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The Influence of *Aloe Vera* Biocoagulant and Mixing Time in Reducing Biological Oxygen Demand, Chemical Oxygen Demand and Total Suspended Solids Levels

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Aloe vera is a plant with complex composition of carbohydrates, sugars, and mucilage, enabling it to bind particles in water and serve as a coagulant in the coagulation-flocculation process. This study aims to assess the impact of varying doses and rapid stirring times on the reduction of biochemical oxygen demand (BOD), chemical oxygen demand (COD), and total suspended solids (TSS) levels in liquid waste from pharmaceutical companies. The research involves two factors: (1) *aloe vera* concentration at three levels (20 mL/L, 40 mL/L, and 60 mL/L); (2) fast mixing time at three levels (20 minutes, 40 minutes, and 60 minutes), with each treatment repeated thrice. Levels of BOD, COD and TSS were measured post-treatment using a jar test tool. The results of the analysis showed that the optimal efficacy of the *aloe vera* coagulant occurred at a concentration of 40 mL/L for 40 minutes. At this optimal condition, the effectiveness of the *aloe vera* coagulant in reducing BOD, COD and TSS levels was 72.3%, 78.5%, and 65.3%, respectively. This indicates that the *aloe vera* coagulant can be effectively utilized in the treatment of pharmaceutical industrial wastewater to reduce BOD, COD and TSS levels.

Keywords: coagulant, *aloe vera*, jar test, liquid waste from pharmaceutical industry.

Introduction

The pharmaceutical industry plays a crucial role in human development, because of its role in improving the health of people. The development of the pharmaceutical industry has great benefits for society, but also negative impacts. Despite its advantages, the pharmaceutical industry poses environmental challenges, primarily through the generation of hazardous and toxic waste, that can adversely affect the local surroundings and contribute to climate change due to the emission of gases (Dermawan et al., 2018; Ningsih et al., 2019). In response to these concerns, the Indonesian government has instituted a Green Pharmacy Policy to mitigate the environmental impact of the pharmaceutical industry. Nevertheless, a significant portion of the pharmaceutical sector has yet to embrace the principles of green pharmacy. Even though many pharmaceutical companies engage in liquid waste processing, the effectiveness of these efforts remains suboptimal, posing potential dangers to the environment (Crisnaningtyas and Vistanty, 2016). Research conducted by Meirdana and Utomo (2020) reveals that liquid waste from the pharmaceutical industry exhibits elevated levels of three key water pollution parameters: biological oxygen demand (BOD), chemical oxygen demand (COD) and total suspended solid (TSS). In addition, according to Dawood et al. (2023), pharmaceutical waste also contains several other compounds, especially Ca^{2+} and Mg^{2+}. Consequently, it is imperative for the pharmaceutical industry to enhance liquid waste treatment processes to decrease BOD, COD and TSS levels before disposal into rivers.

A viable method to mitigate BOD, COD and TSS levels in liquid pharmaceutical industrial waste is through the coagulation process. This involves destabilizing colloids by introducing a coagulant, followed by rapid stirring and subsequent slow stirring or flocculation to induce sedimentation at the bottom of settling tanks. According to Lichtfouse et al. (2022), wastewater treatment generally comprises five stages: 1) pre-treatment utilizing physicochemical and mechanical methods; 2) primary treatment involving physicochemical and chemical techniques; 3) secondary treatment using physicochemical and biological approaches; 4) tertiary or final treatment employing physical and chemical methods; and 5) sludge treatment. The coagulation system, a straightforward yet highly effective wastewater treatment method, proves instrumental in reducing water pollutant parameters, particularly BOD, COD, and TSS (Ang, 2020).

Various plants, including *aloe vera*, can serve as natural coagulants to diminish water turbidity (January et al., 2021; Benalia et al., 2021; Nadiah et al., 2016). *Aloe vera*, with its mucilage content, holds promise as a natural coagulant for reducing water turbidity (January et al., 2021; Benalia et al., 2021; Nadiah et al., 2016). The utilization of natural coagulants is not only cost-effective compared to synthetic alternatives but also environmentally friendly. *Aloe vera*, in particular, stands out for its accessibility and ease of cultivation (Lamsaputra et al., 2021).

To ascertain the optimum coagulant dosage, the jar test is employed. This method evaluates flocculation and coagulation processes by introducing coagulants/flocculants to wastewater samples, observing the formed coagulant or flocculant while stirring. The jar test, as discussed by Lailani et al. (2023), provides valuable insights into the efficacy of coagulation for wastewater treatment. According to Rahimah et al. (2016) and Martina et al. (2018), coagulation is influenced by several factors that affect coagulation, namely (1) pH, i.e., the coagulation process will run well at optimum pH (around 7); (2) type of coagulant, i.e., solution coagulants are more effective than powder coagulants; (3) dissolved ion levels, i.e., anions have a greater influence than cations, thus sodium, calcium and magnesium ions have no effect on the coagulation process; (4) turbidity level, i.e., the higher the turbidity level, the faster the formation of flocs; (5) mixing time, i.e., mixing coagulants into water, where too slow stirring will cause slow floc formation, and conversely, too fast stirring will cause the floc that has been formed to break again; (6) contact time, i.e., flocs will form at the optimum time; (7) coagulant dosage, i.e., producing another floc core from the coagulation and flocculation process is highly dependent on the required coagulation dosage, and if the coagulant is applied in accordance with the required dose, the process of forming the floc core will run well. The optimum contact time is 30 minutes (Uyun et al., 2012).

Aloe vera comprises two distinct parts with contrasting compositions. The inner parenchymal tissue, or flesh, yields a clear, semi-solid gel characterized by a neutral taste and a composition of 99% water with a pH of 4.5. This gel also contains amino acids, minerals, and essential vitamins such as A, C, and E, along with enzymes like carboxypeptidase, proteins, and polysaccharides such as glucomannan and acemannan. In contrast, specialized cells located beneath the skin produce exudates with yellow latex, imparting a bitter taste and exhibiting a potent laxative effect (Benalia et al., 2021; Nadiah et al., 2016).

