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The Journal of Community Based Environmental Engineering and Management is a journal that focuses on the results of studies or research related to various technologies and community-based environmental management. The scope of technology and environmental management that can be assessed include:

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3. Management and treatment of domestic wastewater
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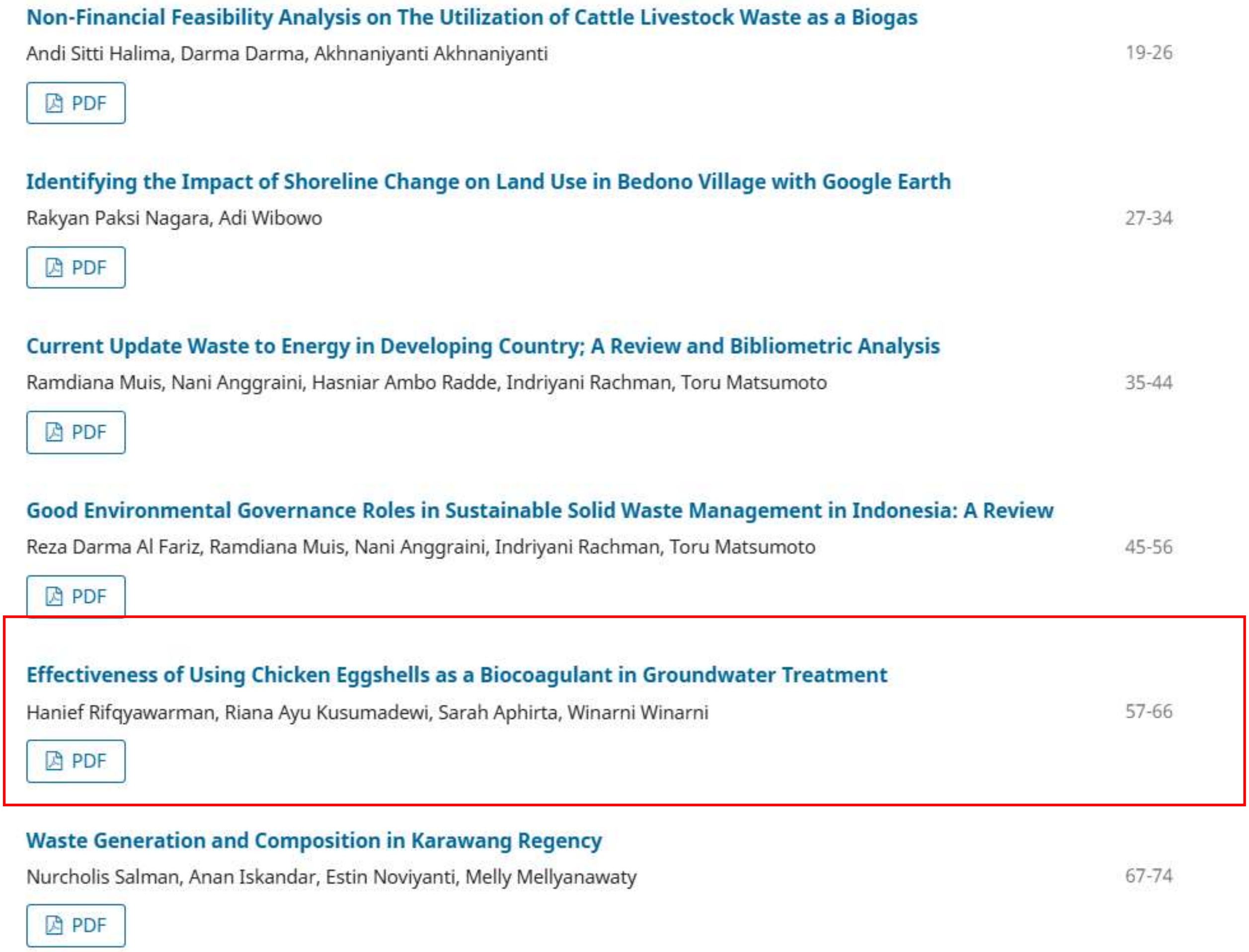

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EFFECTIVENESS OF USING CHICKEN EGGSHELLS AS A BIOCOAGULANT IN GROUNDWATER TREATMENT

