



# Effectiveness of the Coagulation-Flocculation Method in Acid Mine Water Treatment on PT Laskar Semesta Alam Coal Mining Areas

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**Abstract.** This research aims to evaluate acid mine drainage (AMD) treatment methods in the PT Laskar Semesta Alam coal mining area. The open-pit mining system in this area poses serious environmental challenges, especially regarding water and soil pollution. This paper focuses on the use of the coagulation-flocculation method to reduce total suspended solids (TSS) levels in wastewater, as well as analyse the effectiveness of the chemical coagulant Ensiflock C100 with a concentration of 25% and flocculant Greenhydro ST-20 with a concentration of 0.25%. The research results showed that the optimum dose of coagulant was 3.75 ppm and flocculant was 2.50 ppm effective in reducing TSS concentrations to reach environmental quality standards. This research also recommends the use of additional technology in the form of baffles to increase the efficiency of water residence time in settling ponds, so that it can improve water quality before it is discharged into water bodies.

**Keywords:** Acid mine water, Coagulation, Flocculation, Settling Pond

## 1 Introduction

Mining in the Pit PT. Laskar Semesta Alam, Balangan Regency, Paringin District, Tigarun Village is carried out using an open pit mining system. This system can change land structure, the balance of land surface ecosystems, and environmental quality. Water pollution including acid mine drainage (AAT), soil erosion and pollution, exhaust gas emissions, landscape changes and habitat destruction are examples of some of the negative impacts on the environment if mining operations are not controlled [1]. This open mining system is carried out by stripping the overburden to obtain mining materials, in this case coal. Overburden stripping causes degradation of environmental quality due to the extensive vegetation of the cleared land. This system also has the potential to cause exposure to organic and inorganic chemical contents. Inorganic materials can

be sulfide minerals originating from soil and coal which affect the quality of ground-water and surface water so that the total suspended solids (TSS) value is detected to be high at the inlet [2].

Furthermore, there is the potential for mixing rainwater or groundwater with rocks that contain certain sulfides in the coal, thereby changing the chemical properties of water to become very acidic. If water that has been contaminated with acid mine drainage flows into rivers, it will have a huge impact on the survival of all contaminated living creatures, especially the people who live along the river flow. This is in line with the statement of Andrawina et al., that the impact of acid mine water is not only in the mining location but what is more worrying is the contamination of water sources outside the mining area and it is very dangerous for the environment, especially for living creatures [3]. The treatment of acid mine drainage should be carried out at each mining company in accordance with the obligations under Government Regulation Numb. 22/2021 concerning the Implementation of Environmental Protection and Management.

Generally, mining water must be handled to ensure the quality of the water before it is discharged into water bodies. This treatment can be carried out using active and passive methods [4]. Active methods can be carried out by adding chemicals, while passive methods use artificial wetlands as technology or assistance from microorganisms, plants and media that imitate natural wetlands [5]. The costs for environmental management are not cheap. Therefore, strategic planning is needed to create optimal treatment and carry it out effectively and efficiently in terms of time, energy and costs.

The problem in coal mining, apart from the generation of mine wastewater, is the discharge of runoff water from open areas. The problem is characterized by extreme differences in water discharge between mining and reclamation locations in the dry season and rainy season [6], so that it can disrupt mining activities and cause environmental problems. The aim of the paper is to examine the effectiveness of active management methods, namely the use of chemicals as flocculants and coagulant management.

