Effectiveness of Papaya Seed Biocoagulant (*Carica papaya L.*) in Peat Water Treatment

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Abstract. The limited clean water in Indonesia encourages the treatment of other alternative water sources, namely peat water. Peat water contains high levels of suspended humates and particles and has a low pH, so treatment is required before it can be used. This study aims to examine the potential of papaya seeds (Carica papaya L.) as a natural biocoagulant in the coagulation-flocculation process with a variation in coagulant doses of 0.5 g; 1.0 g; 1.5 g; and 2.0 g; The coagulation process is carried out by rapid stirring for 5 minutes at 100 rpm, and flocculation for 30 minutes at 30 rpm. The evaluation of the effectiveness of the process includes pH, Turbidity (NTU), Total Dissolved Solids (TDS), Light Transmination (LUX), Sludge Volume Index (SVI), Sludge Mass (SM), as well as floc characterization (size and structure) to determine the optimal conditions of the coagulation-flocculation process.

1 Introduction

Peat water is a type of water that is widely found in peat swamp forest areas. This water has a characteristic reddish-brown color, is strong acidic, and contains fine particles resulting from leaf and wood weathering (sedimentation). This condition makes peat water unsuitable for direct consumption, so it requires a treatment process first to meet clean water quality standards. In Indonesia, access to clean water services is still limited, with service coverage only around 45% in urban areas and 36% in rural areas [1].

However, based on its characteristics, the use of peat water directly and in the long term has the potential to cause various health problems. Therefore, peat water needs to go through a treatment process before being used in daily activities. This water has a low pH, high Fe and Mn metal content, and a large amount of natural organic matter. These conditions can cause health risks such as skin irritation, tooth decay, diarrhea, and disturbances in the body's metabolic system [2].

Organic substances contained in peat water can be removed through several methods, including precipitation, coagulation-flocculation, adsorption, and filtration with membranes. In this study, a coagulation method was used which aims to destabilize colloidal particles so that they can combine to form larger aggregates and are easy to precipitate. The coagulation process involves a rapid mixing stage which functions to ensure that the coagulant is evenly mixed with the water, so that a homogeneous mixing condition is obtained. Generally, the coagulant materials used are synthetic chemical compounds, such as aluminum sulfate salts, PAC (polyaluminum chloride), and the like (Hendrawati *et al*., 2013). Synthetic coagulants have negative health effects, such as aluminum compounds can trigger Alzheimer's disease and PAC have neurotoxicity properties.

So it is necessary to innovate by utilizing natural ingredients as coagulants. Papaya seeds work as a coagulant due to the presence of positively charged proteins that bind negatively charged particles (silt, clay, bacteria, toxins, etc.), allowing the resulting clumps to settle and obtain clear water (adsorption and neutralization of charge). In addition, papaya seeds have the ability to combine with solids in water and settle at the bottom. Papain (papaya proteinase) is an essential protein that exists, containing 345 amino acid residues and is made up of a single sequence of potent and mature peptides. Papaya seeds have also been used to treat water with fecal bacteria [4].

Papaya fruit contains about 10% sugar and is rich in vitamin A and vitamin C. The sugar composition consists of sucrose of 48.3%, glucose of 29.8%, and fructose of 21.9%. In 100 g of fruit that can be consumed, it contains about 450 mg of vitamin A and 74 mg of vitamin C. Meanwhile, papaya seeds (Carica papaya L.) contain various bioactive compounds such as alkaloids, flavonoids, andrakinone glycosides, tannins, triterpenoids/steroids, and saponins. In addition, the seeds also have a fat content of around 26%, protein 25%, and fiber 29%. The protein contained in papaya seeds plays an important role as a coagulant [5].

One type of biocoagulant that has the potential to be used in the coagulation-flocculation process is papaya seeds *(Carica papaya L.)*. This is because papaya seeds have tannins that function as a compound with the ability to bind molecules and precipitate

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pollutants. In addition, papaya seeds also have a fairly high protein content that acts as a coagulant agent [6]. The positively charged proteins found in papaya seeds are able to interact with charged particles in liquid waste, resulting in neutralization and absorption of charges that cause these particles to settle and produce clearer water.

Papaya seeds have great potential as a biocoagulant for use in liquid waste treatment and can be used as an alternative to chemical coagulants commonly used in wastewater treatment. Biocoagulants have various advantages, including being easily degradable, safe for the environment, economical, and easy-to-find raw materials [7].

