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Efficiency of Chitosan and Alum as Coagulants for Peat Water Treatment

Efisiensi Kitosan Dan Tawas Sebagai Koagulan Untuk Pengolahan Air Gambut

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ABSTRACT

Peat water is widely found in swamp and lowland areas of Indonesia and is characterized by high color intensity, low pH, and elevated concentrations of dissolved organic compounds. These characteristics limit its direct use as a water source and require appropriate treatment methods. This study evaluates the effectiveness of chitosan and alum as coagulants in improving the quality of peat water. The optimum dosage and pH conditions for the coagulation process were determined based on reductions in turbidity and organic compound levels after treatment. The results indicate that the optimum dosage for chitosan was 5 mg/L, while alum required 15 mg/L to achieve effective turbidity removal. Under these conditions, turbidity reductions of 81.91% and 76.28% were obtained for chitosan and alum, respectively. The coagulation performance of both coagulants was strongly influenced by pH. Chitosan showed optimum performance at pH 8, resulting in a turbidity reduction of 83.36%, whereas alum exhibited the best performance at pH 7, achieving a turbidity reduction of 88.02%. Further analysis revealed that alum was more effective than chitosan in reducing the concentration of organic compounds in peat water. Overall, the findings demonstrate that both coagulants can improve peat water quality, although their performance varies depending on operational conditions such as dosage and pH.

Keywords: Peat water, chitosan, alum, coagulation, flocculation.

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1. INTRODUCTION

Peat water is a type of surface water commonly found in swamp areas, coastal regions, and lowland environments, particularly in peatland ecosystems across Sumatra and Kalimantan. This type of water typically exhibits a dark brown to reddish color caused by the presence of dissolved humic substances (Kusnadi, 2010). The high concentration of humic acids and other dissolved organic compounds results in several characteristic properties of peat water, including high organic content, low pH, unpleasant odor, and intense coloration. These characteristics significantly reduce its suitability for direct consumption and may lead to potential health risks if consumed over a long period.

Due to these limitations, various studies have investigated methods to improve peat water quality so that it can be used as a reliable water source. One such study conducted by Rehansyah et al. (2017) reported that appropriate treatment processes are capable of reducing organic substances and color in peat water, thereby improving its suitability as raw water. Among the various treatment technologies available, coagulation is widely applied as an effective method to reduce turbidity and remove suspended particles from water. Research on water clarification through coagulation processes has been extensively conducted. Various types of coagulants have been tested for their effectiveness in improving water quality, including both synthetic and natural coagulants. Synthetic coagulants are commonly used in water treatment processes because they are relatively easy to obtain and economically feasible. However, excessive use of synthetic coagulants may cause environmental and health concerns since many of these materials are not readily biodegradable (Sunardi et al., 2013).

Therefore, there is growing interest in exploring natural materials as alternative coagulants for peat water treatment. One potential natural coagulant is chitosan, a biopolymer derived from chitin (Hendrawati et al., 2015). Chitosan has been widely studied due to its biodegradable nature, non-toxic properties, and strong ability to interact with suspended particles in aqueous systems.

Previous research by Mu'minah (2008) demonstrated that chitosan can function as an effective and efficient coagulant compared with alum, as evidenced by the reduction of water turbidity even at relatively low concentrations of chitosan. Furthermore, Amir and Isnaniawardhana (2010) reported that the efficiency of color removal in water treatment is largely determined by the collision frequency between destabilized colloidal particles, which subsequently form larger flocs that can settle more easily.

Based on these considerations, this study aims to evaluate the efficiency of chitosan and alum as coagulants for peat water treatment. Specifically, the study examines the influence of coagulant dosage and pH on the reduction of turbidity and organic compounds in peat water. In addition, the optimal dosage and pH conditions for the coagulation process are determined in order to obtain the most effective formulation for the application of chitosan and alum as coagulants in peat water treatment.

2. MATERIALS AND METHODS

2.1. Instruments and Materials

The instruments used in this study included standard laboratory glassware, a magnetic stirrer, thermometer, jar test apparatus (VELP Scientifica JLT-6), pH meter (HACH sensION+ PH1), analytical balance (Ohaus PA224), hot plate, turbidimeter (HACH Model 2100Q), sample bottles, volumetric flasks, and plastic containers for water sampling. The materials used consisted of peat water samples, chitosan (degree of deacetylation 87.5%), alum ($Al_2(SO_4)_3$), acetic acid (CH_3COOH, p.a., Merck), sodium hydroxide (NaOH, p.a., Merck), hydrochloric acid (HCl, p.a., Merck), sulfuric acid (H_2SO_4, p.a., Merck), oxalic acid ($H_2C_2O_4$, p.a., Merck), potassium permanganate ($KMnO_4$, p.a., Merck), and distilled water.