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Abstract

The groundwater in Kota Bambu Selatan, West Jakarta, has high levels of turbidity and TDS. Therefore, it is necessary to be treated in order to comply with the regulations outlined in the Minister of Health of the Republic of Indonesia Number 2 of 2023 concerning Environmental Health standards. This study aims to investigate the effectiveness chicken eggshells as a biocoagulant for treating this groundwater. The techniques employed encompassed coagulation and flocculation, involving different coagulation G.td values (17,000, 34,000, 48,000, and 96,000) and a range of biocoagulant doses (100-500 mg/L). The outcomes of the treatment revealed that the utilization of chicken eggshells as a biocoagulant led to the removal of 47.14% of TDS and 97.17% of turbidity. The cost associated with implementing chicken eggshells as a biocoagulant amounted to IDR 230.70 per liter. In light of these findings, it can be deduced that chicken eggshells serve as an effective biocoagulant for reducing TDS and turbidity in the groundwater treatment.

Keywords: *biocoagulant, chicken eggshells, groundwater, Kota Bambu Selatan, treatment*

Introduction

Groundwater, one of the water sources essential for meeting human requirements (Santosa et al., 2014), exhibits inadequate quality within Jakarta City. The majority of groundwater from open and confined aquifers fails to adhere to drinking water standards (Prasetya et al., 2021). In the densely populated urban zone of Kota Bambu Selatan in West Jakarta, roughly 85% of inhabitants rely on groundwater as their primary water source. However, findings from observations indicate that the groundwater utilized by residents demonstrates high levels of Total Dissolved Solids (TDS) and turbidity.

The suitable techniques for addressing TDS and turbidity involve coagulation and flocculation, both of which are physical and chemical approaches (Hendrawati et al., 2013). Coagulation entails rapid–mixing to uniformly distribute coagulant in the basin, causing colloidal particles and suspended solids to lose stability (Reynolds et al., 1996). Meanwhile, flocculation refers to the slow mixing that agglomerates the destabilized particles, hastening the merging of particles to form larger ones. These larger particles can then be removed in the sedimentation unit (Kawamura, 1991).

Nowadays, numerous research endeavors have focused on the utilization of natural substances like biocoagulants. These substances are chosen due to their eco-friendly, cost-effective, and biodegradable characteristics. Among these natural resources, chicken eggshells stand out as a plentiful option for a biocoagulant, albeit their

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potential remains largely untapped. Chicken eggshells are constituted by a majority of calcium carbonate (94%), calcium phosphate (1%) and magnesium carbonate along with some organic components and water (Nguyen, 2022). Generally, plant seed-derived or chicken eggshell-derived coagulants exhibit a cationic nature, enabling them to counteract anionic particles or colloids present in raw water that carry a negative charge. (Lucio, D.S. Villareal et al., 2018). This interaction facilitates the optimal formation of flocs. Notably, in the case of the biocoagulant derived from chicken eggshells, it exhibited impressive efficacy in treating liquid waste from the pharmaceutical industry, achieving an 81.18% reduction in turbidity and a 24.3% reduction in TDS (total dissolved solids) (Hanifah et al., 2020). Hence, this research intends to further assess the effectiveness of chicken eggshells as a biocoagulant in groundwater treatment.

Research Methodology

Raw water

This study utilized groundwater taken from an elevated reservoir located within a sanitation facility in Kota Bambu Selatan, West Jakarta. The TDS and turbidity were 350 mg/L and 70 NTU, respectively, surpassing the criteria set by the Minister of Health of the Republic of Indonesia in regulation number 2/2023, which stipulates TDS should be below 300 mg/L and turbidity should be below 3 NTU.

Activation of Chicken Eggshells as a Biocoagulant

The chicken eggshells were initially cleaned and immersed in hot water for approximately 15 minutes. Afterward, they were dried at a temperature of 105ºC for 30 minutes. These dried eggshells were then ground into a fine powder. Furthermore, the powdered eggshells were sifted using 50, 100, and 150 mesh sieves, with each portion stored in a desiccator. To prepare the solution, 10 grams of biocoagulant powder were combined with 1000 mL of a 1% acetic acid (CH_3COOH) solution. The mixture was stirred at 200 rpm for 9 hours until all the chicken eggshell powder had dissolved (Hanifah et al., 2020).

Research Procedure

The study was performed using a small-scale batch of jar tests in a laboratory setting, simulating the processes of rapid mixing, flocculation, and settling. A standard jar-test device with a mechanical stirrer featuring six paddles was utilized at room temperature. The jar-test device was 650 mm in length, 300 mm in width, and 360 mm in height, while the stirrer's speed ranged from 20 to 220 rpm.