Aloe vera is an appropriate ingredient as a substitute for chemical coagulants because it contains protein and mucilage or gel which is similar to the cactus plant, and binding particles in water, so it can be used to purify water (Hamman, 2008; Pichler et al., 2012). *Aloe vera* was chosen as a biocoagulant, because it is easy to make and the process is fast, as seen in *Fig. 1*. *Aloe vera* can also grow easily in any place. Besides, *aloe vera* is also non-toxic so it has no impact on health and the environment (Furnawanthi, 2002; Lamsaputra et al., 2021), as an environmentally friendly natural material for wastewater treatment (Sukmana et al., 2021). There are several factors that influence coagulation and flocculation process (Saritha et al., 2017), including pH, coagulant doses, and contact time/mixing speed.

The cost-effectiveness and ready availability of *aloe vera* make it a lucrative option for use as a natural coagulant. Consequently, *aloe vera* has found widespread application in research, particularly in the realms of health and water purification (January et al., 2021; Ambarwati et al., 2020; Benalia et al., 2021; Nadiah et al., 2016). Its potential extends to areas such as wound healing, as evidenced by studies in this domain (Mumtaz et al., 2020), while Amran et al. (2018) stated that the advantages of natural coagulants over synthetic coagulants are the following: (a) the resulting precipitate is non-toxic; and (b) they are not harmful to health and the environment.

The pharmaceutical industry in Indonesia is experiencing growth parallel to the expanding population and governmental initiatives aimed at enhancing public health. Despite these positive developments, the adverse consequences stemming from the liquid waste generated by the pharmaceutical sector cannot be overlooked, posing a potential threat to the environment and consequently affecting human health. This research endeavors to investigate the efficacy of natural coagulants derived from *aloe vera* and the influence of contact time on mitigating key water pollutant parameters, specifically BOD, COD and TSS.

Methods

Many studies have been conducted regarding the use of *aloe vera* as a natural coagulant (Ambarwati et al., 2020; Nadiah et al., 2016; Benalia et al., 2021). This experimental research involves two independent variables: (1) *aloe vera* coagulation dosage (K) with levels of 20, 40, and 60 mg/L, and (2) contact time / mixing time (W) with durations of 20, 40, and 60 minutes, each repeated three times. Contact time is one of the variables that determine the effectiveness of using coagulants in water purification (Benalia et al., 2021). The aim is for complete dispersion in the coagulation process but contact time that is too long will make the flocs that have stabilized become unstable again, making the water more turbid (Syahputra and Poedjiastoeti, 2022). Previous studies have mostly examined the effectiveness of the effect of coagulant doses on water purification by giving several doses of *aloe vera* natural coagulant. The addition of contact time as an independent variable in this research makes it possible to examine the effectiveness of the interaction effect between contact time and coagulant dose on the dependent variable (BOD, COD and TSS).

The research aims to explore the impact of varying coagulant dosages and stirring times in the experimental outcomes. The experimental equation for this study is as follows:

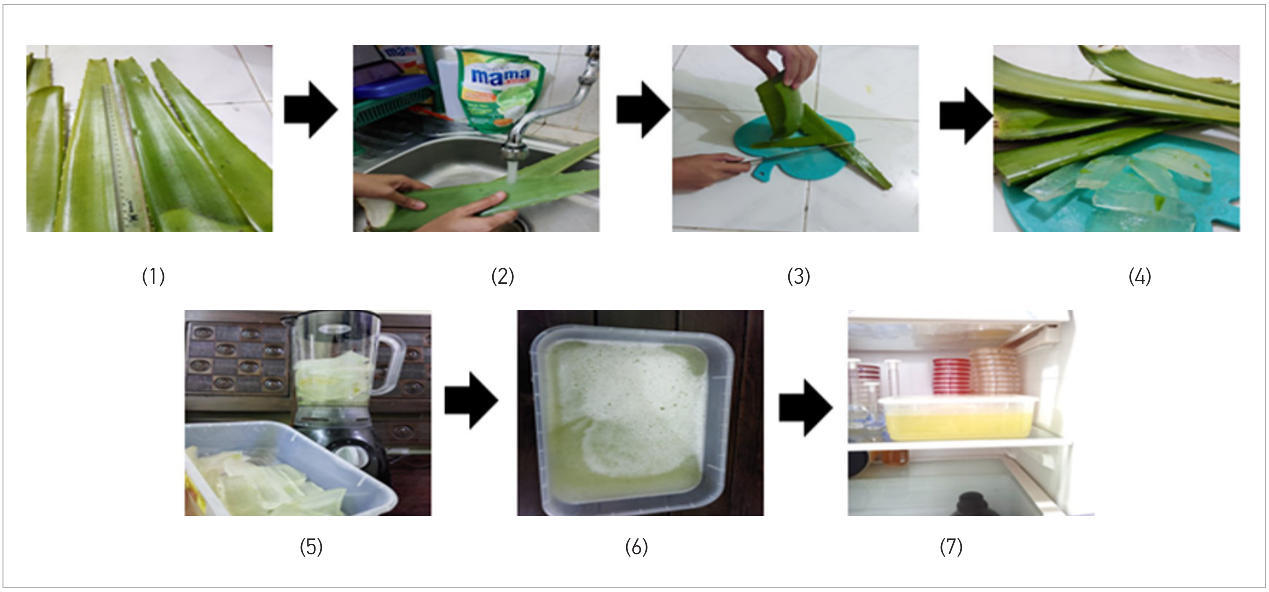
$$Y_{ijk} = U + K_i + W_i + (KW)_{ij} + E_{ijk} \tag{1}$$

Where: Y_{ijk} – the response of BOD, COD, or TSS to the treatment of coagulant dose i, stirring time y, and the interaction of coagulant dose and stirring time replicate k; U – average effect; K_i – effect of dose i; W_j – effect of contact time j; $(KW)_{ij}$ – time effect; E_{ijk} – residual effect.