2.2. Methods

This study was conducted to evaluate the efficiency of chitosan and alum as coagulants for peat water treatment. The experimental procedures consisted of several stages, including the preparation of coagulant solutions, determination of optimum coagulant dosage, determination of optimum

pH conditions, and evaluation of coagulant efficiency in reducing turbidity and organic compounds in peat water. The organic matter content in the treated water was determined using the permanganometric method according to the Indonesian National Standard (SNI 06-6989.22-2004).

The overall experimental workflow involved coagulation–flocculation tests using a jar test apparatus, followed by turbidity measurement and analysis of organic matter concentration. The detailed procedures for each stage are described in the following sections.

2.2.1 Preparation of Coagulant Solutions

The preparation of the chitosan solution followed the method suggested by Pontius et al. (2016). Chitosan (20 g) was dissolved in 1000 mL of 2% acetic acid solution to obtain a 2% (w/v) chitosan solution. The mixture was continuously stirred for approximately one hour until a homogeneous solution was obtained. A similar preparation procedure was applied for the alum coagulant solution.

2.2.2 Determination of Optimum Coagulant Dosage and pH

The determination of optimum dosage and pH conditions was carried out using a jar test coagulation process. A total of 1000 mL of peat water sample was placed in the jar test apparatus. The coagulant dosage was varied at 5, 10, 15, 20, and 25 mg/L, while the pH was adjusted within the range of pH 5–9. The coagulation process consisted of rapid mixing at 100 rpm for 1 minute, followed by slow mixing at 45 rpm for 20 minutes. After mixing, the suspension was allowed to settle for 30 minutes to facilitate sedimentation. The turbidity of the treated water was then measured using a turbidimeter.

2.2.3 Determination of Coagulant Efficiency

The efficiency of each coagulant was evaluated using the optimum dosage and pH conditions obtained from the previous experiments. A total of 500 mL of peat water was placed in a beaker and treated with the respective coagulant. The coagulation process was conducted using the same jar test procedure: rapid mixing at 100 rpm for 1 minute, followed by slow mixing at 45 rpm for 20 minutes. The treated samples were then allowed to settle for 30 minutes, after which the turbidity of the supernatant was measured.

2.2.4 Determination of Organic Matter Content by Permanganometric Method

The determination of organic matter content in peat water was performed using the permanganometric method according to the Indonesian National Standard SNI 06-6989.22-2004. A volume of 100 mL of peat water sample (before and after treatment) was transferred into an Erlenmeyer flask, and several boiling chips were added. The sample was then treated with a few drops of 0.01 N $KMnO_4$ solution until a faint pink color appeared. Subsequently, 5 mL of 8 N H_2SO_4 was added to the solution.

The mixture was heated to approximately 105 °C, followed by the addition of 10 mL of 0.01 N $KMnO_4$ standard solution. The sample was boiled for 10 minutes, after which 10 mL of 0.01 N oxalic acid ($H_2C_2O_4$) was added. The solution was then titrated with 0.01 N $KMnO_4$ until a persistent pale pink endpoint was observed. The volume of $KMnO_4$ required to reach the titration endpoint was recorded and used to determine the permanganate value, which represents the concentration of organic compounds present in the peat water sample.

3. RESULTS AND DISCUSSION

3.1 Determination of Optimum Coagulant Dosage

Coagulant dosage is a critical parameter influencing the efficiency of the coagulation–flocculation process. Both insufficient and excessive dosages may reduce the effectiveness of particle destabilization and

floc formation. Insufficient coagulant results in incomplete neutralization of suspended particles, while excessive dosage may lead to particle restabilization (Rao, 2015).

The effect of coagulant dosage on turbidity removal from peat water is presented in **Table 1**. In this study, the dosage of both chitosan and alum was varied from 5 to 25 mg/L.

Table 1. Effect of coagulant dosage on turbidity removal from peat water

Dosage (mg/L)	Chitosan Final Turbidity (NTU)	Removal (%)	Alum Final Turbidity (NTU)	Removal (%)
5	0.74	81.91	4.01	1.96
10	4.38	-7.09	1.36	66.75
15	4.48	-9.54	0.97	76.28
20	4.37	-6.85	1.31	67.97
25	4.63	-13.20	1.01	75.31

Note: Initial turbidity (T_0) = 4.09 NTU. According to SNI 01-3553-2006, the maximum turbidity level for raw water is 5 NTU

As shown in Table 1, the addition of chitosan significantly reduced the turbidity of peat water at low dosage. The optimum dosage for chitosan was observed at 5 mg/L, resulting in a final turbidity of 0.74 NTU, corresponding to a turbidity removal efficiency of 81.91%. This turbidity value meets the Indonesian raw water quality standard, which specifies a maximum turbidity limit of 5 NTU (SNI 01-3553-2006).