Firstly, 500 mL of untreated water was poured into individual 1 L beakers. The sample was swiftly agitated, and chicken eggshell biocoagulant was introduced simultaneously within a dosage range of 100, 200, 300, 400, and 500 mg/L. This rapid mixing was accomplished using different agitation rates: 17,000, 34,000, 48,000, and 96,000 G.td, corresponding to stirring at 100 rpm for 1 minute, 100 rpm for 2 minutes, 200 rpm for 1 minute, and 200 rpm for 2 minutes, respectively. This was followed by a flocculation at a G.td of 28,000, involving 18 minutes of gentle mixing at 20 rpm. Comparable tests were conducted without adding the coagulant for control purposes. Once a settling period of 30 minutes had been achieved, the clear liquid above the sediment was cautiously extracted.

The raw water and supernatant were subjected to TDS and turbidity measurement using a TDS meter and a turbidimeter. Figure 1 displays the flowchart of the research process.

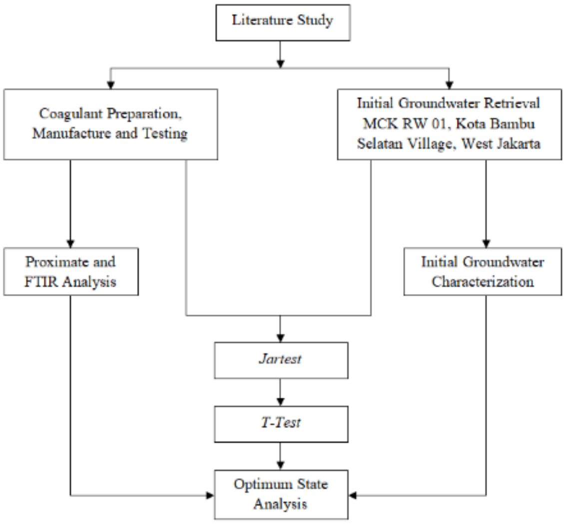


Figure 1. Flowchart of the research process.

Mathematical Formulations

A logical method for assessing the mixing process and designing basins in coagulation and flocculation involves the velocity gradient (G) and detention time (td). The formula for calculating the velocity gradient in mechanical stirring can be derived from Eq. (1), (2), and (3) as outlined in reference (Qasim et al., 2000).

$$P = N_p \times n^3 \times {D_i}^5 \times \rho \qquad (1)$$

$$G = \left(\frac{P}{\mu \times V}\right)^{1/2} \qquad (2)$$

$$n = \left(\frac{G^2 \times \mu \times V}{N_p \times {D_i}^5 \times \rho}\right)^{1/3} \qquad (3)$$

Where P is power that imparted to the water (Watt), Np is power constant, n is mixing speed (rotation per second, rps), D_i is stirrer diameter (m), ρ is density of water (kg/m^3), G is velocity gradient (sec^{-1}), μ is viscosity of water ($N.s/m^2$), and V is volume of water (m^3).

The effectiveness of chicken eggshells biocoagulant in diminishing groundwater contaminants was assessed by calculating the removal efficiency using Eq. (4) as follows (Sanjaya & Agustine, 2015).

$$\eta = \frac{C_0 - C_e}{C_0} \; 100\% \qquad (4)$$

Where η is removal efficiency (%), C_0 is initial concentration and C_e is final concentration.

Results and Discussion

Measurement of $CaCO_3$ Levels and FTIR Analysis on Chicken Eggshells

An examination of the calcium carbonate content of chicken eggshells revealed that they contained 92.6% calcium carbonate, exceeding the minimum requirement of 90.9% as specified in reference (Warsy et al., 2016). Concurrently, the Fourier Transform Infrared (FTIR) analysis showed dual signs of the presence of $CaCO_3$. The initial indication is marked by the occurrence of OH, CO, CH, and CaO functional groups, observable in the spectral regions of 4,000–2,100 cm^{-1} and 1,900 cm^{-1}. The second indication involves the CO functional group, evident in the 2,000–1,500 cm^{-1} range (Ulfa et al., 2019). The outcome of the FTIR analysis is depicted in Figure 2.

