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Article

Calculation of Chemicals and Cost of Water Purification Process at Water Treatment Plant PT.XYZ

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Abstract. Acidic, turbid reservoir water and uncontrolled dosing raise treatment cost at palm oil mills. This study determined jar-test doses of soda ash (Na_2CO_3), aluminum sulfate ($Al_2(SO_4)_3$), and Profloc (Poly(2-propenamide)) and calculated the chemical cost at the water treatment plant of PT XYZ located at Riau, Indonesia. Jar tests (500 mL) were run on 12 working days between 30 September and 12 October 2025 on raw water of pH 5.06–5.51 and turbidity 18–26 NTU (mean 20.6 NTU). Doses were converted to plant injection rates by pump calibration, and cost was consumption multiplied by unit price. Soda Ash B is Na_2CO_3 dosed through an additional injection line. Soda ash (8–14 mg/L) raised pH to a mean of 6.77, but alum then lowered it to 6.20, and only 5 of 12 selected doses reached pH 6.5–7.5. Turbidity fell by 76.5% to a mean of 4.74 NTU and decreased stepwise with alum dose, from 5.55 NTU at 10 mg/L to 4.47 NTU at 12 mg/L. Chemical cost averaged Rp288,410 per day and Rp1.80 and Rp1.67 million in the two calibration weeks. Soda ash should therefore be dosed for the post-alum pH, and alum below 11 mg/L missed the 5 NTU target.

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1. Introduction

Palm oil mills need treated water for crude palm oil (CPO) and kernel processing and for boiler feed, so raw-water quality affects both product quality and plant reliability. At PT XYZ, the raw water comes from a reservoir and is acidic (pH 5.06–5.51) and turbid (18–26 NTU). It cannot be used in the process or as boiler feed water without external treatment. The treatment plant adds soda ash (Na_2CO_3) to raise pH, aluminum sulfate ($Al_2(SO_4)_3$) to form flocs, and Profloc (Poly(2-propenamide)), a polyacrylamide flocculant, to strengthen them. The main operating problems are improper pH, high residual turbidity, and excessive chemical use. The mill's internal standard for external treatment requires a pH of 6.5–7.5, clear water, and a turbidity of 5 NTU.

Aluminum coagulants remove turbidity by charge neutralization and by sweep flocculation, and the dominant mechanism depends on dosage [1] and pH [2]. Alum hydrolysis consumes alkalinity and lowers pH, so alkalinity and pH are treated as dose-determining variables alongside turbidity [2–4]. Response-surface studies placed optimum alum coagulation at pH 6.2–7.0 for drinking water [2] and at pH 7.0 for surface water [5]. Tests on other water matrices reported effective coagulation at pH 6–7 [6] and with alum at pH 8 [7]. In chemical terms, soda ash supplies the alkalinity that lifts acidic raw water into this window, where aluminum hydroxide flocs form. The mill's target window of pH 6.5–7.5, used in this study, therefore lies close to the reported optima.

Polymer flocculants strengthen the flocs formed by the primary coagulant, and a cationic bio-based flocculant used with alum cut COD by 61.3% at lower cost than a commercial flocculant [8]. Combining PAFC with CPAM removed ZnO nanoparticles far better than either component alone [9], and optimized PAC, CPAM, pH, and sludge doses lowered sewage turbidity to 1.19 NTU [10]. Coagulant aids can also keep alum doses low, as low alum doses combined with Moringa extract removed about 96% of greywater turbidity [11]. Overdosing is not harmless, because excess PACl and polymer were linked to pipeline blockage [12]. Chemical-intensive treatment is also costly, as shown for lime and alum softening of groundwater [13] and for PAC dosing, where AI-based optimization cut median chemical cost by 49% [14]. Dose control therefore serves a technical purpose (stable floc and water quality) and an economic one (avoiding wasted chemicals).

The jar test remains the practical basis for setting coagulant dose, and statistical or machine-learning models now predict or optimize dose and residual turbidity from raw-water pH, turbidity, alkalinity, and temperature [3,15–17]. A gene-expression model reached $r = 0.91$ for alum dose [3], and a recurrent neural network reached $R^2 = 0.9908$ for coagulant dosage in a treatment plant [15]. Such models still need reliable jar-test data and calibrated dosing equipment before they can be used in operation. Process changes can also lower chemical demand: aeration and pre-chlorination cut coagulant dosage by about 60% in laboratory and field tests in Indonesia [18]. Raw-water turbidity is a recognized control variable in coagulation studies and also shapes the sludge produced [19,20].