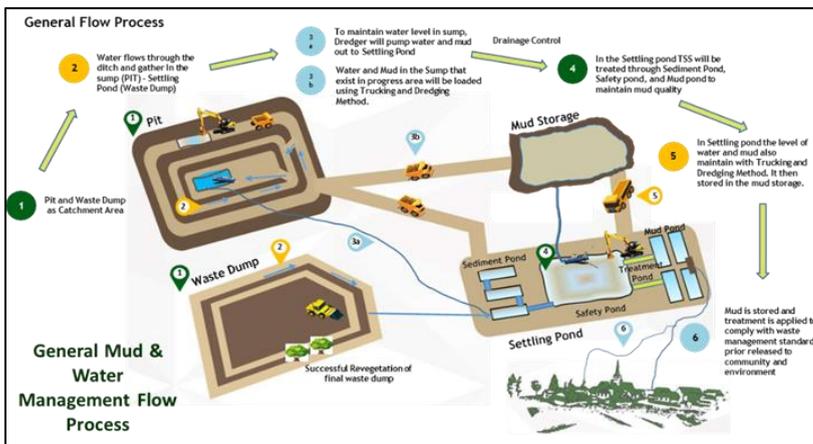


Fig. 1. Water Management Flow Process in Mining

Fig. 1 explains the flow of the water and mud management process in a mining area, starting from collecting water in the pit and waste dump as a catchment area (point 1). The collected water flows through the drainage channel and enters the sump which functions as an initial settling pond. This process helps collect water containing mud from mining activities, before entering further processing stages. This area is the initial center for handling water and mud to ensure that hazardous materials do not directly impact on the environment (point 2).

After the water and mud have been collected, the steps continue by using a pump or dredger to move the mud and water from the pit to the settling pond. At the same time, the mud in the sump in the operational area is also transported using a dump truck as part of the management of denser materials. This removal process is important to maintain the deep-water level in the sump, while ensuring that mud handling is carried out effectively through these two methods: dredging and trucking (point 3).

After reaching the settling pond, the water and mud are processed through several settling stages, starting from the sediment pond and continuing to the safety pond and mud pond (point 4). Each of these stages is designed to separate sediments and reduce the mud content in the water, so that water quality can be improved before being released back into the environment. In the end, the mud collected in each settling pond is stored in mudstorage, which functions as a temporary storage area before further management is carried out (point 5).

The final stage of this process is storing the mud in storage, where the mud is stored and processed in accordance with applicable wastemanagement standards. This sludge processing is carried out to ensure that the waste is safe before it is disposed of or released into the environment. All of these stages are designed to comply with standard mining environmental management parameters and to reduce negative impacts on the community and ecosystem around the mining area (point 6).

## 2 Materials and Methods

This research was carried out with limitations on the scope of management and control activities for acid mine wastewater in settling ponds in coal mining. The data and information collected are in the form of primary data and secondary data. Primary data includes the results of water measurements in settling ponds. Secondary data includes dry and rainy water balance data, settling pond dimensions and water balance. The quantity of water entering the pit is determined by analyzing rainfall data from nearby stations and calculating the run off discharge coefficient.

**Table 1.** Estimated rain intensity

Duration		Rain intensity (mm/hour)					Rain Return Period	
Hour	Minute	2	5	10	20	25	50	100
		Years	Years	Years	Years	Years	Years	Years
0.5	30	55.8	71.4	81.7	91.6	94.7	104.4	114.0
1	60	35.1	45.0	51.5	57.7	59.7	65.8	71.8
2	120	22.1	28.3	32.4	36.3	37.6	41.4	45.2

Duration		Rain intensity (mm/hour)					Rain Return Period	
Hour	Minute	2	5	10	20	25	50	100
		Years	Years	Years	Years	Years	Years	Years
3	180	16.9	21.6	24.7	27.7	28.7	31.6	34.5
6	360	10.6	13.6	15.6	17.5	18.1	19.9	21.8
8	480	8.8	11.2	12.9	14.4	14.9	16.4	18.0
12	720	6.7	8.6	9.8	11.0	11.4	12.5	13.7
24	1.440	4.2	5.4	6.2	6.9	7.2	7.9	8.6
84	5.040	1.8	2.3	2.7	3.0	3.1	3.4	3.7

The research focuses on the rainy season because it takes into account the disaster aspect and the potential for excessive discharge to cause water to overflow if there are dimensional design errors. Calculation of rainy season wastewater runoff discharge must be calculated based on rainfall for 84 hours or 3.5 days [7], so the unit volume is m<sup>3</sup>/3.5 days.

The amount of runoff discharge is determined using a rational formula:

$$Q=0.278 \times C \times I \times A \tag{1}$$

where Q is the runoff discharge (m<sup>3</sup>/second), C is the runoff coefficient, I is the rain Intensity (mm/hour), and A is the catchment area (km<sup>2</sup>) [8].