Based on the description above, a study was conducted on the effectiveness of papaya seed biocoagulant *(Carica Papaya L.)* to the reduction of pH levels, Turbidity, Light Transmittance, TDS, SVI and SMA.

2 Method

2.1 Tools and materials

The tools used in this study were in the form of a digital microscope (Dino-Lite AF4515-FIT, Anmo Electronics Corporation, Taiwan), multi pH checkers, TDS, (Multi Checkers Hanna HI 9813-5, Romania), turbidimeter (Thermo Scientific, EUTECH TN-100, Netherland), lux meter (Lutron Electronic, LX-103, Taiwan), analytical balance (Ohaus Pioneer PA214, China), imhoff funnel 500 mL (Duran, Germany), buchner (Duran, Germany), vacuum pump (Rocker 300, Taiwan), shaker (Orbital Shaker SK-0330-PRO DLAB, DLAB Scientific Co.Ltd., China), 250 mesh sieve (Retsch, US 200 Basic, USA), oven (Binder, 08-37521, USA), 550 watt blender (AQUA AB KF815G, Japan), magnetic stirrer (SH-2B, China), 8 cm wide mouth pipette (Pyrex, Japan), and set of glassware (Iwaki Pyrex, Japan), watch glass, spoon, spatula, sample bottle.

The material used in this research process is papaya seeds, 90% humic acid (AH-90, Indonesia) which is produced from the natural humus purification process, with organic matter in the form of humic acid and fulvic acid, and a small amount of metal. $Fe(NO3)3.9H2O$ (Sigma-Aldrich, CAS 10421-48-4, USA), NaCl 99.99% (Merck, CAS-7647145-5, Germany), NaOH 99.99% (Merck, 011-022-00-6, Germany), HCl 36% (Merck, CAS 7647-01-0, Germany), membrane disc filters (CN-S, 0.45) aqueducts, petroleum jelly.

2.2 Preparation of synthetic peat water

A raw solution of humic acid with a concentration of 1000 mg/L is made by dissolving 1 g of humic acid in a solution of 4 g NaOH using 1 L of aquades. Then stirred using a stirer magnet within 24 hours [8]. Furthermore, 250 mL of humic acid raw solution was diluted using aqueducts in a 500 mL measuring flask, so that a working solution of 500 mg/L of humic acid was obtained. After that, the pH of peat water was adjusted to pH 5 using 0.1 M NaOH and 0.1 M HCl.

2.3 Natural coagulant preparation from papaya fruit seeds (*Carica papaya L.*)

Papaya Seed Powder *(Carica papaya L.)* from the marketplace is dried in an oven at 105 °C for 30 minutes. After the drying process, the powder is then sifted with a size of 250 mesh to obtain a uniform particle size, before being used as a natural coagulant.

2.4 Natural coagulant preparation from papaya fruit seeds (*Carica papaya L.*)

The flocs formed during the coagulation process are taken directly from the aquarium. Floc imagery is done using a digital microscope that has been manually calibrated with a calibration sheet at a magnification of 60-80 × with a distance of 2-5 cm from the object. **Fig 1.** Showing a series of floc images using a digital microscope.

Fig 1. Systematics of floc imagery using digital microscopes

3 Results and discussion

3.1 Early characteristics of peat water samples

In the analysis of peat water characteristics, peat water has a pH between 3-5, making peat water acidic. The suspended content of peat water is low, the content of organic substances is high and the intensity of dyes is high. The characteristics of peat water can be indicated by several parameters such as pH, turbidity (NTU), TDS (mg/L), and light intensity (lux). The characteristics of synthetic peat water can be shown in **Table 1.**

Table 1. Characteristics of Peat Water

Yes	Parameters	Synthetic Peat Water in research	Tungkal ilir synthetic peat water
1	pH	5	3,1
2	Turbidity (NTU)	97,6	10,58
3	TDS (mg/L)	2641	107,9
4	Light Transmission (lux)	56,6	-