Materials

The materials needed in the manufacture of natural coagulants from *aloe vera* are: 1) $HgSO_4$ powder (mercury sulfate); 2) $K_2Cr_2O_7$ 0.25 N (potassium dichromate); 3) sulfuric acid-silver sulfate; 4) distilled water (Aquades); 5) ferroin; 6) FAS solution; and 7) liquid waste samples. The necessary equipment includes: 1) Erlenmeyer flask; 2) pipette; 3) Liebig condenser; 4) hot plate or electric heater; 5) burette; 6) retort stand; and 7) beaker.

Fig. 1. *Aloe vera coagulant production process*



The process of making natural coagulation from *aloe vera* is quite simple and easy, and the materials and tools are easily available. The process is also not harmful to health. In general, the steps are as shown in *Fig. 1*.

1 Harvest mature aloe vera leaves; (2) peel the skin; (3) cut aloe vera into 1–2 cm pieces; (4) place in a container; (5) dry at 80°C in an oven for 15–20 hours; (6) blend until smooth, and (7) store in a cool cabinet.

The levels of BOD, COD and TSS were measured through these following steps:

a) **BOD measurement.** BOD was measured based on the following formula:

$$DO(mg/L) = V \times N \times 800/(Vsample - 4) \quad (2)$$

Where: *V* – volume of $Na_2S_2O_3$ (mL); *N* – concentration of $Na_2S_2O_3$ (N).

$$BOD"5" = DO" - DO"5" \quad (3)$$

The calculation for the efficiency of BOD removal before and after treatment is as follows:

$$BOD \text{ removal efficiency} = (A - B)/A \times 100\ \% \quad (4)$$

Where: *A* – *BOD* concentration before treatment (mg/L); *B* – *BOD* concentration after treatment (mg/L).

b) **COD measurement** uses the following formula:

$$Normality\ FAS = (V_1 \times N_1) / V_2 \quad (5)$$

Where: V_1 – volume of $K_2Cr_2O_7$ solution used (mL); V_2 – volume of ferro ammonium sulfate (FAS) solution required (mL); N_1 – normality of $K_2Cr_2O_7$ solution.

$$COD(mg/L) = (A - B) \times N \times 800\ /\ Vsample \quad (6)$$

Where: *A* – volume of FAS solution for blank (mL); *B* – volume of FAS solution needed for the sample (mL); *N* – normality of FAS solution.

$$\%COD\ removal\ efficiency = (A - B)/A \times 100\% \quad (7)$$

Where: *A* – *COD* concentration before treatment (mg/L); *B* – *COD* concentration after treatment (mg/L).

(c) **TSS measurement** uses the following formula:

$$"TSS"("mg"/"L") = ("A" - B)/A \times 100C \quad (8)$$

Where: *A* – weight of filter paper + dry residue (mg); *B* – weight of filter paper + initial media (mg); *C* – sample volume (mL); 1000 – conversion from mL to liters.

The calculation for the efficiency of TSS removal before and after treatment is as follows:

$$\%TSS\ removal\ efficiency = (A - B")/A \times 100\%" \quad (9)$$

Where: *A* – TSS concentration before treatment (mg/L); *B* – TSS concentration after treatment (mg/L).

A combination of treatments is shown in *Table 1*.

Analysis of a variance test is used to determine the effect of treatment, and then followed by the least significant difference (LSD) test to identify the difference of mean values.

Tabel 1. *Combination of treatments*

	Coagulant (B)		
	B1 = 20 mg/L	B2 = 40 mg/L	B3 = 60 mg/L
A1 = 20 minutes	A1B1	A1B2	A1B3
A2 = 40 minutes	A2B1	A2B2	A2B3
A3 = 60 minutes	A3B1	A3B2	A3B3

Results and Discussion

The discussion will begin with normality testing, treatment effect test and treatment mean test. For simplicity, the effects of coagulation treatment and mixing time will be discussed for each parameter, namely BOD, COD and TSS, as follows:

BOD efficiency

The effectiveness and efficiency (%) of BOD removal due to coagulation are calculated using formulas 2, 3 and 4, as shown in *Table 2*.

The normality test yielded a significance value of 0.318 and the homogeneity test resulted in a significance value of 0.235, both of which are greater than 0.05. Consequently, the data in *Table 2* are distributed normally and homogeneously. After the data were declared homogeneous and normal, an F test was conducted to determine the impact of coagulation treatment and mixing time on the efficiency of BOD removal. The analysis results are as shown in *Table 3*.

Table 2. *Efficiency (%) of BOD removal (mg/L)*

A (Time)-contact time	Repetition	B (dose of coagulant) mg/L (%)		
Minute		20	40	60
20	1	57.1	69.0	62.6
	2	58.1	68.1	61.7
	3	59.0	68.1	61.7
Average		58.1	68.4	62.0
40	1	62.6	71.7	70.0
	2	62.6	72.6	63.5
	3	61.7	72.6	66.3
Average		62.3	72.3	66.3
60	1	59.0	65.3	58.1
	2	59.0	67.2	59.0
	3	58.1	67.2	58.1
Average		58.7	66.6	58.4

According to the results of the treatment effect test (*Table 3*), both the coagulation and mixing time factors exhibit significant effects with *P* values of 0.000 (< 0.05). Additionally, the interaction between coagulation and mixing time also shows significance at 0.004. These findings indicate that the treatment and interaction effects exert a substantial influence on BOD removal efficiency. To discern the specific differences between treatments, the LSD test was selected. The mean test results for the impact of coagulants on BOD removal efficiency are detailed in *Table 4*.

Table 3. *Test results of treatment effect on efficiency of BOD removal (mg/L)*

Source	Type III sum of squares	df	Mean square	F	Sig
Corrected Model	586.376[a]	8	73.297	114.926	0.000
Intercept	108 972.374	1	108 972.374	170 862.607	0.000
Coagulant	134.223	2	67.111	105.227	0.000
Mixing Time	437.490	2	218.745	342.980	0.000
Coagulant*mixing time	24.664	4	3.666	5.748	0.004
Error	11.480	18	0.638		
Total	109 570.230	27			
Corrected total	597.856	26			

a. R squared = 0.981 (adjusted R squared = 0.972).