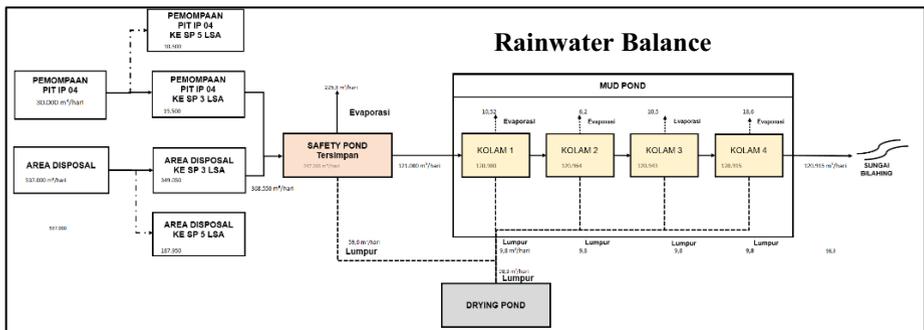
**Table 2.** Calculation of Runoff Coefficient

Catchment Area	Runoff Coefficient	Pit IP 04 Area (Ha)	Disposal Area (Ha)
Pit	0.85	87.89	0.44
Disposal OB	0.75	5.31	162.51
Disposal Soil	0.75		38.03
Disposal Mud	0.95		
Mining/Infrastructure	0.70	1.50	25.34
Rehab. <1 Year	0.45		22.99
Rehab. 1 Year	0.43		10.23
Rehab. 2 Years	0.40		9.29
Rehab. 3 Years	0.37		13.68
Rehab. >3 Years	0.35		4.58
Secondary Land Forest (Dry)	0.32		27.62
Plantation Forest	0.32		17.23
Plantation	0.45	4.75	18.91
Agriculture (Dry)	0.45	12.13	5.23
Bushes	0.90		0.12
Land	0.35	3.64	15.17
Water Surface	1.00	0.47	18.95
<b>Total Area (Ha)</b>		<b>115.69</b>	<b>390.33</b>
<b>Runoff Coeff.</b>		<b>0.781</b>	<b>0.637</b>

Note : The runoff coefficient and rain catchment area values are taken from the period with the largest runoff volume (2024)

**Table 3.** Calculation of Wastewater Discharge entering SP

Catchment Area	PARAMETER	UNIT	CATCHMENT AREA		INFORMATION
			PIT IP 04	AREA DISPOSAL	
<b>RAINY SEASON</b>					
Run off Settling Pond Area	Runoff Coefficient	-	0.781	0.637	Based on calculation PUH 15 years Rainfall Mode, Periode 84 hour - Kepmen 1827
	Rain Intensity (plan)	mm/3.5 days	216.11	216.11	Calculated using software WMS Rational Method Pit SCM dan LSA
	Rain Catchment Area	Ha	115.69	390.33	Hydrogeological study (Golder, 2020)
	Runoff Discharge	m <sup>3</sup> /3.5 days	196,000	537,000	65% flows to SP 3 LSA dan 35% flows to SP 5 LSA
	Groundwater Flow Discharge	m <sup>3</sup> /3.5 days	10.771	-	
Pump Flowrate from Sump	Runoff Flow SP 3 LSA	m <sup>3</sup> /3.5 days	-	349,050	
	Water flow that enters sump pit	m <sup>3</sup> /3.5 days	207,000	-	
	Pump Capacity	Liter/sec	200	-	MFV-420 pump
	Pump Utilization	Unit	2	-	
	Pumping time	Days	7	-	Average sump pit pumping
	Pit Pumping discharge	m <sup>3</sup> /days	30,000	-	
Total Discharge to SP	Total Pumping Discharge to SP 3 LSA	m <sup>3</sup> /days	19,500	-	65% flows to SP 3 LSA dan 35% flows to SP 5 LSA
				<b>368,550</b>	



**Fig. 2.** The Actual Design of SP 3 LSA

Jar tests are also carried out in the SP 3 LSA area. Jar Test is a testing method used to assess coagulant capabilities and determine the optimum dose in the water and wastewater purification process. Measurements and recording in the Jar Test include raw water pH, TDS and turbidity, as well as the dose of coagulant added for a certain volume

of raw water. This allows determining the actual coagulant requirements in wastewater treatment. The Jar Test method simulates the coagulation and flocculation process to remove suspended solids and organic substances that can cause turbidity, odor and taste [9].



Fig. 3. Jar Test Laboratory

PT. Laskar Semesta Alam made the Decree of the Minister of Environment Number 113 of 2003 the legal basis for managing mine water so that the waste water released complies with quality standards.