Most published work addresses drinking water [21–23] or industrial effluents [7,16,24]. For palm oil mills, the available examples concern effluent, where an alum optimum of 1000 mg/L was reported for metal removal [24], far above the 63–80 mg/L reported for drinking-water coagulation [2]. Studies that combine jar-test dosing, conversion to plant injection rates, and chemical cost accounting for the raw-water plant of a mill appear to be scarce in the literature reviewed. This study is therefore a jar-test-based dosage determination for one plant, supported by an operational cost evaluation, without a

comparative or control design. The problem it addresses is how much soda ash, aluminum sulfate, and Profloc the mill needs to meet its pH and turbidity targets, and what this costs.

The objectives are to (i) determine the jar-test dosage that brings the reservoir water to the target pH and turbidity, (ii) convert the dosage into plant injection rates through pump calibration, and (iii) calculate the chemical cost per day and per calibration week. The novelty lies in linking these three steps in one documented data set from a working mill.

2. Experimental Section

2.1. Study Site and Plant Description

The study was carried out at the water treatment plant of PT XYZ Riau, from 30 September to 12 October 2025. The plant draws river water into a reservoir and passes it through a static mixer, where soda ash, aluminum sulfate, and Profloc are injected (Figure 1). The water then flows through a clarifier tank, a water basin, and a sand filter. Filtered water is stored in two tower tanks that supply domestic use and the factory.

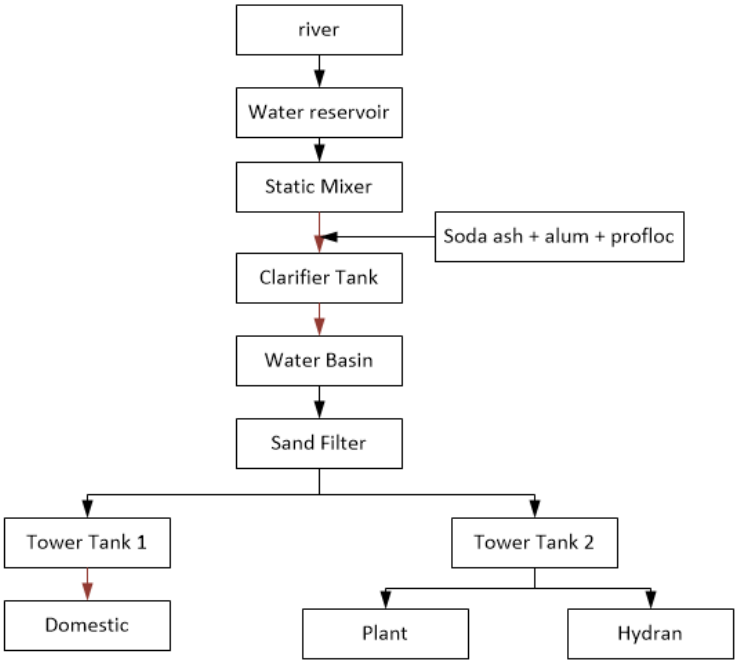


Figure 1. Water treatment process flow diagram of the mill

2.2. Sampling

Raw water was sampled from the reservoir on 12 working days: Days 1–6 on 30 September–5 October and Days 7–12 on 7–12 October 2025. The pH and turbidity of the raw water were measured on each daily sample before dosing. Grab samples of about 2 L were taken at the raw-water inlet of the plant in the morning and tested in the mill laboratory within 1 h. Each daily sample supplied three jar-test runs of 500 mL at different dosage levels, giving 36 runs in total (Table 1). Chemical consumption was obtained from the dosing records and field observation of the dosing system during the same period. The plant treats about 80 m^3/h and operates 17 h/day from Monday to Saturday and 10 h on Sunday.