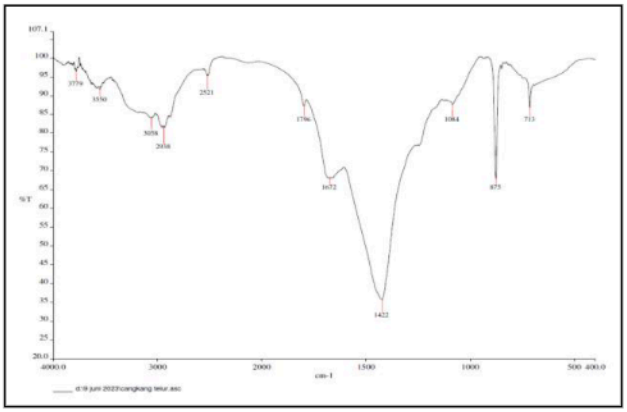


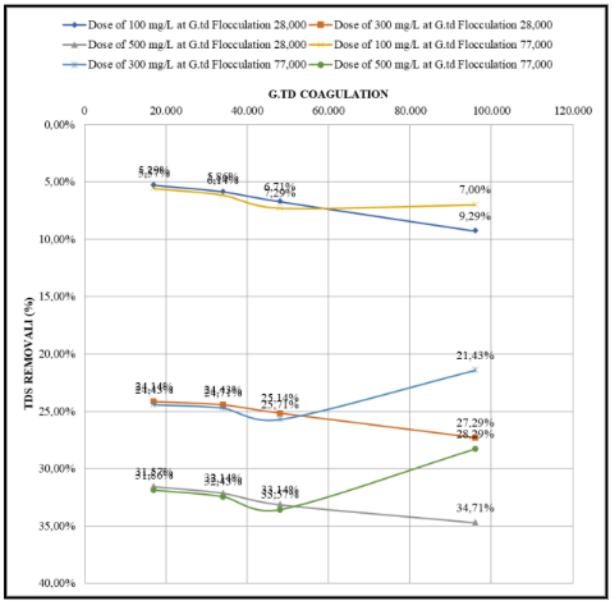
Figure 2. FTIR analysis of chicken eggshells

The FTIR test results indicate the existence of two functional groups within the 2,000–1,500 cm^{-1} range, recognizable by a distinct steep descent. These groups are specifically located at 1,796 cm^{-1} and 1,672 cm^{-1}. Consequently, the identification of these functional groups within the absorption range suggests the presence of calcium carbonate ($CaCO_3$) in the chicken eggshell, which holds potential as a biocoagulant.

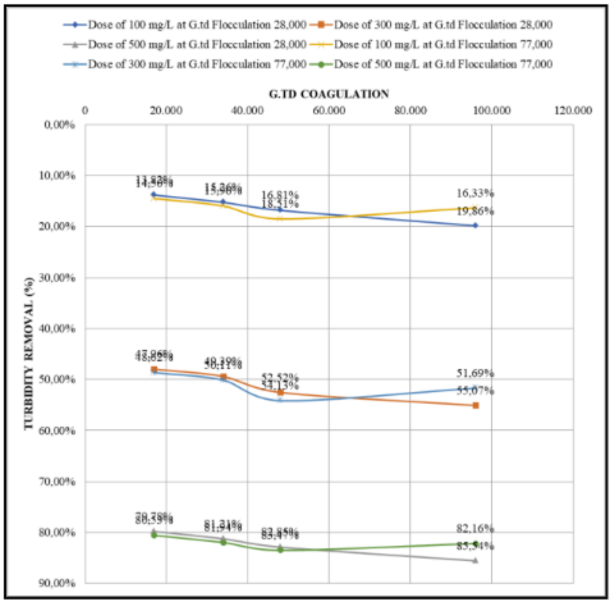
Coagulation Using Chicken Eggshells Biocoagulant on 50-Mesh Size

Figure 3.a and 3.b illustrate the outcomes of TDS and turbidity removal employing 50-mesh chicken egg shells. Based on Figure 3, it can be inferred that the biocoagulant derived from chicken eggshells effectively reduced TDS and turbidity. This efficacy can be attributed to the substantial calcium carbonate ($CaCO_3$) content of 92.6% within chicken eggshells. This composition has been demonstrated to counteract the TDS and turbidity attributes in untreated water due to the presence of cations capable of neutralizing negatively charged colloidal particles within the untreated water. As a result, these particles can combine and form aggregates optimally. (Puteri et al., 2020).

The targeted level of turbidity removal is established based on the capability of the groundwater filter located in Kota Bambu Selatan Village, which aims to achieve a range of 15-20 NTU. However, in the pursuit of attaining optimal outcomes, it's insufficient to solely pursue higher results, as the consideration of operational costs efficiency is equally crucial.



(a)



(b)

Figure 3. Removal efficiency using 50 mesh chicken egg shells at flocculation G.td 28,000 and 77,000 for (a) TDS and (b) turbidity.