Table 4. Calculation of Wastewater Discharge entering SP

No.	Parameter	Unit	Influent	Mud Pond		Proposed Wastewater Quality Standard		Wastewater Quality Standard
				% removal	Discharge	Dry	Rainy	
1.	pH	-	3.02-7.29	-	6-8	6-9	6-9	6-9
2.	TSS	mg/L	700	97%	21	64.49	177.63	200
3.	Fe	mg/L	0.2995	50%	0.14975	0.46	1.2	7
4.	Mn	mg/L	3.1901	94%	0.191406	0.2	0.65	4
5.	Cd	mg/L	0.013	-	-	0.02	0.05	0.05

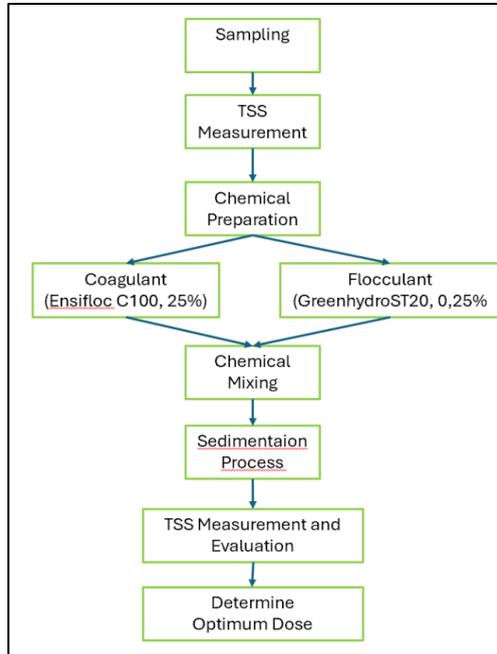
Note : Waste water quality standards are based on technical approval documents for waste water discharge to surface water bodies PT Laskar Semesta Alam (2024)

### 3 Results and Discussion

The process begins with taking wastewater samples from the test location, followed by initial TSS measurements to determine suspended solids levels. After that, chemical preparation was carried out by preparing two main components, namely coagulant (En-siflock C100) and flocculant (Greenhydro ST-20). These chemicals are prepared in diluted concentrations, namely 25% for coagulants and 0.25% for flocculants

After chemical preparation, both substances are added to the wastewater sample to initiate the coagulation-flocculation process, in which the suspended particles begin to combine and settle. This settling process is followed by TSS measurements every few times to evaluate changes in suspended solids concentration. Based on the results of

these measurements, researchers can determine the optimum dosage of coagulants and flocculants that are most effective in reducing TSS to reach the desired quality standards.



**Fig. 4.** Research Method Flow Chart

In the initial stage of testing, waste water samples were taken from the Inlet Mud Pond Settling Pond (SP) 3 Laskar Semesta Alam in the amount of 1000 ml and labeled A1. Initial Total Suspended Solids (TSS) parameter measurements were carried out using the HACH DR 900 test equipment (TSS meter). Cloudy watersamples cause the tool to not be able to read the TSS value directly, because the maximum measurement limit for the tool is 1,000 ppm, so 20 times dilution is required. The dilution process is carried out by mixing 1 ml of sample with distilled water until it reaches a volume of 20 ml in the TSS meter bottle. The final results of the measurements show that the initial TSS value for sample A1 is 9,600 ppm.

The coagulation process was carried out by adding Ensiflock C100 with a concentration of 25%, while flocculation was assisted by the anionic polymer GreenhydroST-20 with a concentration of 0.25%. These coagulants and flocculants are diluted first to achieve optimal concentration. The dilution process was carried out using a Portable Flocculation Tester at a speed of 200 rpm for  $\pm 30$  minutes. After dilution, C100 coagulant was added to sample A1 at 3.75 ppm, and ST20 at 2.50 ppm.

After deposition for 30 minutes, TSS measurements were carried out every 10 minutes. The measurement results showed that the TSS value after 10 minutes was 138 ppm, at 20 minutes it decreased to 116 ppm, and at 30 minutes it increased slightly to

126 ppm. This TSS value is still above the BMAL TSS quality standard in the dry season (70.74 ppm) and rainy season (68.44 ppm) in SP 3 LSA, so this dose cannot be considered the optimum dose.