2.3. Chemicals and Instruments

The chemicals were the plant's operational products: technical sodium carbonate (Na_2CO_3, 99.35%), aluminum sulfate ($Al_2(SO_4)_3$, LITAKI), and Profloc 1018 (Poly(2-propenamide), AQUAKIMIA), and jar-test stock solutions were 10 g/L (1%) for Na_2CO_3 and $Al_2(SO_4)_3$ and about 0.5 g/L for Profloc (assumed). Soda Ash B is the same Na_2CO_3 product, with the same unit price (Section 2.6), dosed through an additional injection line that is assumed to lie downstream of the alum dosing point and to correct the pH lowered by alum, which would explain why it is dosed separately.

Jar tests used a laboratory jar-test apparatus with 500 mL beakers and variable-speed paddles (brand and model not recorded). pH was measured with a pH meter calibrated with pH 4.01 and 7.00 buffers (assumed; brand and model not recorded), and turbidity was read in NTU with a DR-900 colorimeter from a 25 mL cell whose absorptometric turbidity program is specified by the manufacturer for 21–1000 FAU (1 FAU ≈ 1 NTU of formazin), so readings below about 21 NTU are indicative and have coarse resolution. An analytical balance, 500 mL volumetric flasks, 0.5 mL and 0.2 mL graduated pipettes, and a stopwatch completed the equipment. Measuring instruments were calibrated once a week, as required at the mill, because sensor wear, contamination, and environmental conditions cause drift.

2.4. Jar-Test Procedure

Each 500 mL sample was dosed in the plant sequence: soda ash first, then aluminum sulfate, then Profloc. Soda ash was mixed at 20 rpm for 5 min, and the pH was read on a sample taken after 15 min. Aluminum sulfate was then mixed at 100 rpm for 1 min (rapid mixing) and at 45 rpm for 15 min (slow mixing), which is comparable with the 55–100 rpm used in other jar-test studies [7,25]. Profloc was added at 20 rpm for 5 min, and the flocs were then left to settle for about 5 min before the final pH and turbidity were read.

Three dosage levels were tested per day: Na_2CO_3 at 8–14 mg/L in steps of 1–2 mg/L, $Al_2(SO_4)_3$ at 10–14 mg/L (10–12 mg/L on most days), and Profloc at 0.15 mg/L (0.15 mL per beaker) (assumed from the plant calculation, which also uses 0.15 mg/L; the jar-test sheet lists 4 mg/L). The stock volume added to each beaker was $D \times V_j / C_s$, with C_s = 10 g/L for Na_2CO_3 and $Al_2(SO_4)_3$, so 9 mg/L Na_2CO_3 needed 0.45 mL. The dosage used for plant calculations was marked in the laboratory record and coincided with the run in which a floc deposit settled after Profloc addition (✓ in Table 1).

2.5. Scale-Up from Jar Test to Plant

The jar-test dose D (mg/L) is the mass of chemical m (mg) added to the sample volume V_j (0.5 L), as in Equation (1). The stock-solution injection rate q (L/h) needed to deliver this dose to a plant flow Q (m^3/h) follows from the stock-solution strength C (g/L), as in Equation (2). The delivered pump rate was measured by calibration: the time t (s) to fill a 0.5 L measuring vessel (V_c) was recorded in triplicate on 30 September and 7 October, as in Equation (3).

Daily consumption M (kg/day) then follows from Equation (4), where t_r is the running time of the pump. The plant flow was taken as Q = 80 m^3/h (79 m^3/h in the laboratory record), and the dosing tanks held 372 L (Na_2CO_3, $Al_2(SO_4)_3$, and Profloc) and 151 L (Soda Ash B). The plant stock-solution strength was not recorded, so it was estimated from Equation (2) as $C = D \times Q / q$, which gives about 37–45 g/L for Na_2CO_3 and $Al_2(SO_4)_3$ and about 0.5 g/L for Profloc (Table 2).

$$D = m / V_j \quad (1)$$

$$q = D \times Q / C \quad (2)$$

$$q = 3600 \times V_c / t \quad (3)$$

$$M = D \times Q \times t_r / 1000 \quad (4)$$

The doses in Tables 2 and 3 follow the mill's calculation sheet, which used the pump rate q (numerically 14.6–22.6) in place of t_r in Equation (4); the tank run time V_t/q (10–19 h) would give lower doses, for example 13.6 instead of 18 kg/day $Al_2(SO_4)_3$ on 30 September 2025.