However, increasing the dosage of chitosan beyond this concentration did not improve turbidity removal. At higher dosages (10–25 mg/L), the turbidity values increased to 4.38–4.63 NTU, and the calculated removal efficiency even became negative. This phenomenon may occur due to overdosing of the polymer coagulant, which can lead to the restabilization of suspended particles when excess polymer chains remain in the solution.

Compared with chitosan, alum required a higher dosage to achieve effective turbidity removal. The optimum dosage for alum was 15 mg/L, which produced a final turbidity of 0.97 NTU and a removal efficiency of 76.28%. The coagulation mechanism of alum involves the release of Al^{3+} ions in aqueous solution.

These positively charged ions neutralize negatively charged colloidal particles suspended in water, enabling them to aggregate and form larger flocs that can settle more easily. The higher dosage required for alum may be associated with the characteristics of suspended particles in peat water, which are dominated by macromolecular humic substances. These particles generally require a higher concentration of metal ions to effectively neutralize their surface charge before aggregation occurs.

Chitosan, on the other hand, contains amino functional groups (–NH_2) that can be protonated to form –NH_3^+ groups in aqueous media. These positively charged sites interact electrostatically with negatively charged colloidal particles, promoting particle destabilization and floc formation. According to Agusnar (2003), the coagulation mechanism of chitosan commonly occurs through adsorption and interparticle bridging, where polymer chains act as bridges that connect multiple particles and form larger flocs.

Overall, the results indicate that chitosan is more efficient than alum in terms of the dosage required to achieve optimal turbidity removal, although alum still provides effective turbidity reduction under appropriate conditions.

3.2 Determination of Optimum pH

The pH of the solution plays an important role in the coagulation–flocculation process because it influences the surface charge of suspended particles as well as the chemical speciation of the coagulant. Changes in pH can therefore significantly affect the efficiency of particle destabilization and floc formation. Previous studies have reported that the effectiveness of coagulation processes strongly depends on the pH conditions of the treated water (Herawati et al., 2017).

The effect of pH on turbidity removal using chitosan and alum is presented in **Table 2**. For chitosan, turbidity removal increased significantly as the pH approached neutral and slightly alkaline conditions.

Table 2. Effect of pH on turbidity removal using chitosan and alum

pH	Chitosan Final Turbidity (NTU)	Removal (%)	Alum Final Turbidity (NTU)	Removal (%)
5	11.7	12.69	3.07	74.63
6	11.4	14.93	1.78	85.29
7	3.22	75.97	1.45	88.02
8	2.23	83.36	2.45	79.75
9	3.04	77.31	2.27	81.24

Note: Initial turbidity = 13.4 NTU (chitosan) and 12.1 NTU (alum). According to SNI 01-3553-2006, the maximum turbidity standard for raw water is 5 NTU.

As shown in Table 2, the highest turbidity removal was obtained at pH 8, where the final turbidity decreased to 2.23 NTU, corresponding to a removal efficiency of 83.36%. At lower pH values (pH 5–6), the turbidity removal efficiency was much lower, with reductions of only 12.69% and 14.93%, respectively.

This behavior is closely related to the chemical characteristics of humic substances present in peat water. Under acidic conditions, many functional groups within humic substances remain protonated, resulting in fewer negatively charged sites available for electrostatic interaction with the coagulant. As a result, the interaction between humic particles and chitosan becomes weaker, leading to lower coagulation efficiency.

At near-neutral and slightly alkaline pH values, humic substances contain a greater number of deprotonated carboxylate groups (–COO^-). These negatively charged groups can interact electrostatically with the protonated amino groups (–NH_3^+) present in chitosan molecules. This interaction promotes particle destabilization and facilitates the formation of larger flocs that settle more easily. In contrast, the optimum coagulation performance for alum was observed at pH 7, where turbidity decreased to 1.45 NTU, corresponding to a

removal efficiency of 88.02%, as shown in Table 2. Alum also exhibited relatively good turbidity removal across the investigated pH range, although the highest efficiency was achieved near neutral conditions.

According to Hu et al. (2006), aluminum-based coagulants generally perform best within a limited pH range and may lose efficiency under strongly acidic or highly alkaline conditions. At low pH values, aluminum tends to exist predominantly as monomeric Al^{3+} species, which are less effective in destabilizing suspended particles. When alum is dissolved in water, it undergoes hydrolysis to form various aluminum hydroxo complexes, and the distribution of these species strongly depends on the pH of the solution (Yang et al., 2010).