Table 4. *Multiple comparisons for BOD*

(I) Coagulation	(J) Coagulation	Mean difference (I-J)	Std. error	Sig	95% Confidence interval	
					Lower bound	Upper bound
20.00	40.00	−3.7222*	0.37747	0.000	−4.5132	−2.9313
	60.00	1.6000*	0.37647	0.074	0.8091	2.3909
40.00	20.00	3.7222*	0.37747	0.016	2.9313	4.5132
	60.00	5.3222*	0.37447	0.000	4.5313	6.1132
60.00	20.00	−1.6000*	0.37647	0.074	−2.3909	−0.8091
	40.00	−5.3222*	0.37447	0.000	−6.1132	−4.5313

The error term is mean square (error) = 0.638. *The mean difference is significant at the 0.05 level.

The results of the mean value test using LSD (*Table 4*) indicate that the coagulation treatment at levels 1 (20 mg/L) and 2 (40 mg/L), as well as levels 2 (40 mg/L) and 3 (60 mg/L), have a significance value of 0.000 (< 0.05). Therefore, it is statistically deemed to be highly significantly different. Meanwhile, at levels 1 (20 mg/L) and 3 (60 mg/L), the significance value is 0.074 (> 0.05), suggesting that statistically there is no significant difference between these two levels.

COD efficiency

By using formulaa 5, 6 and 7, the effectiveness and efficiency (%) of COD removal as a result of coagulation treatment are presented in *Table 5.* Each treatment was repeated 3 times, as shown in *Table 5*.

The normality and homogeneity tests conducted on the data in *Table 5* indicate that the significance values for both tests were 0.339 and 0.335, respectively. Therefore, it can be asserted that the data in *Table 5* are normally distributed and homogenous.

After being declared normal and homogeneous, further testing on the effects of the treatment was conducted using an F test. The test results are presented in *Table 6*.

The test results (*Table 6*) demonstrate that the effects of coagulation treatment, mixing time, and the interaction between coagulation and time have a significant influence on COD removal efficiency, as indicated by a significance value of 0.000 (< 0.05). The LSD test was subsequently conducted to discern differences in treatment mean values. The results revealed highly significant differences between treatments 1 and 2 (coagulation 20 mg/L and 40 mg/L), and treatments 2 and 3 (coagulation 40 mg/L and 60 mg/L), with respective significance values of 0.000 (< 0.05). Similarly, a significant difference was observed between treatments 1 and 3 (coagulation 20 mg/L and 60 mg/L) with a significance value of 0.016 (< 0.05). Consequently, all treatments exhibited variations in mean values, as depicted in *Table 7*.

Table 5. *Efficiency of COD removal (mg/L)*

T (Time)	Repetition	W (Dose) mg/L (%)		
Minute		20	40	60
20	1	62.8	72.7	65.3
	2	65.3	70.2	62.8
	3	62.8	70.2	65.3
Average		63.6	71.1	64.5
40	1	65.3	77.7	67.8
	2	65.3	77.7	65.3
	3	65.3	80.2	67.8
Average		65.3	78.5	66.9
60	1	62.8	72.7	67.8
	2	62.8	72.7	70.2
	3	62.8	70.2	67.8
Average		62.8	71.9	68.6

Table 7 shows that there is little difference between the BOD and COD parameters. In the COD parameter, the average mean value for all treatments (treatments 1 and 2, 1 and 3; and 2 and 3) was significantly different. While in BOD the average mean value between treatments 1 and 3 was not significant. This is because in BOD the flocculation that has been formed will be destroyed again during the 60-minute mixing time. These results also show the difference in character between BOD and COD due to the treatment of adding *aloe vera* natural coagulant.

Table 6. *Test results of treatment effect on efficiency of COD removal (mg/L)*

Source	Type III sum of squares	df	Mean square	F	Sig
Corrected model	254.772[a]	8	31.846	30.963	0.000
Intercept	116 755.565	1	116 755.565	113 518.194	0.000
Coagulant	102.263	2	51.311	49.889	0.000
Mixing time	46.356	2	23.178	22.535	0.000
Coagulant* Mixing time	105.793	4	26.448	25.715	0.000
Error	18.513	18	1.029		
Total	117 028.850	27			
Corrected total	273.285	26			

a. R squared = 0.932 (adjusted R squared = 0.902).

Table 7. *Multiple comparisons for COD*

(I) Coagulation	(J) Coagulation	Mean difference (I–J)	Std. error	Sig	95% Confidence interval	
					Lower bound	Upper bound
20	40.00	−3.6556*	0.27808	0.000	−4.6600	−2.6511
	60.00	5.4889*	0.47808	0.000	−6.4933	4.4845
40	20.00	3.6556*	0.27808	0.016	2.6511	4.6600
	60.00	−1.8333*	0.17808	0.000	−2.8377	0.8289
60	20.00	5.48889*	0.47808	0.000	4.4845	6.4933
	40.00	1.8333*	0.17808	0.016	0.8289	2.8377

Based on observed means. The error term is mean square (Error) = 1.029. *The mean difference is significant at the 0.05 level.

TSS efficiency

Using the same formulas 8 and 9, the efficiency of TSS removal due to coagulation treatment is presented in *Table 8.*

Similar to BOD and COD, before conducting the treatment effect test using the F test, normality and homogeneity tests were performed. The test results show that the significant value for normality and homogeneity is 0.073 and 0.87, respectively; so we concluded that the data are normally distributed and homogenous, and each treatment is repeated 3 time.

As in the BOD and COD parameters, the next test is to determine the effect of *aloe vera* natural coagulant treatment and mixing time using the F test. The results of the analysis of the treatment effect of coagulation on the TSS parameter, along with its removal efficiency, are presented in *Table 9*.

Based on *Table 9*, it is evident that the application of coagulation, mixing time and the interaction between coagulation and time significantly influence TSS removal efficiency. This is indicated by a significance value of 0.000 (< 0.05) as shown in *Table 9*. Subsequently, a test of mean differences was conducted, similar to BOD and COD. The results of the mean difference test using LSD are presented in *Table 10*.

