120 minutes contact time, the AAS reading showed a negative value (-0.054 mg/L). This does not mean that there is a negative Fe metal concentration in the sample, the negative value detected by the AAS is interpreted as a metal level that is below the detection limit of the device.

To calculate the efficiency of reducing Fe levels can be calculated using the formula:

$$Efisiensi\ Adsorpsi\ (\%) = \frac{0{,}774-0}{0} \times 100\% = 100 \quad \ldots\ldots\ldots\ldots(1)$$

This shows that the zeolite successfully removed the entire Fe content in the dug well water after 120 minutes of immersion. At 2 g/L immersion in the sample, the most significant results were obtained, where at 60 minutes all the fe metals in the sample were gone.

Graph of zeolite mass 2 gram/liter

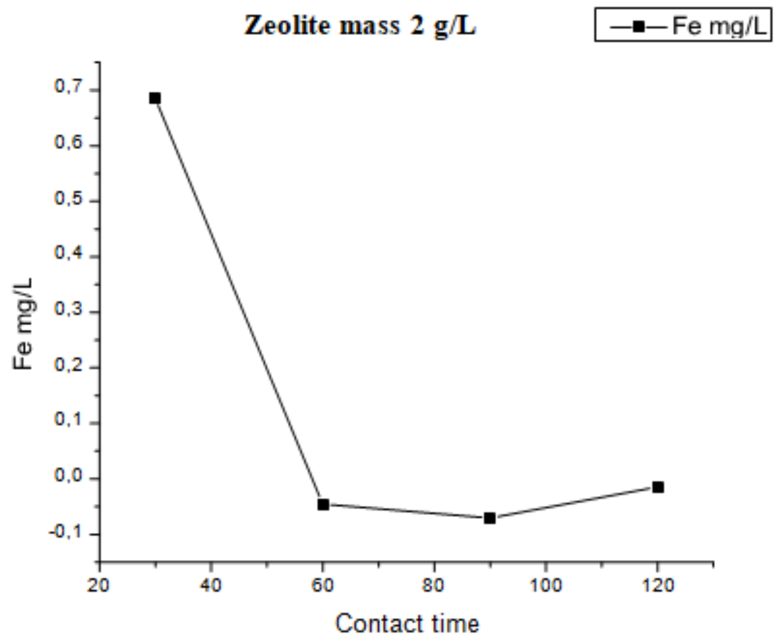


Figure 5. Graph of test results with zeolite mass 2g/L

At the use of 2 grams of zeolite the results show that at 30 minutes the Fe concentration is still detected at 0.687 mg/L, indicating that in a short time, the adsorption process has not reached its maximum capacity and is still ongoing. At 60 - 120 minutes, the drastic decrease in Fe concentration to undetectable shows that zeolite with a dose of 2 grams/L is very effective in removing Fe ions from water within 60 minutes. After 60 minutes, the adsorption process reached saturation point, where almost all Fe ions in the solution have been adsorbed by zeolite

To calculate the efficiency of reducing Fe levels can be calculated using the formula:

$$Efisiensi\ Adsorpsi(\%) = \frac{0{,}687-0}{0} \times 100\% = 100\% \ldots\ldots\ldots(2)$$

This shows that the zeolite successfully removed the entire Fe content within 60 minutes.

In the immersion of zeolite with a concentration of 3 g/L in the sample, the results obtained again increased compared to the concentration of 2 g/L. This is due to the saturation of the zeolite due to the amount of zeolite that is too much mixed into the water.

Graph of zeolite mass 3 gram/liter

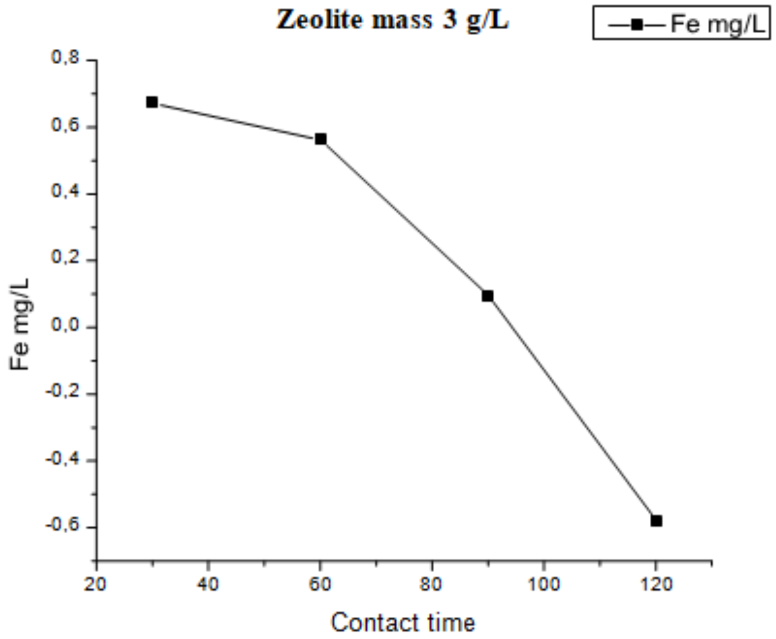


Figure 6. Graph of test results with zeolite mass 2g/L

The use of 3 grams of zeolite results show that at 30 minutes the Fe concentration is still detected at 0.676 mg/L, indicating that the adsorption process has not reached its maximum capacity. At 60 minutes the decrease in concentration to 0.566 mg/L indicates that the adsorption process takes place gradually**.** 90 min A significant decrease to 0.098 mg/L indicates that most of the Fe ions have been adsorbed. 120 min The negative value (-0.579 mg/L) indicates that almost all Fe ions have been adsorbed, and the AAS device detects concentrations below the detection limit

To calculate the efficiency of reducing Fe levels can be calculated using the formula:

- At 90 minutes

$$Efisiensi\ Adsorpsi(\%) = \frac{0{,}676-0{,}098}{0{,}676} \times 100\% = 85{,}5\% \text{......(3)}$$

- At 120 minutes

$$Efisiensi\ Adsorpsi(\%) = \frac{0{,}676-0}{0} \times 100\% = 100\% \text{...........(4)}$$

This shows that the zeolite successfully removed almost all of the Fe metal content in the well water within 90 minutes and successfully removed all of the Fe metal content within 120 minutes. Based on the results of the Fe reduction test, the use of zeolites from rice husk ash and coal ash proved optimal for reducing Fe metal levels in dug well water [13]. The optimal use of zeolite is at a concentration of 2 g/L with a contact time of 60 minutes. This result is consistent with previous research[15].

4. Conclusion

Zeolites from rice husk ash and coal ash proved effective as adsorbents in reducing Fe metal content in dug well water. If the mass of zeolite and contact time increases, the Fe metal content decreases. The most optimal mass and time variation is 2g/L in 60 minutes. Where at a mass of 2g/L almost all metals are exhausted or undetectable and within 60 minutes it meets the quality standards of clean water.

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