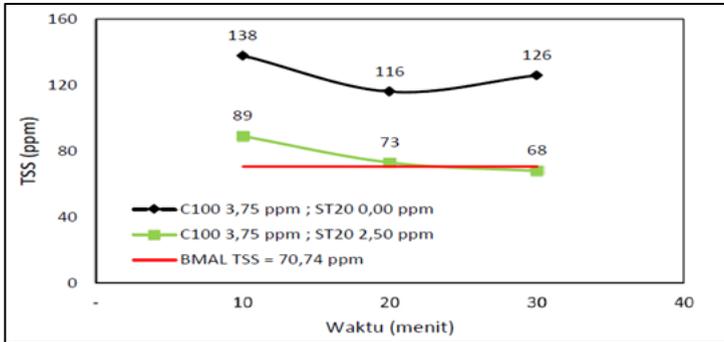


Fig. 5. TSS value for each sample at 10, 20 and 30 minutes on the Jar Test

A significant decrease in the TSS value only occurred at the 10th and 20th minutes, while at the 30th minute, there was an increase in the TSS value. This increase value indicates a decrease in removal efficiency of 0.1%. At this dose, floc destabilization occurs, where excessive electrostatic charges result in the rupture of the floc that has formed.

This increased value will cause a decrease in removal efficiency as shown in Fig. 4. Removal efficiency decreased by 0.1% with a breakdown of 98.8% to 98.7%. The reduction is caused by the use of excessive doses or exceeding the optimum limit, which can cause the electrostatic force on the colloids that have joined the floc to become greater and have an impact on breaking the floc bonds that have formed [10].

This is different from after adding the flocculant of 2.50 ppm along with the same coagulant dose in the previous variation. The difference is shown by a more significant reduction in TSS compared to the previous sample with detailed TSS values at 10, 20 and 30 minutes respectively of 89 ppm, 73 ppm and 68 ppm (Fig. 4). The reduction in TSS concentration occurs because the positively charged organic coagulant neutralizes the negative charge on the suspended particles. This allows the particles to combine and form floc nuclei, which then agglomerate into larger flocs that are easy to settle. The formation of these flocs will facilitate the settling process in the next compartment, resulting in a value of sedimented solids in the SP outlet that meets the BMAL in SP 3 LSA. So, this dose can be used as a reference dose in actual practice in the field.

Another supporting fact is that there is a higher removal efficiency value which continues to increase linearly up to 30 minutes of sediment deposition in the sample which can be seen in Fig. 5. The dose of C100 3.75 ppm and ST20 2.50 ppm continues to increase even though it is only around 0.1%. The details of the increase in efficiency are 99.1%; 99.2%; and 99.3%. When compared with the dose of C100 3.75 ppm and ST20 0.00 ppm, there is a decrease in efficiency of 0.1% at the 30th minute which decreases from 98.8% efficiency (20th minute) to 98.7%, so this fact can strengthen the selection of the optimum dose. The choice of C100 dose of 3.75 ppm and ST20 2.50

ppm Initial TSS as a reference in applying coagulant and flocculant doses in SP 3 LSA will be compared with the actual coagulant and flocculant dose values in the field against the initial TSS and discharge parameters.

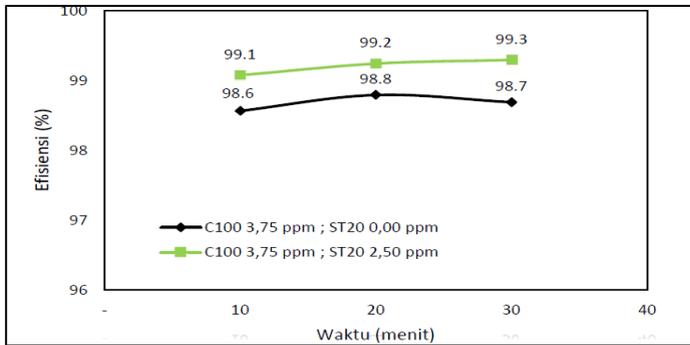


Fig. 6. TSS reduction efficiency value at every 10 minutes interval

The research then compared the TSS values and coagulant and flocculant doses in July 2024 (Fig. 6), it was seen that the actual TSS value was 709 ppm, while the Jar Test results showed a TSS value of 9600 ppm. The coagulant dose given in actual conditions is around 2.14 ppm, while the flocculant dose is around 0.18 ppm. The flocculant dosage given in the field was in accordance with the comparison of the Jar Test results. However, the Jar Test results showed that to achieve more effective settling and reduced costs, the coagulant dosage needed to be reduced to 0.28 ppm. If coagulants are applied excessively, several negative impacts can occur such as increased chemical costs, the potential for excess sludge formation, and the possibility of chemical residues in the treated water. Therefore, it is important to adjust the dose based on appropriate test results in order to optimize the water treatment process without causing negative impacts.