Table 10 illustrates that the mean values for all treatments indicate that characteristics of TSS are similar with BOD. The LSD test results for the treatment effects reveal differences between treatments 1 and 2 (coagulant doses of 20 and 40 mg/L), and treatments 2 and 4 (doses of 40 mg/L and 60 mg/L) with a significance value of 0.00 (< 0.05). However, there was no significant difference between coagulant treatment doses 1 and 3 (20 mg/L and 60 mg/L), as indicated by the significance value of 0.082 (> 0.05).

Table 8. *Efficiency of TSS removal (mg/L)*

T (Mixing time)	Repetition	W (Dose) mg/L (%)		
Minute		**20**	**40**	**60**
20	1	54.2	61.9	59.3
	2	54.2	59.3	61.9
	3	54.2	61.9	59.8
T (Mixing time)	Repetition	W (Dose) mg/L (%)		
Average		54.2	61.0	60.3
40	1	59.3	66.9	61.9
	2	61.9	64.4	64.4
	3	59.3	64.4	61.9
Average		60.2	65.3	62.7
60	1	56.8	61.9	56.8
	2	59.3	61.9	54.2
	3	56.8	64.4	54.2
Average		57.6	62.7	55.1

Table 9. *Tests of between-subject effects for TSS dependent*

	Type III Sum of Squares	df	Mean Square	F	Sig
Corrected model	384.923[a]	8	48.115	87.719	
Intercept	99 056.784	1	99 056.784	180 589.680	0.000
Coagulant	180.583	2	90.291	164.610	0.000
Mixing time	92.116	2	46.058	83.968	0.000
Coagulant* Mixing time	112.224	4	28.056	51.149	0.000
Error	9.873	18	0.549		
Total	99 451.580	27			
Corrected total	394.796	26			

a. R squared = 0.975 (adjusted R squared = 0.964)

Table 10. *Multiple comparisons test for TSS*

(I) TIME Coagulation	(J) TIME Coagulation	Mean difference (I–J)	Std. error	Sig	95% Confidence interval	
					Lower bound	Upper bound
20	40.00	−4.4778*	0.34913	0.000	−5.2113	−3.7443
	60.00	2.8000*	0.34913	0.082	−3.5335	−2.0665
40	20.00	4.4778*	0.34913	0.000	3.7443	5.2113
	60.00	1.6778*	0.34913	0.000	0.9443	2.4113
60	20.00	2.8000*	0.34913	0.082	2.0665	3.5335
	40.00	−1.6778*	0.34913	0.000	−2.4113	−0.9443

Based on observed means. The error term is mean square (Error) = 0.549.; *. The mean difference is significant at the 0.05 level.

In summary, the initial values for BOD, COD and TSS in wastewater samples before coagulation are presented in *Table 11*.

Based on the *Table 3*, *6* and *9*, the analysis results of treatment effects reveal that the application of coagulation to wastewater samples significantly influences the removal efficiency of BOD, COD and TSS, as indicated by a significance value of 0.000 (< 0.05). This reduction is attributed to a chemical process or bond formed between the natural coagulant derived from *aloe vera* and the pharmaceutical waste. *Aloe vera* proves effective as a coagulant due to its content of complex carbohydrates and sugars, which facilitate the binding of particles in water. These particles then interact with the coagulant to form clumps, resulting in lower water turbidity and clearer water.

The coagulation process itself involves the destabilization of colloidal particles present in liquid waste, demonstrating the efficacy of *aloe vera* as a natural coagulant in fostering the removal of pollutants from wastewater samples, as shown in *Fig. 2*.

The formation of flocs plays a crucial role in reducing the values of BOD, COD and TSS parameters. The BOD parameter signifies the amount of oxygen required by microbes for the oxidation of organic compounds present in pharmaceutical waste. This oxidation process is essential for breaking down organic chemical compounds within liquid waste. The chemical reaction illustrating the microbial oxidation of organic compounds in liquid waste is expressed as follows:

Organic compounds + O_2 bacteria $\longrightarrow$ CO_2 + H_2 + energy + cellular substances in waste

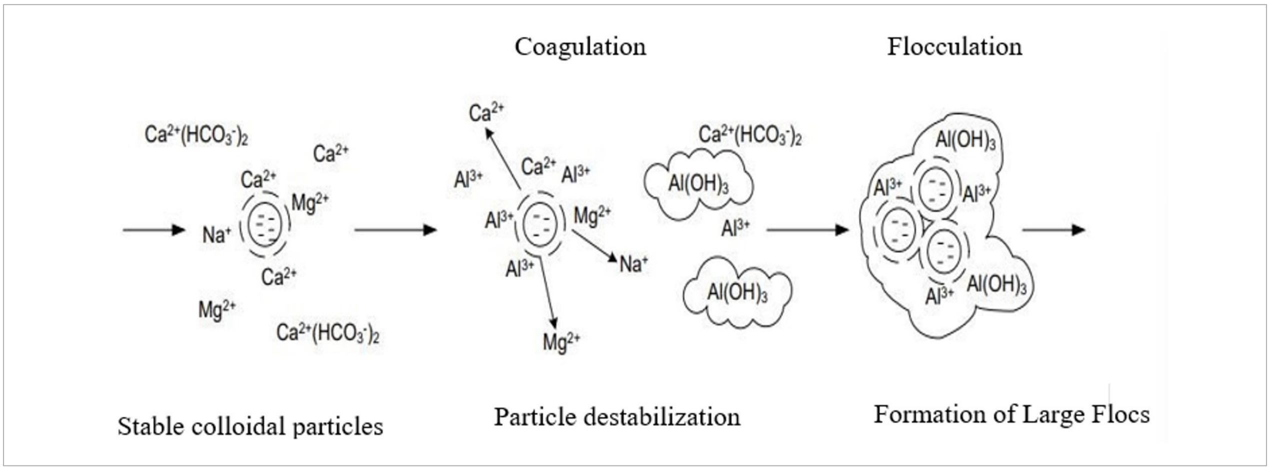
This reaction underscores that the microbial conversion of hazardous compounds in wastewater results in the generation of CO_2 gas, water, cellular materials, and energy.