3.2 Early characteristics of peat water samples

3.2.1 Proximate analysis

Proximate analysis is carried out to see the characteristics of natural coagulants such as papaya seeds. In **Table 2.** Show the results of proximate analysis of papaya seeds. The results showed that papaya seeds had a moisture content of 7.2751%, ash content of 7.7627%, and protein content of 24.739%. The moisture content reflects the amount of water contained in a sample and plays a role in determining its shelf life, as well as helping to determine the appropriate treatment for the sample. Meanwhile, ash content indicates the total percentage of inorganic or mineral components in the sample. The carbohydrate content of 16.225% serves as a supporting polymer that strengthens the floc structure through the bonding of hydrogen with peat water organic molecules and increases the viscosity of the solution for optimal coagulant distribution. And the relatively large fat content of 43.998% can be at risk of emulsion formation

Table 2. Proximate analysis

		Parameters (%)		
Water	Ash	Carbohydrates	Protein	Fat
7,2751	7,7627	16,225	24,739	43,998

4 Final parameter analysis data

4.1 pH (Power of Hydrogen) analysis

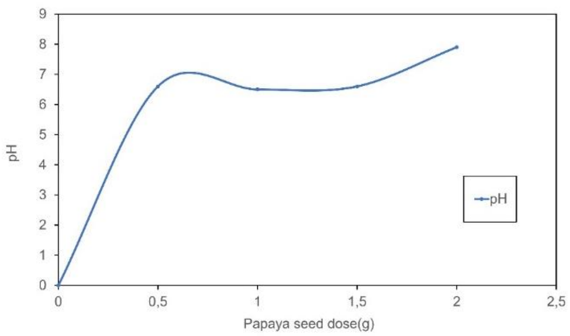

Fig 2. pH Analysis Results Graph

The results of the pH change test on peat water quality can be shown in **Fig 2.** Where there is a change in the pH value based on the results of the study, the initial pH of the sample is at 0 and after the addition of papaya seed coagulant there is a significant increase in pH. At a dose of 0.5 g the pH rises to 6.6, and decreases slightly at a dose of 1 g i.e. 6.5 returns to stable 6.6 at a dose of 1.5 g, and increases to 7.9 at a dose of 2 g. These results show that the larger the dose of papaya seed coagulant, the more optimal the ability to neutralize acidic substances. According to [9], papaya seeds are effective in normalizing the pH of liquid waste to the quality standard range due to its active compound content. In addition, polyelectrolyte compounds such as proteins and tannins in papaya seeds play a role in the coagulation-flocculation process thereby improving water quality. Thus, papaya seeds have been proven to have the potential to be a natural coagulant in increasing the pH of peat water to meet clean water quality standards.

4.2 Turbidity (NTU) and TDS (mg/L) analysis

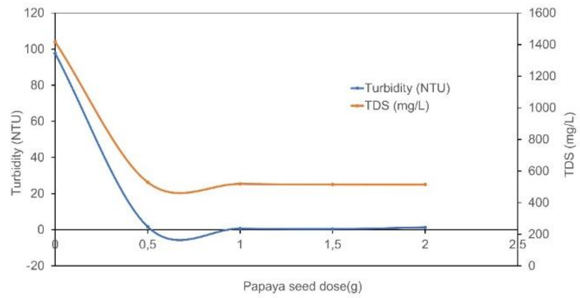

Fig 3. Graph of Turbidity (NTU) and TDS (mg/L) Analysis Results on Peat Water Decline

From the results of the data above **Fig 3.** Showing a dose that is too low of 0.5 g, the positively charged protein of papaya seeds is not enough to neutralize the negative charge of colloidal particles in water, so the floc is not fully formed. This is reflected in the turbidity remaining of 1.70 NTU (98.26% effectiveness) even though the TDS has dropped to 530 mg/L with a decrease of 62.6%. At an optimum dose of 1 g, the biocoagulant performance reached the best equilibrium point, where turbidity dropped drastically to 0.64 NTU (99.34% effectiveness) and TDS decreased significantly to 519 mg/L (63.4% decrease). This condition shows that the amount of positively charged protein released from papaya seeds is proportional to the negative charge of colloidal particles, so that the mechanism of neutralizing the charge is perfect. Increasing the dose to 1.5 g made the turbidity lower to 0.41 NTU (99.58% effectiveness), while the TDS decreased slightly better to 515 mg/L (63.6% decrease). However, this additional dose did not provide a significant difference to the results obtained at a dose of 1 g. On the contrary, at a dose of 2 g, an overdose phenomenon occurs. The turbidity rose back to 1.29 NTU (a decrease of only 98.68%) and the TDS did not change much, remaining around 515 mg/L (a decrease of 63.6%). This condition indicates the presence of charge reversal or colloidal restabilization, which is when the excess positive charge of papaya seed protein causes the formed floc to disperse back into the water, so that the effectiveness of coagulation decreases.