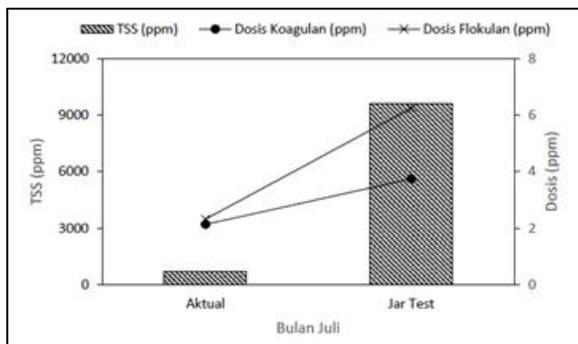


Fig. 7. Comparison of the actual values of coagulant and flocculant dosages (July)

Data comparison was carried out by looking at secondary data in the form of actual dose, TSS and discharge data in the field from January to June. The selected TSS jar test value will be compared with the actual TSS value in the field in July. The purpose of this comparison is to find out whether in the field the coagulant or flocculant dosage was given correctly or excessively by looking at the TSS jar test data that has been carried out.

The actual coagulant dosage is very fluctuating as shown by a downward pattern in the graph (Fig. 7) which is in the interval 3.0 ppm to 1.5 ppm with the actual TSS value in the interval 3000 ppm to 1000 ppm. This dose value indicates that an excessive dose was given which is not in accordance with a lower TSS value compared to a TSS value which has a higher value. This case can be seen in April where the coagulant dose value given is higher compared to January even though the TSS value in April has a lower TSS value compared to January. Giving excess doses results in an increase in turbidity values in the water [11]. This is because the floc that has settled will become a colloid again due to the presence of excess cations from the coagulant, thus forming a positively charged colloid. Excessive doses will also result in wasted costs in providing doses.

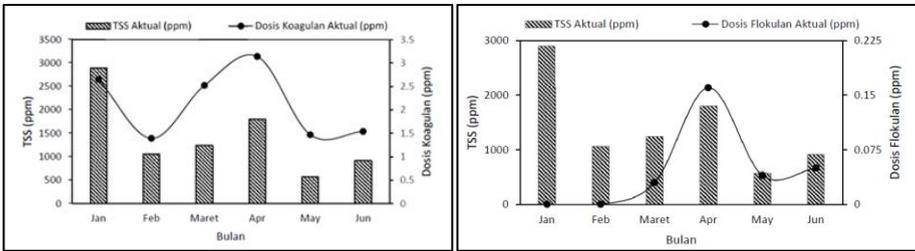


Fig. 8. Comparison of actual values of flocculant dose and TSS on Januari till June 2024

The administration of the flocculant dose also showed an excessive dose when compared with the results of the jar test that had been carried out (Fig. 7). Over-dosing occurred again in April, where the dose given was higher than in January, even though the TSS value in January was higher than in April. Excessive doses of flocculant in the form of polymers can cause the colloid to become stable again because there is no space to form bonds between particles. Under certain conditions, a system that has been destabilized and formed aggregates can become stable again by increasing agitation, because the polymer on the particle surface is released and a repetition process occurs between the remaining polymer and the particle surface. Meanwhile, particles with opposite charges will attract each other [12].

Other recommendations for improvements that can be made apart from determining the effectiveness of the optimum dosage of coagulants and flocculants are by increasing the flow velocity in the existing settling pond by reconfiguring the hydraulic aspect by installing structures such as baffles in the settling pond. Installation of baffles will cause a short circuit so that some water particles reach the outlet very quickly in a much shorter time than the nominal time in the pool. Many studies have investigated the relationship between screened ponds and processing efficiency, primarily through the use of hydrodynamics and/or laboratory experiments.