2.6. Cost Analysis

The cost of each chemical i was calculated as its daily consumption M_i multiplied by its unit price P_i, as in Equation (5), and the daily total as the sum over the four chemicals, as in Equation (6). The cost of a calibration week is the sum of the daily costs over its six working days. Unit prices were taken from the mill's chemical price list: Rp5,603/kg for soda ash and Soda Ash B, Rp3,411/kg for aluminum sulfate, and Rp158,510/kg for Profloc. The two calibration weeks were 30 September – 5 October and 7–12 October 2025. Only chemical cost was considered; labor, energy, and sludge handling were excluded.

$$C_i = M_i \times P_i \quad (5)$$

$$C_d = \Sigma\ C_i \quad (6)$$

2.7. Study Design and Data Analysis

The study followed three stages (Figure 2): an initial stage (site review, sampling, and target setting), an implementation stage (jar tests, dose selection, scale-up, and field records), and a final stage (interpretation, analysis, and evaluation). Data were collected with the jar-test apparatus, the pH meter, the DR-900, calibrated dosing pumps, and the mill's daily consumption records. Results were interpreted against the mill's internal standard for external treatment, which requires pH 6.5–7.5, clear water, and turbidity of 5 NTU, and against the turbidity removal efficiency E defined in Equation (7). Data analysis used the mean, range, and Pearson correlation coefficient (r), calculated in Microsoft Excel. Costs were evaluated per day and per calibration week and compared across the two weeks.

$$E = (T_0 - T_1) / T_0 \times 100\% \quad (7)$$

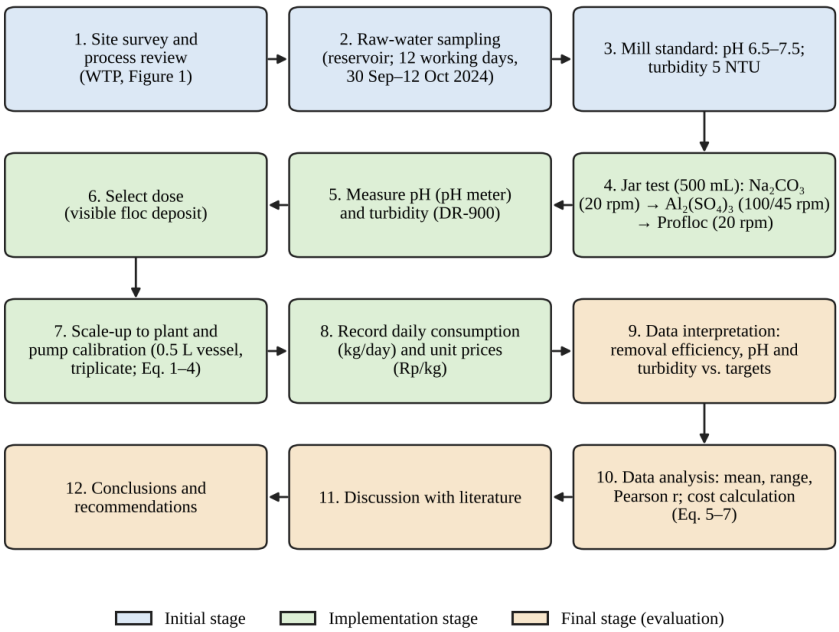


Figure 2. Flowchart of the research methodology

3. Results and Discussion

3.1. pH Adjustment by Soda Ash and Aluminum Sulfate

Raw reservoir water had pH 5.06–5.51 (mean 5.28) and turbidity 18–26 NTU (mean 20.6 NTU) over the 12 sampling days (Table 1). Soda ash was dosed at 8–14 mg/L (mean 10.9 mg/L) and raised pH to 5.35–7.61, with a mean of 6.77. The mean rise of 1.5 pH units shows that soda ash supplied enough alkalinity to offset the acidity of the raw water. The rise was only weakly related to dose ($r = 0.30$), because lower doses were given on days with higher raw pH ($r = \square 0.53$ between dose and raw pH). After soda ash, 23 of 36 runs and 10 of the 12 selected doses were within pH 6.5–7.5. Alkalinity and pH are the variables that determine alum dose in coagulation studies, which is why they were adjusted first [2–4].