When faced with a variation that yields higher results yet still meets quality standards, the prudent choice is to opt for the more economically viable option in terms of operational expenses (Warsy et al., 2016).

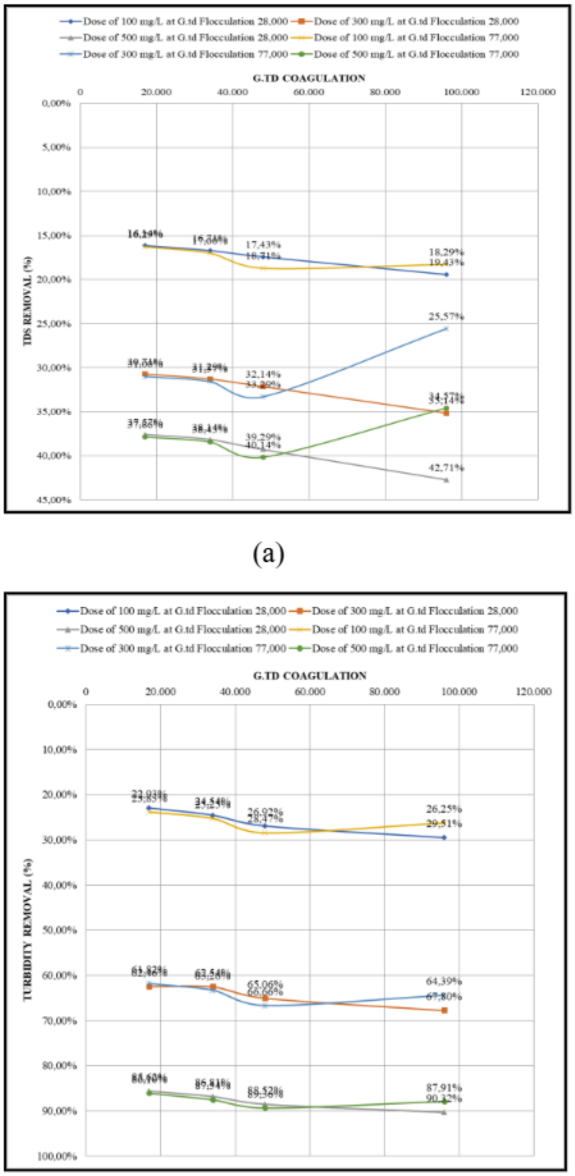
Figure 3.a portrays the TDS removal percentage using a 50-mesh biocoagulant size. The most favorable TDS removal of 34.71% was achieved at a flocculation G.td of 28,000 combined with a coagulation G.td of 96,000 at a biocoagulant dose of 500 mg/L. Meanwhile, the optimal removal percentage of 33.57% emerged at a flocculation G.td of 77,000 alongside a coagulation G.td of 48,000 at the same biocoagulant dosage. Notably, the variation involving a flocculation G.td of 77,000 demonstrated a decline in the TDS removal percentage at a coagulation G.td of 96,000.

It can be seen in Figure 3.b that the most favorable turbidity removal of 85.54% occurred at a flocculation G.td of 28,000 combined with a coagulation G.td of 96,000 at a biocoagulant dose of 500 mg/L. Moreover, the most optimal turbidity removal percentage of 83.47% was observed at a flocculation G.td of 77,000 along with a coagulation G.td of 48,000 at the same biocoagulant dosage. The variation involving a flocculation G.td of 77,000 indicates a decrease in turbidity removal percentage at a coagulation G.td of 96,000. It can be concluded that the optimal variation with a 50-mesh size corresponds to a coagulation G.td of 96,000 combined with a flocculation G.td of 28,000, using a biocoagulant dose of 500 mg/L.

Coagulation Using Chicken Eggshells Biocoagulant on 100-Mesh Size

The results of TDS and turbidity removal using 100-mesh chicken eggshells are presented in Figures 4.a and 4.b. Drawing insights from the data in Figure 4, it can be inferred that the biocoagulant derived from chicken eggshells effectively removed TDS and turbidity. This efficacy can be attributed to the substantial calcium carbonate ($CaCO_3$) content of 92.6% within chicken eggshells. Based on the graphs, the removal of TDS and turbidity using the 100-mesh size biocoagulant is greater than the 50-mesh size with a difference of about 11%. The larger the sieve size, the smaller the biocoagulant size, thus increasing the possibility of being absorbed on the colloid surface.