The introduction of natural coagulants, such as *aloe vera*, aims to reduce the repulsive forces between colloidal particles. Coagulation effectiveness reaches its optimum when ions with an opposite charge to the colloidal particles are introduced until flocs are formed. Colloidal particles usually carry a negative charge; therefore, the ions added should have a positive charge. *Aloe vera* contains polysaccharides which can help form clots or flocs in water, and agglomerate small

Table 11. *Average values of BOD, COD and TSS parameters before and after the application of coagulation to wastewater samples*

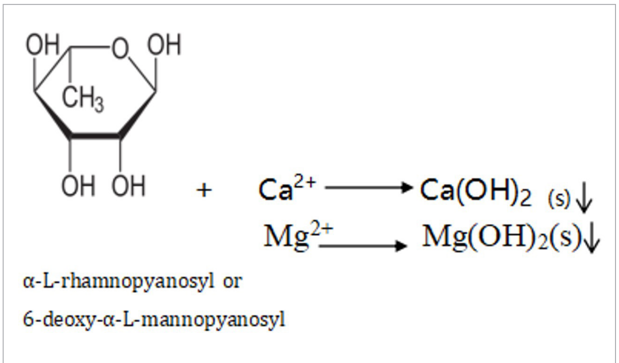
No.	Parameter	Std Quality (mg/L)	Initial Condition (mg/L)	Final Condition (mg/L)	Effectiveness (%)
1	BOD	75	178.4	45	74.8%
2	COD	150	403	60	85.1%
3	TSS	75	157	54.7	65.3%

Fig. 2. *Coagulation flocculation process*



particles dissolved in water, making the settling or filtration process easier. Beside that, *aloe vera* also contains other compounds, such as enzymes and phenolic compounds, which have antibacterial and antimicrobial properties, to eliminate pathogenic microorganisms. Pharmaceutical industry wastewater contains several positive ions such as Ca^{2+}, Mg^{2+} and K^{+}, which will form a precipitate if they react with the natural *aloe vera* coagulant which contains OH^{-} ions. In general, the reaction between natural coagulant *aloe vera* and wastewater is shown is *Fig. 3*. Pharmaceutical waste usually contains positive ions such as Ca^{2+}, Mg^{2+} (Dawood et al., 2023); if reacting with *aloe vera*, it will produce $Ca(OH)_2$ or $Mg(OH)_2$, which precipitates, and causes the water to become clearer.

Fig. 3. *Aloe vera reaction in pharmaceutical waste*



Based on discussion above, *aloe vera* can be used as a coagulant because it contains complex carbohydrates and sugars that can bind particles in water. it also contains mucilage as in cactus plants that have been used as water purifiers.

Based on the discussion above, *aloe vera* serves as an effective coagulant due to its polygalacturonic acid content, a compound proven to diminish water turbidity (Pichler et al., 2012). The coagulation process involves galacturonic acid, which acts by adsorption and combination mechanisms, causing particles to bind to the polygalacturonic acid compound without direct contact (Theodoro et al., 2013). Turbidity, as a water parameter, signifies the presence of both organic and inorganic materials in the water (Malaka, 2011).

The total suspended solids (TSS) measurements reveal a significant correlation between the quantity of *aloe vera* gel and turbidity reduction. Post-treatment, turbidity decreases by 61.11%, 72.22%, and 70.56% for 0.1 mL, 0.3 mL, and 0.5 mL of *aloe vera* gel, respectively. The trend indicates a consistent reduction in residual turbidity with increasing coagulant dosage. However, a noteworthy observation occurs at 0.5 mL, where a slight turbidity increase is noted. This phenomenon is attributed to the delicate balance required in coagulant dosage; while higher amounts generally decrease turbidity, excessive dosage can impede proper floc formation, leading to a resurgence in turbidity. This aligns with Yuliastri's (2010) findings, emphasizing the importance of careful coagulant dosage to achieve and maintain optimal turbidity reduction in water treatment processes.

Pharmaceutical waste, characterized by elevated levels of biochemical oxygen demand (BOD), chemical oxygen demand (COD), and total suspended solids (TSS) can undergo a coagulation-flocculation process through the administration of an *aloe vera* coagulant. This physical treatment method involves introducing a coagulant that binds colloidal particles in the liquid waste, forming clumps or flocs due to opposite charges. The subsequent precipitation of these clumps leads to a reduction in BOD, COD, and TSS parameters. This coagulation-flocculation process in pharmaceutical liquid waste bears similarities to the treatment of batik liquid waste, as reported by Radityaningrum in 2017. The sedimentation induced by flocculation contributes to a decline in BOD, COD and TSS parameters. The study's results support previous research by January et al. (2021) and Meirdana and Utomo (2020), highlighting the effectiveness of *aloe vera* as a coagulant in mitigating BOD, COD and TSS levels in liquid waste.

The introduction of *aloe vera* coagulation significantly impacted the reduction of biochemical oxygen demand (BOD), with the initial value of 178.4 mg/L exceeding the quality standard of 75. Following coagulation, the average BOD decreased to 45 mg/L (*Table 10*), resulting in an average reduction of 133.144 mL/g and an effectiveness of 74.8%, categorizing it as quite effective. The removal efficiency findings in *Table 3* indicate that administering coagulation at a dose of 40 mg/L with 40 minutes of stirring proved most effective, yielding the highest removal efficiency of 72.3% compared to other conditions. The optimal precipitation occurred within this timeframe, leading to maximal BOD removal efficiency. However, extending stirring time to 60 minutes with a 60 mg/L coagulant resulted in a decreased average efficiency of 58.5%, lower than the 40-minute contact time. Statistical analysis using the LSD test revealed significant differences in mean values between coagulant doses of 20 mg/L and 40 mg/L, as well as doses of 40 mg/L and 60 mg/L. Conversely, no significant difference was observed between doses of 20 mg/L and 60 mg/L. As per *Table 18*, the application of coagulants effectively reduced BOD concentration in wastewater from 178.4 mg/L to 45 mg/L, meeting the standard quality requirement of 75 mg/L.