These hydrolysis products eventually form amorphous $Al(OH)_3$ precipitates, which act as sweep flocs capable of adsorbing suspended particles and organic substances from the water. This mechanism explains why alum shows high turbidity removal efficiency at pH values close to neutral. Overall, the results indicate that both coagulants are influenced by pH conditions. Chitosan exhibited optimum performance at pH 8, while alum achieved its highest efficiency at pH 7. These findings highlight the importance of controlling pH conditions in order to optimize the coagulation process for peat water treatment.

3.3 Evaluation of Coagulant Efficiency

The coagulation efficiency of chitosan and alum under their respective optimum conditions was further evaluated using three different peat water samples. The results of turbidity reduction obtained using both coagulants are summarized in **Table 3**.For sample 1, the initial turbidity of the peat water was 14.1 NTU. After treatment with chitosan, the turbidity decreased to 2.32 NTU, corresponding to a turbidity removal efficiency of 83.58%.

Table 3. Comparison of turbidity removal efficiency of chitosan and alum

Sample	Treatment	Turbidity (NTU)	Turbidity Reduction (NTU)	Removal (%)
1	Control	14.1	0	0
	Chitosan	2.32	11.79	83.58
	Alum	1.88	12.23	86.70
2	Control	14.1	0	0
	Chitosan	2.58	11.52	81.70
	Alum	2.29	11.82	83.79
3	Control	1.34	0	0
	Chitosan	1.55	-0.21	-15.30
	Alum	0.77	0.57	42.54

When alum was used as the coagulant, the turbidity decreased further to 1.88 NTU, resulting in a removal efficiency of 86.70%. These results indicate that both coagulants were highly effective in reducing turbidity under these conditions. A similar trend was observed for sample 2, where the initial turbidity was also 14.1 NTU. Treatment with chitosan reduced the turbidity to 2.58 NTU, corresponding to a removal efficiency of 81.70%, while alum reduced the turbidity to 2.29 NTU, with a removal efficiency of

83.79%. These results further confirm that both coagulants can effectively destabilize suspended particles in peat water.

However, different behavior was observed for sample 3, which had a much lower initial turbidity of 1.34 NTU. After treatment with chitosan, the turbidity slightly increased to 1.55 NTU, resulting in a calculated removal efficiency of −15.30%. This phenomenon may occur when the initial turbidity of the water is already very low. Under such conditions, the addition of polymeric coagulants may lead to incomplete floc formation or the formation of fine suspended particles that remain dispersed in the solution.

In contrast, treatment with alum reduced the turbidity of sample 3 to 0.77 NTU, corresponding to a turbidity removal efficiency of 42.54%. Although the removal efficiency was lower compared with samples 1 and 2, alum still showed measurable turbidity reduction. Overall, the average turbidity removal obtained from the three samples was 49.99% for chitosan and 71.34% for alum, as shown in Table 3. These results indicate that alum exhibited higher overall turbidity removal efficiency compared with chitosan under the experimental conditions used in this study.

The coagulation mechanism of chitosan is mainly attributed to electrostatic interactions between the positively charged sites of chitosan and negatively charged colloidal particles present in water. These interactions promote the formation of larger flocs that can settle more easily (Weiner & Matthews, 2003). However, when the initial turbidity is very low, the distance between suspended particles becomes larger, which may reduce the probability of particle bridging.

Zemmouri et al. (2011) reported that chitosan tends to be less effective in treating water with low turbidity levels. This limitation is related to the bridging mechanism of polymeric coagulants, which requires sufficient particle concentration to form stable flocs. Huang and Chen (1996) also explained that chitosan coagulation primarily occurs through a bridging mechanism, where polymer chains link multiple particles together. Furthermore, Divakaran and Pillai (2001) suggested that floc formation through polymer bridging may require longer sedimentation time to produce larger and more stable flocs. Therefore, the relatively short sedimentation time applied in this study may have contributed to the lower effectiveness of chitosan in some samples.

3.4 Removal of Organic Compounds Based on Permanganate Value

The determination of organic matter content in peat water was carried out using the permanganometric method, which measures the permanganate value as an indicator of oxidizable organic compounds present in the sample. A higher permanganate value indicates a higher concentration of organic substances in the water. The influence of coagulant dosage, pH conditions, and coagulant type on the removal of organic compounds in peat water is presented in Tables 4, 5, and 6, respectively.