The objective for reducing turbidity aligns with the capabilities of the groundwater filter in Kota Bambu Selatan Village, maintaining a target range of 15–20 NTU. However, when seeking optimal outcomes, merely achieving higher results isn't sufficient; it's imperative to account for enhanced operational efficiency as well. If a particular variation yields higher outcomes while still meeting quality standards, the prudent choice is to opt for the variation that proves more cost-effective in terms of operations (Warsy et al., 2016).



(a)

(b)

Figure 4. Removal efficiency using 100-mesh chicken eggshells at flocculation G.td values of 28,000 and 77,000 for (a) TDS and (b) turbidity.

In Figure 4.a, the utilization of a biocoagulant mesh size of 100 for TDS removal percentage is depicted. The most favorable TDS removal of 42.71% was achieved at a flocculation G.td of 28,000 combined with a coagulation G.td of 96,000 at a biocoagulant dose of 500 mg/L. The optimal removal percentage of 40.14% emerged at a flocculation G.td of 77,000 alongside a coagulation G.td of 48,000 at the same biocoagulant dosage. Notably, the variation involving a flocculation G.td of 77,000 demonstrated a decline in the TDS removal percentage at a coagulation G.td of 96,000.

In Figure 4.b, it is evident that the most favorable removal percentage of 90.32% was yielded at a flocculation G.td of 28,000 combined with a coagulation G.td of 96,000 at a biocoagulant dose of 500 mg/L. Furthermore, the most optimal removal of 89.36% took place at a flocculation G.td of 77,000 along with a coagulation G.td of 48,000 at the same biocoagulant dosage. The variation involving a flocculation G.td of 77,000 indicates a decrease in the percentage of turbidity removal at a coagulation G.td of 96,000.

It can be concluded that the most favorable variation with a mesh size of 100 corresponds to a coagulation G.td of 96,000 combined with a flocculation G.td of 28,000, using a biocoagulant dose of 500 mg/L.

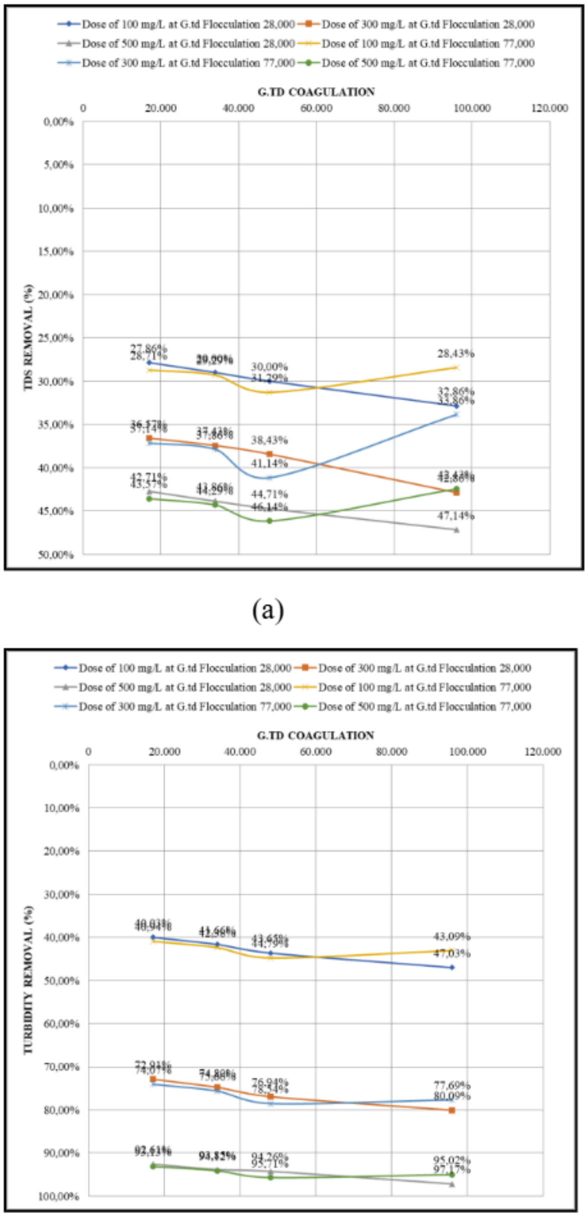
Coagulation Using Chicken Eggshells Biocoagulant on 150-Mesh Size

The outcomes of TDS and turbidity elimination using a 150-mesh chicken eggshells are depicted in Figure 5.a and 5.b. Drawing insights from the graphical representation in Figure 5, it can be deduced that the biocoagulant derived from chicken eggshells effectively eradicated TDS and turbidity. This efficacy can be attributed to the substantial calcium carbonate ($CaCO_3$) content of 92.6% within chicken eggshells. Based on the results on the graph, the removal of TDS and turbidity formed in the 150 mesh size biocoagulant is greater than the 50 and 100 mesh size biocoagulant with a difference of about 10-11%. This is consistent with what happened at mesh 100, the larger the sieve size, the smaller the biocoagulant size, thereby increasing the possibility of being absorbed on the colloid surface.