Baffle planning was carried out at SP 3 LSA in the 1st pond as in Fig. 8. This location was chosen because the dimensions of the pond are larger compared to the others, so the water residence time will be longer. This selected pond has dimensions of 145 meters long, 25 meters wide and 5 meters deep, which is known from the PT LSA Technical Study of Wastewater Disposal to Surface Water Bodies document.



Fig. 9. Baffle plan in pond 1 SP LSA

The selection of baffle dimensions was based on research [13]. The dimensions of the baffles used are 2/3 of the pool width, around 16 meters, both on baffles 1, 2, 3 and 4 (Fig. 9). The choice of baffle length was because previous research stated that a baffle length of 2/3 of the pool width or in other words having an overlap of 0.25 would increase the mud residence time by 20% (Fig. 10). To compare the results of the modeling, the parameters average residence time, moment index, and short circuit index are used. The average residence time ( $t_{mean}$ ) for each scenario is calculated from the model output with the following formula:

$$t_{mean} = \frac{\int_0^{\infty} tC(t)dt}{\int_0^{\infty} C(t)dt} \quad (2)$$

where  $t_{mean}$  is the average residence time and  $tC$  is the tracer concentration at the certain time.

Based on research by Coggins et al, not all added tracers leave the pool during the duration of the experiment, so the calculated  $t_{mean}$  value tends to represent the minimum estimated value [13].



Site	Date	Sludge infill %	$t_n$ (days)	$t_{mean}$ (days)	% change	Mass recovery %
Pond 1	2015	45	14.0	11.9	-15	76
	2013	21.5	19.1	14.0	-27	84
Pond 2	2015	29	18.1	17.0	-6	94

Fig. 10. Baffle planning [13]

Apart from that, the choice of baffle length is because the baffle meets a sloping wall, where the sloping wall in the pool will provide a limited volume of water to the end of the baffle, so that incoming flow can quickly pass through the area around the end of the baffle. The distance between the baffles used is 26 meters. Installation of this baffle will provide a decrease in hydraulic efficiency as indicated by a decrease in the moment index number of 2% and an S value of 22% and a residence time of 4% when the flow is low. This phenomenon indicates that there is a short circuit in the flow, thereby accelerating the flow speed and creating a dead zone [13].

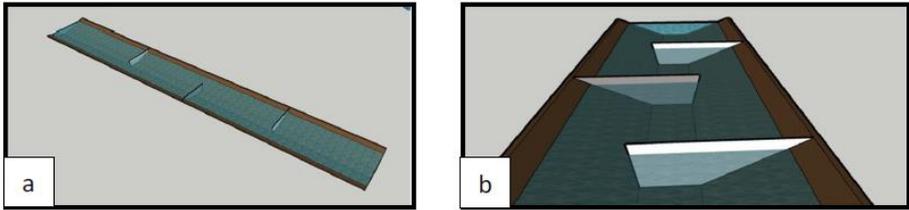


Fig. 11. 3D baffle visualization (a)side view, (b)front view

## 4 Conclusions

Open pit mining systems can have a significant impact on the environment, including water pollution and damage to the surrounding ecosystem, including living creatures. Acid mine drainage contamination of surface water bodies can occur if safety and efficiency considerations are not taken in its management. Therefore, wastewater management using effective active and passive methods is very important,

Tests using coagulants and flocculants show that appropriate dosages can increase processing efficiency wastewater treatment. that the coagulation-flocculation method using Ensiflock C100 coagulant with a concentration of 25% and flocculant Greenhydro ST-20 with a concentration of 0.25% is effective in reducing the levels of Total Suspended Solids (TSS) in acid mine water at PT Laskar Semesta Alam. Using the optimum dose of coagulant of 3.75 ppm and flocculant of 2.50 ppm succeeded in achieving a TSS reduction efficiency of up to 99.3%, meeting applicable environmental quality standards. This research also recommends improvements in settling pond design, such as adding baffles to increase flow velocity and settling efficiency. Thus, this coagulation-flocculation method can be widely applied as a solution for managing mine wastewater, so that the risk of environmental pollution can be significantly minimized. Overall, strategic planning and good environmental management are needed to minimize the negative impacts of mining activities.

**Acknowledgements.** The author would like to thank all parties who have supported the author in completing this paper. We would also like to thank all the lecturers and academic staff of the Professional Engineer Study Program, Faculty of Engineering, Gadjah Mada University who have provided knowledge, insight, inspiration and facilities during the education process.

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