3.4.1 Effect of Coagulant Dosage

The effect of coagulant dosage on organic matter removal is shown in **Table 4**. In contrast, the use of alum resulted in less consistent organic matter removal. The lowest permanganate value obtained using alum was 15.168 mg/L at a dosage of 20 mg/L, corresponding to a reduction of 11.11%. However, this value still exceeded the permissible limit for organic compounds in raw water. In several cases, the permanganate value increased after alum addition, resulting in negative removal percentages.

Table 4. Effect of coagulant dosage on organic matter removal (permanganate value)

Dosage (mg/L)	Chitosan Permanganate (mg/L)	Removal (%)	Alum Permanganate (mg/L)	Removal (%)
5	7.90	64.29	21.804	-27.78
10	7.90	64.29	33.812	-98.15
15	7.90	64.29	15.484	9.26
20	13.272	40.00	15.168	11.11
25	9.796	55.71	17.38	-1.85

Note: Initial permanganate value = 22.12 mg/L (chitosan) and 17.064 mg/L (alum). According to SNI 01-3553-2006, the maximum permissible organic matter concentration is 10 mg/L.

This phenomenon may be related to the hydrolysis reactions of Al^{3+} ions, which produce various hydroxo complexes such as $Al(OH)^{2+}$, $Al_2(OH)_2^{4+}$, and $Al_3(OH)_4^{5+}$. These reactions may influence the dissociation behavior of humic substances in the solution, potentially causing previously aggregated organic compounds to redisperse. Overall, the results indicate that chitosan exhibited better performance than alum in reducing organic compounds when evaluated based on dosage variation.

3.4.2 Effect of pH on Organic Matter Removal

The influence of pH on organic matter removal is presented in **Table 5**.

Table 5. Effect of pH on organic matter removal

pH	Control (mg/L)	Chitosan (mg/L)	Removal (%)	Alum (mg/L)	Removal (%)
5	12.5	20.856	-20.00	17.696	13.85
6	12.7	15.168	12.73	16.116	21.54
7	12.5	16.116	7.27	17.38	15.39
8	12.8	22.12	-27.27	11.376	44.62
9	12.0	17.38	0.00	13.272	35.39

For chitosan, slight reductions in organic matter concentration were observed at pH 6 and pH 7, with removal efficiencies of 12.73% and 7.27%, respectively. Under these conditions, some of the amino functional groups in chitosan remain available to interact with organic molecules present in the peat water. The interaction between chitosan and humic substances may occur through hydrogen bonding and electrostatic interactions between amino groups in chitosan and functional groups present in humic compounds. For alum, the highest organic matter reduction occurred at pH 8, where the permanganate value decreased to 11.376 mg/L, corresponding to a removal efficiency of 44.62%. This behavior may be explained by the formation of aluminum hydroxide precipitates under slightly alkaline conditions. When alum is dissolved in water, hydrolysis reactions produce positively charged hydroxo complexes and eventually form $Al(OH)_3$ flocs, which can adsorb organic compounds present in the water. In alkaline conditions, the presence of hydroxide ions facilitates the formation of these hydrolysis products, thereby enhancing the removal of organic substances. However, it should be noted that

in most experimental conditions, the remaining organic matter concentration after treatment still exceeded the recommended limit of 10 mg/L, indicating that coagulation alone may not be sufficient to completely remove organic compounds from peat water.

3.4.3 Effect of Coagulant Type on Organic Matter Removal

The overall effectiveness of the two coagulants in removing organic compounds was evaluated using three peat water samples, as summarized in **Table 6**.

For chitosan, the average permanganate value obtained after treatment was 13.114 mg/L, corresponding to an average reduction of 4.57%. In contrast, alum produced a lower average permanganate value of 11.903 mg/L, corresponding to a reduction efficiency of 12.27%. These results suggest that alum was relatively more effective than chitosan in reducing organic compounds in peat water. The reduction in organic matter may occur through adsorption of organic molecules onto the flocs formed during the coagulation process.

During alum coagulation, the formation of $Al(OH)_3$ precipitates provides a large surface area that can trap and adsorb organic substances. These flocs subsequently settle during the sedimentation process, thereby reducing the concentration of dissolved organic compounds in the treated water (Suprihanto, 1994).

Table 6. Reduction of organic compounds in peat water

Sample	Treatment	Permanganate Value (mg/L)	Reduction (mg/L)	Removal (%)
	Control	9.796	0	0
1	Chitosan	7.426	2.37	24.19
	Alum	8.374	1.422	14.52
	Control	13.588	0	0
2	Chitosan	15.642	-2.054	-15.12
	Alum	11.692	1.896	13.95
	Control	17.064	0	0
3	Chitosan	16.274	0.79	4.63
	Alum	15.642	1.422	8.33

Overall, although both coagulants contributed to the reduction of organic compounds, the results indicate that alum exhibited slightly higher efficiency than chitosan in reducing organic matter based on the permanganate value.