A significant decrease in TDS of up to 63% at doses of 1–1.5 g indicates that papaya seeds not only bind to suspended particles, but are also able to partially absorb dissolved compounds. This is consistent with the report (Kusniawati et al., 2023). Which found that papaya seeds can lower TDS and turbidity in well water with the highest effectiveness at certain optimum doses. In addition, the water-soluble protein content in papaya seeds acts as a natural polyelectrolyte that can interact with negatively charged colloidal particles through the charge neutralization and polymer bridging mechanisms. This allows the formation of large and dense flocs that are easy to settle, so that the turbidity drops drastically to below 1 NTU. However, it is important to note that although the TDS decreases significantly, the final value is still above the WHO drinking water quality standard of <500 mg/L. Therefore, the use of papaya seed biocoagulants can be seen as an early stage of water treatment, which should be followed by an advanced filtration process or simple desalination to lower the TDS to meet the standard. Thus, this study supports the use of papaya seeds as an environmentally friendly and economical natural coagulant alternative, especially for peat water treatment in rural areas. The highest effectiveness is at doses of 1–1.5 g, so this range is recommended in field practice because it is able to lower turbidity by more than 99% and TDS by about 63%.

4.3 Turbidity (NTU) and light transmission (LUX) analysis

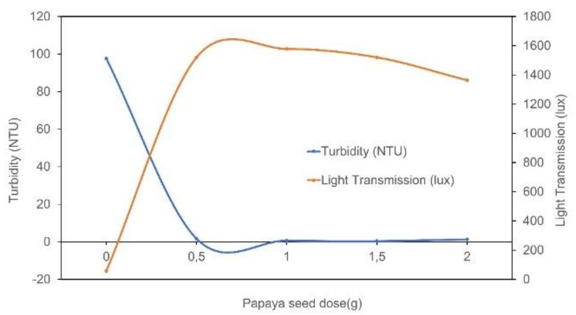

Fig 4. Graph of Results of Analysis of Tubido (NTU) and Light Transmission on Peat Water Decline

Based on the observations, it can be shown in **Fig 4.** Where there was a significant decrease in the turbidity value after the addition of papaya seed coagulant at a dose of 0.5 g to 1.5 g. The initial turbidity value of 97.6 NTU decreased drastically to 1.70 NTU (a decrease of 98.26%) at a dose of 0.5 g, then continued to decrease until it reached 0.64 NTU (a decrease of 99.34%) at a dose of 1 g, and reached a low point at a dose of 1.5 g, which was 0.41 NTU (a decrease of 99.58%). This decrease indicates the effectiveness of coagulants in precipitating suspended particles at certain concentrations. However, at a dose of 2 g, turbidity actually increased to 1.29 NTU (a decrease of 98.68%), which was likely caused by an overdose of coagulants so that the particles were dispersed again (restabilized).

Thus the decrease in turbidity, the intensity of light penetrating the sample shows a significant increase. The initial sample had a light transmission value of 57 lux, which indicates turbid peat water conditions with low translucent. After the addition of 0.5 g of coagulants, the light intensity increased drastically to 1520 lux (an increase of 96.27%). At a dose of 1 g this value increases further to 1578 lux (an increase of 96.41%), indicating the optimum point of water clarity. The dose of 1.5 g produced an intensity of 1520 lux (an increase of 96.27%), while at a dose of 2 g there was a decrease to 1364 lux (an increase of 95.84%).

The correlation between the decrease in turbidity and the increase in light intensity showed that the coagulation process was effective at an optimal dose of 1–1.5 g. A sharp decrease in turbidity of more than 99% is directly proportional to the increase in light intensity to more than 1500 lux, signaling the successful deposition of colloidal particles that cause the water to be clearer. The phenomenon of quality degradation at a dose of 2 g reinforces the theory of particle restabilization due to coagulant overdose [10].