The application of *aloe vera* coagulant significantly reduces chemical oxygen demand (COD) and total suspended solids (TSS), as evidenced by highly significant removal efficiencies (*P* value < 0.05) in F test results (*Tables 6* and *8*). Coagulant and stirring induce flocculation, leading to precipitation that settles, causing a substantial drop in COD and TSS levels. Initial averages of 403 mg/L (COD) and 157 mg/L (TSS) in pharmaceutical waste samples decrease to 60 mg/L and 54.7 mg/L, respectively, after coagulant and stirring. The average removal efficiencies are 85.1% for COD and 65.3% for TSS, indicating notably high efficiency in COD removal and moderately high efficiency in TSS removal. Importantly, both parameters meet specified quality standards (*Table 8*).

The LSD test outcomes for the mean values of COD and TSS reveal a substantial influence of the treatment involving coagulant application and contact time on their respective averages. This is substantiated by the significance level of the test results, all of which register at 0.000 (< 0.05), as depicted in *Tables 7* and *9*. While exhibiting slight differences from BOD, the observed pattern is largely analogous. Both COD and TSS demonstrate optimal removal efficiency at a coagulant dose of 40 mg/L and a stirring time of 40 minutes, yielding peak efficiencies of 78.5% for COD and 65.3% for TSS. This can be attributed to the nearly perfect flocculation process at this dosage, resulting in effective sedimentation. Conversely, elevating the coagulant dose and stirring time induces the re-solubilization of COD and TSS, leading to a reduction in removal efficiency. These findings corroborate with January et al. (2021) and Meirdiana (2020) and validate the research outcomes of Benalia et al. (2021).

The analysis and discussion presented above strongly support the efficacy of *aloe vera* as a natural coagulant for diminishing biochemical oxygen demand (BOD), chemical oxygen demand (COD), and total suspended solids (TSS) in pharmaceutical wastewater. Although the price of natural coagulants is slightly more expensive than synthetic coagulants per kilogram (IDR 86.000 vs. 85.0000), the use of natural coagulants has several advantages: (1) they are environmentally friendly; and (2) they produce decomposable and non-toxic precipitates (Andiwijaya, 2017). Meanwhile, the precipitate resulting from coagulant synthesis is still toxic and a danger to health. However, the challenge lies in scaling up production to meet industrial demands and efficiently reduce BOD, COD and TSS in liquid waste from diverse chemical industries. Addressing this challenge requires meticulous calculations to determine the necessary plantation area, coagulant quantities, and the development of an economically viable and environmentally friendly industrial process.

Conclusion

The dose of *aloe vera* natural coagulant, stirring time and the interaction between coagulant dose and stirring time had a very significant effect on the effectiveness of reducing BOD, COD and TSS in pharmaceutical industry wastewater. The reduction efficiency reached an optimum at a coagulant dose of 40 mg/L and a contact time of 40 minutes with an efficiency value of 74.8% for BOD, 85.1% for COD and 65.3% for TSS. The results of the reaction at this dose will form flocs that settle, thus making the wastewater clearer. The stirring time must be done properly, because if it passes the optimal time, the floc that has been formed will break again and make the turbidity increase again.

This research is preliminary; therefore, further research with more varied doses of natural coagulants and contact times needs to be carried out, to design the development of *aloe vera* natural coagulants on an industrial scale in an effort to ensure that chemical industry waste does not pollute the environment, especially river water.

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References

Amran A.H., Zaidi N.M., Muda K., Loan L.W. (2018) Effectiveness of Natural Coagulant in Coagulation Process: A Review. International Journal of Engineering & Technology 7(3.9):34-37. https://doi.org/10.14419/ijet.v7i3.9.15269

Ambarwati N. S. S., Supiani T., Laksmi N. A., and Atmanto D. (2020) Peningkatan Kesejahteraan Dengan Pemanfaatan Lidah Buaya Untuk Perawatan Kulit Kepala dn Rambu [Welfare Improvement by Utilizing Aloe Vera for Scalp and Hair Care]. JKKP (Jurnal Kesejahteraan Keluarga Dan Pendidikan) 7(02):117-129. https://doi.org/10.21009/JKKP.072.01 (in Indonesia)

Andiwijaya A.F. (2017) Aternatif Koagulan Alami Sebagai Pengganti atau Pembantu Aluminium Sulfat pada Proses Pengolahan Air Minum [Alternative Natural Coagulants as a Substitute or Helper for Aluminum Sulfate in Drinking Water Treatment Processes]. Semantic Scholar 251896129. Available at: https://api.semanticscholar.org/CorpusID:251896129, (in Indonesian)

Ang W. L. A. B. M. (2020) State of the Art and Sustainability of Natural Coagulant in Water and Wastwater Treatment. Journal of Cleaner Production 3(1):262-272. https://doi.org/10.1016/j.jclepro.2020.121267

Benalia A., Derbal K., Khalfaoui A., Bouchareb R., Panico A., Gisonni C., Crispino G., Pirozzi F., & Pizzi A. (2021). Use of Aloe Vera as an organic coagulant for improving drinking water quality. Water 13(15). https://doi.org/10.3390/w13152024

Crisnaningtyas F., & Vistanty H. (2016) Pengolahan Limbah Cair Industri Farmasi dengan Metode Anaerob-Aerob dan Aerob-Koagulasi [Pharmaceutical Industry Liquid Waste Treatment with Anaerobic-Aerobic and Aerobic-Coagulation Methods]. Jurnal Riset Teknologi Pencegahan Pencemaran Industri 7(1):13-22. https://doi.org/10.21771/jrtppi.2016.v7.no1.p13-22 (in Indonesian)

Dawood A.H., Aziz S.Q., Ismael S.O. (2023) A Review on Pharmaceutical Wastewater Characteristics, Treatment Techniques and Reusing. Environmental Protection 3(1), 181-193. https://doi.org/10.37256/epr.3120232273

Dermawan D., Bahtiar R., & Sofian F. F. (2018) Implements green supply chain management (GSCM) pada industri farmasi di Indonesia: Analisis kelayakan dan studi kasus. Jurnal Ilmiah Farmasi 14(2):80-86. https://doi.org/10.20885/jif.vol14.iss2.art3 (in Indonesia).