4. CONCLUSIONS

This study evaluated the performance of chitosan and alum as coagulants for peat water treatment, with particular emphasis on the effects of coagulant dosage and pH on turbidity and organic matter removal. The results showed that the optimum dosage of chitosan was 5 mg/L, producing a turbidity removal efficiency of 81.91%, while the optimum dosage for alum was 15 mg/L, achieving a turbidity removal efficiency of 76.28%. These results indicate that chitosan requires a lower dosage to achieve effective turbidity reduction compared with alum.

The efficiency of the coagulation process was also influenced by pH conditions. Chitosan exhibited optimum performance at pH 8, while alum showed the highest turbidity removal at pH 7. These findings highlight the importance of controlling pH conditions to optimize coagulation performance during peat water treatment.

In terms of organic matter removal, evaluated through the permanganate value, alum demonstrated slightly higher effectiveness than chitosan. The average reduction in organic compounds obtained using alum was 12.27%, whereas chitosan achieved an average reduction of 4.57%.

Overall, the results suggest that chitosan has potential as an alternative natural coagulant due to its ability to achieve effective turbidity reduction at relatively low dosages, while alum remains more effective in reducing organic matter content in peat water. The combination of operational parameters such as coagulant dosage and pH is therefore essential for optimizing the treatment of peat water.

Further studies are recommended to investigate additional operational parameters, including mixing intensity and sedimentation time, in order to enhance the efficiency of coagulation processes for peat water treatment.

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LIST OF REFERENCES

Agusnar, H. 2003. Analisa Keefektifan Penggunaan Kitosan untuk Menurunkan Kadar Logam Berat. Jurnal Sains Kimia. 7(1): 7-10.

Amir, R & Isnaniawardhana, J.N. 2008. Penentuan Dosis Optimum Aluminium Sulfat dalam Pengolahan Air Sungai Cileueur Kota Ciamis dan Pemanfatan Resirkulasi Lumpur dengan Parameter pH, Warna, Kekeruhan, dan TSS. Jurnal Program Studi Teknik Lingkungan, Fakultas Teknik Sipil dan Lingkungan Institut Teknologi Bandung.

Anderson, E., L. Darmayanti & Rinaldi. 2013. Pengolahan Air Gambut dengan Media Filter Batu Apung. Jurnal Ilmiah Teknik Sipil UNRI. 1(1): 2-5.

Bachia, M.F. 2006. Gambut: Agroekosistem dan Transformasi Karbon. Yogyakarta: Gadjah Mada University Press.

Budiman, A., C.Wahyudi., W. Irawaty & H. Hindarso. 2008. Kinerja Koagulan Poly Aluminium Chloride (PAC) dalam Penjernihan Air Sungai Kalimas Surabaya menjadi Air Bersih. Widya Teknik. 7(1): 25-34.

Budiyono & Sumardiono. 2013. Teknik Pengolahan Air. Yogyakarta: Graha Ilmu.

Burgess, J., M. Meeker., J. Minton & M. O'Donohue. 2015. International Research Agency Perspectives on Potable Water Reuse. Environmental Science: Water Research & Technology. The royal Society of Chemistry. 5: 563-580.

Campbell, A. 2002. The Potential Role of Aluminium in Alzheimer's Disease. Neprhol Dial transplant. 17(2): 17-20.

Chung, G.H., B.S. Kim., J.W. Hur & H.K. No. 1996. Physicochemical Properties of Chitin and Chitosan Prepared from Lobster Shrimp Shell. Korean Journal Food Science Technology. 28: 870-876.

Crittenden, J.C., R.R Trussell., D.W. Hand., K.J. Howe & G. Tchobanoglous. 2012. MWH's Water Treatment: Principles and Design 3rd Edision. New Jersey: John Wiley and Sons.

Divakaran, R & V.N.S. Pillai. 2001. Flocculation of Kaolinite Suspensions In Water By Chitosan. Wat.Res. 35(1):3904-3908.

Duan, J & J. Gregory. 2003. Coagulation By Hydrolysing Metal Salts.

Ermal, A.S. 2016. Pemanfaatan Precipitated Calsium Carbonate (PCC) dari Limbah Cangkang Kerang Darah (Anadara Granosa) sebagai Adsorben Pengolahan Air Gambut. Skripsi Program Studi Teknik Lingkungan Universitas Riau, Riau.

Goosen, M.F.A. 1997. Application of Chitin and Chitosan. Tecnomic Publishing Company. Inc, Pennsylvania.