This effectiveness shows the success of positively charged proteins and hydroxyl groups in papaya seeds that function as natural biopolymers in the flocculation process. Thus, it can be concluded that the optimal dose of papaya seeds in this study is in the range of 1–1.5 g, which provides a maximum reduction in turbidity (99.58%) as well as an increase in the highest light intensity (96.41%), indicating optimal effectiveness in improving peat water quality.

4.4 Analysis of Sludge Volume Index (SVI) and Sludge Mass (SM)

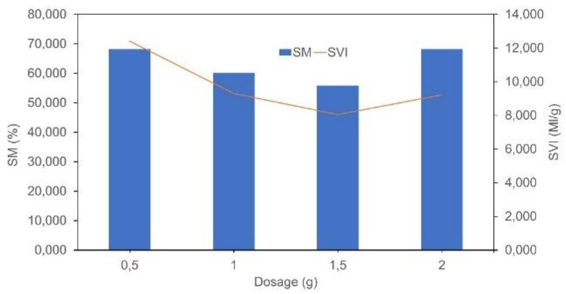

Fig 5. Graph of SM and SVI Analysis Results at Various Dose Variations

From the test results on **Fig 5.** showed that the SVI value decreased from 12,405 mL/g at a dose of 0.5 g to 8,046 mL/g at a dose of 1.5 g, while the value of SM (%) gradually increased from 68,227% to 68,277% at a dose of 2 g. Lower SVI values indicate a denser floc ability and are more effective at precipitation, This is in accordance with the results of the study of Riananda et al. (2024) [11] which shows that papaya seeds are effective in forming high-density flocs at optimal doses. Meanwhile, an increased SM indicates that the number of floc masses formed is higher as the dose increases. Doses of 1–1.5 g were seen to be the lowest optimal range of SVI (8,046 mL/g) and relatively high SM (55,908%), indicating that floc particles formed dense and precipitated quickly. In contrast, the dose of 2 g despite producing high SM, SVI rose again (9,218 mL/g), indicating that the floc was getting lighter and less stable despite increasing mass.

A re-increase in SVI values at a dose of 2 g indicates an excess of coagulant that causes the floc to become unstable, as also explained by Christian et al.

(2018) [12] , that an overdose of natural coagulants can trigger the redisperse of the particles that have been bound. Decreased SVI at low to moderate doses shows a more dense floc quality and can settle well. This is consistent with the function of the positively charged protein of papaya seeds in forming dense and stable flocs—resulting in optimal deposition. A decrease in efficiency at high doses (as seen from an increased SVI) may indicate the presence of an overload that causes the floc to regain stability and be lighter, even though the floc mass is much formed. Which shows that the SVI value decreases at the optimum dose of the natural coagulant, but increases again if the dose exceeds the binding capacity of the suspended particles.

These results confirm that a dose of 1–1.5 g of papaya seeds results in stable, dense, and easily precipitated flocs—suitable for high-efficiency application of natural coagulation. Low SVI values followed by high SM indicate good floc quality, while increased SVI at high doses indicates a decrease in floc quality even though mass increases. Therefore, dose optimization is very important so that the performance of this natural biocoagulant is maximized in terms of turbidity, floc mass, and sedimentation.

4.5 Floc characterization analysis (size and structure)

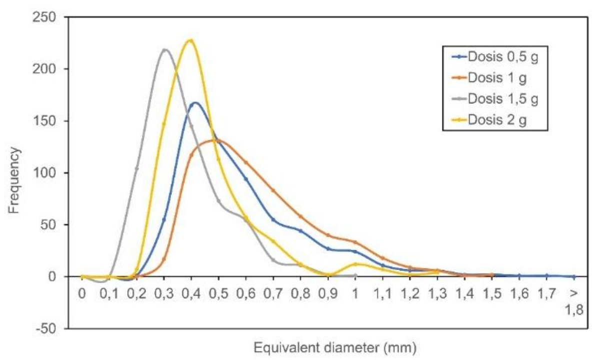

Fig 6. Graph of Floc Size Distribution Analysis at Various Dose Variations

The floc size distribution formed at each dose showed significant differences in frequency and particle size dominance. By **Fig 6.** At doses of 0.5 g and 1 g, most flocs are seen to have a diameter in the range of 0.4-0.6 mm, which indicates the formation of relatively stable medium-sized flocs. The peak frequency at a dose of 0.5 g was 165 particles at a diameter of 0.4 mm, while at a dose of 1 g it reached 131 particles at a diameter of 0.5 mm. Other research by Kusniawati et al. (2023) [13] It is reported that low doses of papaya seeds tend to form fairly dense and evenly distributed flocs in medium size, which favors sedimentation efficiency and water clarity.