Furnawanthi I. S. (2002) Khasiat dan manfaat lidah buaya: si tanaman ajaib Irni Furnawanthi. [Properties and benefits of Aloe Vera]. Jakarta: PT Agromedia Pustaka. Available at: https://api.semanticscholar.org/CorpusID:178941648 (in Indonesian).

Hamman J. H. (2008) Composition and applications of Aloe Vera leaf gel. Molecules 13(8):1599-1616. https://doi.org/10.3390/molecules13081599

January E., Putra H. S. C., & Zairinayati Z. (2021) Penggunaan Lidah Buaya (Aloe Vera) Sebagai Koagulan Alamai Untuk Menurunkan Kekeruhan Air. Ruwa Jurai [Use of Aloe Vera as a natural coagulant to reduce water turbidity. Ruwa Jurai] Journal of Environmental Health. Environmental Health Journal 15(1): 23. https://doi.org/10.26630/rj.v15i1.2152 (in Indonesia).

Lailani N., Razie F., Biyatmoko D., Lilimantik M. (2023) Kajian flokulan polimer anionic dengan metode jar test untuk pemanfaatan Lumpur Cair pt air minum bandarmasih (perseroda). [Study of Anionic Polymer Floculants Using the Jar Test Method for the Utilization of Liquid Mud at PT Air Minum Bandarmasih (Perseroda)]. EnviroScienteae 19(3):64-75. https://doi.org/10.20527/es.v19i3.17264

Lamsaputra, Andika V., Suharto B., Wirosoedarmo R. (2021) Studi Penggunaan Lidah Buaya (Aloe Vera) sebagai Koagulan Alami dalam Proses Pengolahan Air Limbah Rumah Tangga dengan Metode Koagulasi-Flokulasi [Study the Use of Aloe Vera as a Natural Coagulant in Household Wastewater Treatment Process with Coagulation-Flocculation Method.] Thesis, Barawijaya University. Available at: http://repository.ub.ac.id/id/eprint/187707/ (in Indonesia).

Lichtfouse E., Morin-Crini N., Bradu C., Boussouga Y. A., Aliaskari M., Schäfer A. I., Das S., Wilson L. D., Ike M., Inoue D., Kuroda M., Déon S., Fievet P., & Crini G. (2022) Methods for selenium removal from contaminated waters: a review. Environmental Chemistry Letters 20(3): 2019-2041. https://doi.org/10.1007/s10311-022-01419-8

Martina A., D.S. Effendy, J.N.M. Soetedjo (2018) Aplikasi Koagulan Biji Asam Jawa dalam Penurunan Konsentrasi Zat Warna Drimaren Red pada Limbah Tekstil Sintetik pada Berbagai Variasi Operasi. [Application of Tamarind Seed Coagulant in Reducing Substance Concentration Drimaren Red Color in Synthetic Textile Waste at Various Operation Variations]. Jurnal Rekayasa Proses (12(2): 98-103. https://doi.org/10.22146/jrekpros.38948 (in Indonesian).

Meirdana S., & Utomo S. W. (2020) Studi kasus evaluasi penaatan aspek pengolahan limbah cair industri farmasi [Case study on evaluating compliance of effluent treatment aspects of the pharmaceutical industry]. JPLB 2020(3):592-603. https://doi.org/10.36813/jplb.4.3.592-603 (in Indonesian).

Mumtaz A., Dokter H. P., Kedokteran F., & Lampung U. (2020) Efektifitas Aloe Vera terhadap Luka Bakar [Effectiveness of Aloe Vera on Burns]. Online Scientific Journal of Medicine Wijaya Kusuma 9(2). https://doi.org/10.30742/jikw.v9i2.800 (in Indonesian).

Nadiah N., Bakar A., Sultan P., Shah I., Suhaili N., Zin M., Nurhazirah W., Kamaruzaman B., & Lee C. S. (2016) Study the Effectiveness of Biocoagulant Between Aloevera (L.). Burm. F And Okra Mucilage. Coagulation and Flocculation Treatment. Available at: https://www.researchgate.net/publication/346492308.

Ningsih E., Chandra Ayunaningsih M., & Adythia P Teknik Kimia T. B. (2019) Prosiding Seminar Nasional Kimia dan Pembelajarannya (SNKP). [Proceedings of the National Seminar on Chemistry and Learning (NSCP)]. 2019 Malang (in Indonesian).

Pichler, Young K., & Alcantar N. (2012) Eliminating turbidity in drinking water using the mucilage of a common cactus. Water Science & Technology: Water Supply 1(3):179-186. https://doi.org/10.2166/ws.2012.126

Rahimah Z., H. Heldawati, I. Syauqiah (2016) Pengolahan Limbah deterjen dengan metode koagulasi-flokulasi menggunakan koagulan Kapur dan PAC. [Treatment of detergent liquid waste by coagulation-flocculation method using lime and PAC coagulants]. Jurnal Konvensi 5(2):13-19. https://doi.org/10.20527/k.v5i2.4767 (in Indonesian).

Saritha V., Srinivas N., Vuppala N.V.S. (2017) Analysis and Optimation of Coagulation and Flocculation Process. Applied Water Science 1(7): 451-460. https://doi.org/10.1007/s13201-014-0262-y

Sukmana H., Bellahsen N., Pantoja F., & Hodur C. (2021) Adsorption and coagulation in wastewater treatment - Review. Progress in Agricultural Engineering Sciences 17(1): 49-68). https://doi.org/10.1556/446.2021.00029

Syahputra B. and Poedjiastoeti H. (2022). Chapter-4 Coagulation. Available at: https://www.researchgate.net/publication/362429399.

Uyun K., Ilim, W. Simanjuntak (2012) Studi pengaruh potensial, waktu kontak, Dan pH Terhadap metode elektrokoagulasu limbah cair restoran menggunakan elektroda Fe dengan susunan monopolar dan dipolar. [Study of the effect of potential, contact time, and pH on the method of electro coagulation of restaurant wastewater using Fe electrodes with monopolar and dipolar arrays]. Prosiding SNSMAIP III-2012. Available a: http://repository.lppm.unila.ac.id/39853/1/Khuratal%20Uyun_Ilim_Prosiding%20SNSMAIP%20III-2012.pdf (in Indonesian).