Hendrawati., S. Sumarni & Nurhasni. 2015. Penggunaan Kitosan sebagai Koagulan Alami dalam Perbaikan Kualitas Air Danau. Jurnal Penelitian dan Pengembangan Ilmu Kimia. 1(1): 1-11.

Herawati, A., R. Asti, B. Ismuyanto, J. Nanda & A.D.S.N. Hidayati. 2017. Pengaruh pH dan Dosis Koagulan Ekstrak Biji Kelor dalam Koagulasi Terhadap Pengurangan Kekeruhan Limbah Cair. Jurnal Rekayasa Bahan Alam dan Energi Berkelanjutan. 1(1): 25-28.

Hesami, F., B. Bina & A. Ebrahimi. 2014. The Effectiveness of Chitosan as Coagulant Aid in Turbidity Removal from Water. International Journal of Environmental Health Engineering. 2 (6): 46-51.

Howe, K.J., D.W. Hand., J.C. Crittenden., R.R. Trussell & G. Tchobanoglous. 2012. Principle of Water Treatment. John Wiley and Sons, Inc, New Jersey.

Hu, C., H. Liu., J. Qu., D. Wang & J. Ru. 2006. Coagulation Behavior of Aluminum Salts in Eutrophic Water: Significance of Al13 Species and Ph Control. Environmental science & technology. 40(1): 325-331.

Huang, C & Y. Chen. 1996. Coagulation of Colloidal Particles in Water by Chitosan. Journal Chem. Tech. Biotechnol. 66:221-232.

Ismirantie, R., Atmono & T.T. Praja. 2018. Perbandingan Kitosan dari Limbah Udang Windu dan Kitosan Murni Terhadap Penurunan Kadar Besi (Fe) pada Air Sumur Gali. Jurnal Rekayasa, Teknologi, dan Sains. 2 (2): 103-110.

Jana, S., A. Saha., A.K. Nayak., K.K. Sen & S.K. Basu. 2013. Aceclofenac-loaded Chitosan-tamarind Seed Polysaccharide Interpenetrating Polymeric Network Microparticles. Colloids and Surfaces B: Biointerfaces. 105(1): 303–309.

Kalsum, S.U & Indro. 2020. Pemanfaatan Limbah Udang (Kitosan) sebagai Koagulan Alami dalam Penurunan Parameter Air Gambut. Jurnal Daur Lingkungan Hidup. 3(1): 1-4.

Kawamura, S. 1991. Integrated Design of Water Treatment Facilities. John Wiley & Sons, Inc, USA.

Kusnaedi. 2006. Mengolah Air Gambut dan Air Kotor untuk Air Minum. Jakarta: Penebar Swadaya.

Kusnaidi. 2010. Mengolah Air Kotor untuk Air Minum. Jakarta: Swadaya.

Larry, D.B., F.J. Joseph & L.W. Barron. 1982. Process Chemistry for Water and Wastewater Treatment.

Majjid, S.Z & Dernengsih. 2018. Pemanfaatan Kitosan dari Limbah Kulit Udang sebagai Koagulan Penjernih Air. Chemical Process Engineering. 3(1): 27-32.

Manurung, M. 2011. Potensi Kitin/Kitosan dari Kulit Udang sebagai Biokoagulan Penjernih Air. Jurnal Kimia. 5(2): 182-188.

Meicahayanti, I., Marwah & Y. Setiawan. 2018. Efektivitas Kitosan Limbah Kulit Udang dan Alum sebagai Koagulan dalam Penurunan TSS Limbah Cair Tekstil. Jurnal Chemurgy. 2(1): 1-5.

Mu'minah. 2008. Aplikasi Kitosan Sebagai Koagulan untuk Penjernihan Air Keruh. Tesis Program Studi Kimia, FMIPA ITB.

Nastiti, Y., Y. Syarfi & H. Syamsu. 2015. Penyisihan Warna, Zat Organik dan Kekeruhan pada Air Gambut dengan Kombinasi Proses Koagulasi-Flokulasi Menggunakan Koagulan Aluminium Sulfat (AL2(SO4)) dan Membran Ultrafiltrasi. JOM FTEKNIK Unri. 2(2):1-7.

Ozacar, M., & I.A. Sengil. 2003. Evaluation of Tannin as a Coagulant Aid for Coagulation of Colloidal Particles, Colloid and Surfaces A. Physicochem Eng. Aspects. 229: 85 – 96.

Pahlevi, M.R. 2009. Analisis Kadar (Fe) dan Mangan dari Air Gambut Setelah Dijernihkan dengan Penambahan Tulang Ayam. Medan : Pascasarjana – Universitas Sumatera Utara (USU).