The dose of 1.5 g showed the highest frequency at 0.3 mm diameter of 218 particles, while the 2 g dose recorded the highest peak of 227 particles at 0.4 mm diameter. However, at high doses (2 g), the floc distribution also spreads more widely to small diameters (0.2 mm) and remains significant until larger sizes up to (>0.9 mm), which indicates inuniformity of shape and stability of the floc. According to research [10], flocs formed due to too high doses of coagulants tend to be lighter and unstable, due to the restabilization of the charge that causes the particles to disperse again.

The most even and stable floc distribution was seen at the 1 g dose, with a predominance of a fairly high size of 0.4–0.6 mm and a more sloping distribution of large sizes. This suggests that at such doses, a floc is formed that is not only dense, but also large enough to settle properly. In contrast, a dose of 2 g showed the formation of large amounts of flocs but with very small and varied sizes, which could potentially be difficult to settle efficiently within the water treatment system. The narrow and dominant floc distribution at a certain size is an efficiency indicator for the coagulation-flocculation process using natural coagulants. Too small a flock size can cause the floc to be suspended again or carried over to the next filtration process.

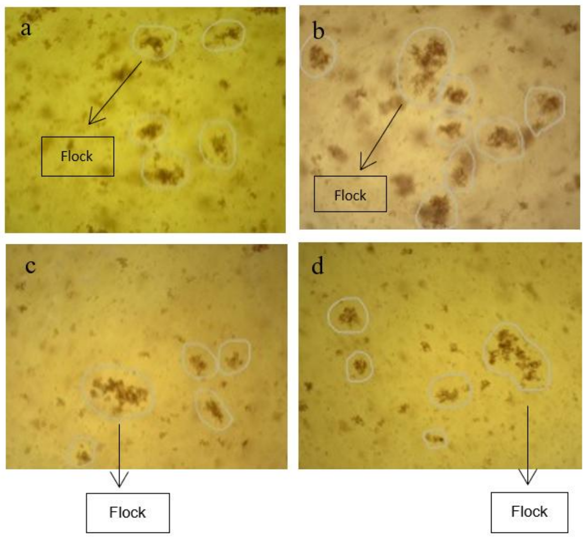

Fig 7. Flock Image Formed at a Dose of 0.5 g (a), Dose 1 g (b), Dose 1.5 g (c) and Dose 2 g (d)

The floc image shows that the floc formed at a dose of 0.5 g is still relatively small and not yet solid. Its size distribution is dominated by fine flocs in the range of 0.3-0.5 mm. The image shows that flocs are starting to form, but they have not been fully integrated. This dose is not yet effective enough to produce a stable floc. Flocs are formed in uniform size and dense at a dose of 1 g, predominantly at a diameter of 0.4-0.5 mm. The image shows a large flock and is clearly visible. This is the most optimal dosage because it produces a floc that is easy to settle and stable. Furthermore, the floc image at a dose of 1.5 g of floc is still quite large and dense, but it begins to appear a wider variation in size. Some flocs look inhomogeneous. The effectiveness is still high, but it is close to the optimal dose limit. Meanwhile, at a dose of 2 g the floc distribution is widespread, with many small flocs that are mild and unstable. The image shows an uneven flock that is easily dispersed again. This indicates that this dose is too high and decreases the efficiency of the coagulation process.

5 Conclusion

Peat water does not meet clean water quality standards and contains compounds that are harmful to health, so it requires a treatment process before use. Coagulation is an effective method to reduce turbidity, but the use of synthetic coagulants poses a risk to human health. The results of the study show that papaya seeds can be used as a natural coagulant that is safe and environmentally friendly. Based on the floc size distribution analysis, the dose of papaya seed biocoagulant had a significant effect on the formation and stability of flocs. A dose of 1 g produces a uniform floc in the size range of 0.4-0.5 mm and shows the best coagulation efficiency. Meanwhile, high doses such as 2 g tend to produce flocs with uneven size distribution due to excess coagulants. Thus, the optimal dose of papaya seed biocoagulant for the coagulation-flocculation process of peat water is in the range of 1–1.5 g.

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