The goal of reducing turbidity is established according to the capacity of the groundwater filter in Kota Bambu Selatan Village, which ranges from 15 to 20 NTU. Nevertheless, when striving for optimal outcomes, achieving higher results alone is insufficient; it's imperative to consider enhanced operational cost-efficiency. If a particular approach yields higher outcomes while still meeting quality standards, the wiser choice is to opt for the variation that proves more economically viable in terms of operational expenses (Warsy et al., 2016).

In Figure 5.a, the utilization of a biocoagulant mesh size of 150 for TDS removal percentage is depicted. The most favorable TDS outcome was achieved at a flocculation G.td of 28,000 combined with a coagulation G.td of 96,000, resulting in a removal percentage of 47.14% at a biocoagulant dose of 500 mg/L. Meanwhile, the optimal removal percentage of 46.14% emerged at a flocculation G.td of 77,000 alongside a coagulation G.td of 48,000 at the same biocoagulant dosage. Notably, the variation involving a flocculation G.td of 77,000 demonstrated a decline in the TDS removal percentage at a coagulation G.td of 96,000.

As portrayed in Figure 5.b, the most favorable removal percentage of 97.17% was yielded at a flocculation G.td of 28,000 combined with a coagulation G.td of 96,000 at a biocoagulant dose of 500 mg/L. Moreover, the most optimal percentage of 95.71% was observed at a flocculation G.td of 77,000 along with a coagulation G.td of 48,000 at the same biocoagulant dosage. The variation involving a flocculation G.td of 77,000 indicates a decrease in the percentage of turbidity removal at a coagulation G.td of 96,000. It can be concluded that the most favorable variation of the 150-mesh size corresponds to a coagulation G.td of 96,000 combined with a flocculation G.td of 28,000, using a biocoagulant dose of 500 mg/L.



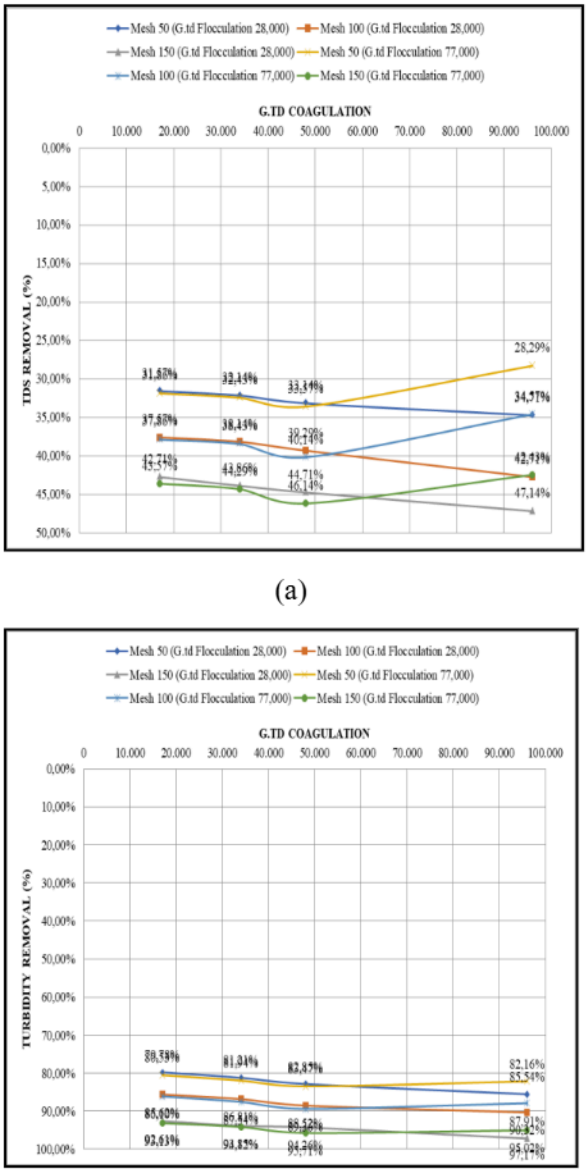
(a)

(b)

Figure 5. Removal efficiency using 150-mesh chicken eggshells at flocculation G.td values of 28,000 and 77,000 for (a) TDS and (b) turbidity.