Prayudi, T. 2001. Pengaruh Ukuran Partikel Kitosan pada Proses Degradasi Limbah Cair Tektil. Jurnal Teknologi Lingkungan. 2(3):296-299.

Prihatinningtyas, E., & A.J. Effendi. 2013. Aplikasi Koagulan Alami dari Biji

Jagung dalam Pengolahan Air Bersih. Jurnal Tekno Sains. 2(2): 93-95.

Pontius, F.W. 2016. Chitosan as a Drinking Water Treatment Coagulant. American Journal of Civil Engineering. 4: 205-215.

Rathke, T.D & S.M. Hudson. 1994. Review of Chitin and Chitosan as Fiber and Film Formers. Macromol Chem Phys. 34(3): 375-473.

Rao, L.N. 2015. Coagulation and Flocculation of Industrial Wastewater by Chitosan. International Journal of Engineering and Applied Sciences. 2: 50-52.

Rehansyah, M.A., H.S. Edward & S. Elystia. 2017. Penyisihan Zat Organik dan Warna pada Air Gambut dengan Koagulan Alami Campuran (Biji Jagung, Biji Kelor dan Biji Semangka). Jom FTEKNIK. 4(2): 1-9.

Renault, F., B. Sancey., P.M. Badot & G. Crini. 2009. Chitosan for coagulation/flocculation processes – An eco-friendly approach. European Polymer. Journal. 45: 1337-1348.

Rumapea, N. 2009. Penggunaan Kitosan dan Polyalumunium Chlorida (PAC) untuk Menurunkan Kadar Logam Besi (Fe) dan Seng (Zn) dalam Air Gambut. [Tesis]. Universitas Sumatera Utara.

Sinardi., P. Suwondo & Suprihanto. 2013. Pembuatan, Karakterisasi dan Aplikasi Kitosan dari Cangkang Kerang Hijau (Mytulus Virdis Linneaus) sebagai Koagulan Penjernih Air. Teknik Sipil UNS. 2: 5-10.

Soekardi, M & A. Hidayat. 1988. Extent and Distribution of Peat Soils of Indonesia. Dalam paper presented at Third Meeting of the Cooperative Research on Problem Soils.

Suherman, D & N. Sumawijaya. 2013. Menghilangkan Warna dan Zat Organik Air Gambut dengan Metode Koagulasi-flokulasi Suasana Basa. Jurnal Riset Geologi dan Pertambangan. 23(2): 127-139.

Suprihanto. 1994. Pengolahan Air Gambut Kajian Terhadap Studi Labolatorium. Teknik Lingkungan ITB. Bandung.

Suptijah, P., W. Zahiruddin & D. Firdaus. 2008. Pemurnian air sumur dengan kitosan melalui tahapan koagulasi dan filtrasi. Buletin Teknologi Hasil Perikanan. 11(1): 65-72.

Sutrisno, Muhdarina & T.A. Amri. 2014. Pengolahan Air Gambut dengan Koagulasi Cair Hasil Ekstraksi Lempung Alam Desa Cengar Menggunakan H2SO4. JOM FMIPA UNRI. 1(2):13-20.

Trimaily, D., Nofrizal & E. Maryanti. 2017. Efektivitas Penggunaan Tawas dan Tanah Lempung pada Pengolahan Air Gambut menjadi Air Bersih. Dinamika Lingkungan Indonesia. 4(1): 39-52.

Wasisto, S. 1980. Laporan Penelitian Sumber Air Minum dan Cara Pembuangan Kotoran di Daerah Pasang Surut Rantau Rasau Jambi. Pusat Penelitian Ekologi Kesehatan. Badan Litbangkes Depkes RI. Jakarta.

Weiner, R.F & Matthews, R.A. 2003. Enviromental Engineering, Fourth Edision. Elsevier Science, USA.

Yang, Z., B. Gao & Q. Yue. 2010. Coagulation Performance and Residual Aluminium Speciation of Al2(SO4)3 and Polyaluminium Chloride (PAC) in Yellow River Water Treatment. Chemical Engineering Journal. 165: 122-132.

Zadow, R. 2009. The Real Dirth On Humic Subtances. Maximum Yield. 40-44.

Zeijang, 2008.The physical and chemical property of Aluminum sulfat. http://www.chemnet.com/cas/id/10043-013/Aluminumsulfate. html. (Diakses pada tanggal 9 Maret 2021)

Zemmouria, H., S. Kadouche., H. Lounici., M. Hadioui & N. Mameri. 2011. Use of Chitosan in Coagulation Flocculation of Raw Water of Jeddara and Beni Amrene Dams. Water Supply. 11(2): 202-21.