Determination of Optimum Chicken Eggshells Biocoagulant Size

The outcomes of TDS and turbidity removal at various mesh sizes are depicted in Figures 6.a and 6.b. In Figure 6.a, the greatest TDS removal of 47.41% is attained at 150-mesh size, coupled with a coagulation G.td of 96,000 and a flocculation G.td of 28,000. Consequently, it can be concluded that the most effective size for TDS removal is 150 mesh.



(a)

(b)

Figure 6. (a) TDS and **(b)** turbidity removal efficiency at each biocoagulant size.

In Figure 6.b, the maximum turbidity removal percentage of 97.17% is attained using a mesh size of 150, along with a coagulation G.td of 96,000 and a flocculation G.td of 28,000. It can be inferred that the most suitable size for effective turbidity removal is 150 mesh. Hence, the analysis of the graphical representations in

Figure 6 reveals that the most efficient biocoagulant size for reducing both TDS and turbidity levels is 150 mesh.

The variation in biocoagulant size affects the results obtained, primarily because a larger mesh size for the biocoagulant increases the ratio between the surface area and volume of the particles, thus requiring a higher concentration for the absorption of colloidal particles dispersed in the groundwater.

Conversely, employing a smaller mesh size of biocoagulant leads to a smaller ratio between the surface area and volume of the particles, enabling the active constituents within the chicken eggshells to exert a more potent and effective impact (Hanifah et al., 2020).

Cost of Using Chicken Eggshells Biocoagulant

The cost specifications will be represented in terms of per liter, per day, and per year. The daily requirement for chicken eggshells was computed by multiplying the optimal dose of 0.33 kg/day with the treatment capacity of 675 L/day.

Table 1. Details of the component cost requirements for using chicken eggshell biocoagulant.

No	Component	Unit	Cost per Unit (IDR)	Quantity of The Needs /day	Quantity of The Needs /year	Quantity of The Needs /liter	Cost /day (IDR)	Cost /year (IDR)	Cost /liter (IDR)
1	Mortar dan Pestle 1)*	pcs	75,000	1	0	0	0	75,000	0.30
2	*Sieve Analys* 1)*	pcs	177,000	1	0	0	0	177,000	0.72
3	Worker Salary 2)*	hour	19,167	8	2,920	0.012	153,333.36	55,966,676	227
4	Chicken Eggshells Waste	kg	0	0.3375	123.37	0.0005	0	0	0
5	CH_3COOH liquid 1)*	mL	81	337.5	123,187.5	0.5	27,337.50	9,978,188	0.12
	SUB TOTAL						180,670.86	66,196,864	228.14

* 1) Benchmark from e-commerce, 2) Statistics Indonesia (2023)

Table 2. Details of the transportation cost requirements for using chicken eggshell biocoagulant.

No	Component	Unit	Cost /day (IDR)	Cost /year (IDR)	Cost /liter (IDR)
1	Chicken Eggshells Waste 3)*	kg	333.33	121,665.45	0.49
2	CH_3COOH liquid 1)*	mL	1,400	511,000	2.07
	SUB TOTAL		1,733.33	632,665.45	2.56

* 1) Benchmark from e-commerce, 3) Fuel Oil Cost in Jakarta (2023)

Table 3. Details of the total cost requirements for using chicken eggshell biocoagulant.

No	Component	Cost /year (IDR)	Cost /liter (IDR)
1	Component Cost	66,196,864	228.14
2	Transportation Cost	632,665.45	2.56
	TOTAL	66,829,529	230.7

A breakdown of the individual cost components associated with the utilization of chicken eggshells biocoagulant is displayed in Table 1, while the expenses linked to transportation are presented in Table 2. The comprehensive cost requirements are summarized in Table 3. Based on the detailed list above, the cost of using chicken eggshells as a biocoagulant is approximately IDR 230.7 per liter.

Conclusions

The most favorable settings for treating groundwater with chicken eggshells as a biocoagulant involve employing a G.td coagulation of 48,000 and G.td flocculation of 28,000, along with a dosage of 500 mg/L. The smaller the size of the biocoagulant, the greater the reduction of TDS and turbidity. These conditions yield a TDS removal efficiency of 42.00% and a turbidity removal efficiency of 94.26%, all at a cost of IDR 230.7 per liter. Drawing from this depiction, the effectiveness of chicken eggshells biocoagulant for eliminating TDS and turbidity in groundwater treatment is evident.

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