Aluminum sulfate then lowered pH by 0.5–0.7 units in every run (mean 0.57), so the final pH averaged 6.20 (range 4.75–6.96). Only 15 of 36 runs and 5 of the 12 selected doses ended within the mill target of pH 6.5–7.5, and the selected doses ended at pH 5.77–6.66 (mean 6.25). All 15 compliant runs had a pH of at least 7.01 after soda ash, and the two runs at exactly 7.01 ended at 6.51 and 6.46. This agrees with alum hydrolysis consuming alkalinity [2,3] and with reported alum optima of pH 6.2–7.0 [2] and pH 7.0 [5], which most final values here lie below. The pH after soda ash (mean 6.77) therefore overstates the quality of the treated water, and the soda ash dose should be set for the post-alum pH, which in these data means about pH 7.0 or higher before alum. The jar test did not include the mill's second soda ash line (Soda Ash B), which may raise the pH of the plant water above the jar-test values.

Table 1. Jar-test results for 12 sampling days (three dosage levels per day)

Day	Run	Raw pH	Raw turbidity (NTU)	Na_2CO_3 (mg/L)	$Al_2(SO_4)_3$ (mg/L)	pH after soda ash	Final pH	Final turbidity (NTU)	Selected
1	a	5.34	19	9	10	7.01	6.51	5.53	✓
	b			10	10	7.11	6.61	5.55	–
	c			11	10	7.21	6.71	5.56	–
2	a	5.24	20	8	12	5.35	4.75	4.45	–
	b			10	12	6.37	5.77	4.43	✓
	c			12	12	6.55	5.95	4.47	–
3	a	5.06	20	10	12	5.40	4.80	4.47	–
	b			12	12	6.46	5.86	4.43	–
	c			14	12	6.57	5.97	4.44	✓
4	a	5.23	21	10	12	6.29	5.69	4.42	–
	b			11	12	6.38	5.78	4.44	–
	c			14	12	6.54	5.94	4.45	✓
5	a	5.23	18	10	11	6.20	5.65	4.87	–
	b			11	10	6.35	5.85	5.54	✓
	c			12	11	6.50	5.95	4.89	–
6	a	5.23	19	10	11	6.22	5.70	4.83	–
	b			11	11	6.40	5.85	4.85	–
	c			12	11	6.53	5.98	4.87	✓
7	a	5.17	22	10	11	6.35	5.80	4.85	–
	b			11	11	6.74	6.19	4.86	✓
	c			13	13	7.38	6.73	4.87	–
8	a	5.22	25	11	12	7.21	6.61	4.42	✓
	b			11	12	7.34	6.74	4.43	–

Day	Run	Raw pH	Raw turbidity (NTU)	Na_2CO_3 (mg/L)	$Al_2(SO_4)_3$ (mg/L)	pH after soda ash	Final pH	Final turbidity (NTU)	Selected
	c			14	14	7.52	6.82	2.88	–
9	a	5.26	26	11	11	7.09	6.54	4.88	✓
	b			12	12	7.15	6.55	4.44	–
	c			13	13	7.61	6.96	3.55	–
10	a	5.51	18	8	10	6.83	6.33	5.54	–
	b			9	11	7.21	6.66	4.87	✓
	c			10	12	7.49	6.89	4.89	–
11	a	5.49	19	8	10	6.73	6.23	5.57	–
	b			9	10	6.81	6.31	5.53	✓
	c			11	11	7.23	6.68	4.85	–
12	a	5.34	20	10	11	7.01	6.46	4.87	–
	b			11	12	7.25	6.65	4.43	✓
	c			12	12	7.49	6.89	4.45	–

Profloc was added at a fixed dose of 0.15 mg/L in all runs. Days 1–6 are 30 September–5 October and Days 7–12 are 7–12 October 2025. ✓ = dosage used for plant calculations (floc deposit observed after Profloc addition); – = not selected. Final pH and turbidity are the values after the full dosing sequence.

Final turbidity was not related to final pH (r = □ 0.02). On Days 2 and 3 the alum dose was constant at 12 mg/L, and soda ash doses of 8–14 mg/L changed the final pH from 4.75 to 5.97 while turbidity stayed at 4.43–4.47 NTU. This contrasts with an alum–hydrocolloid system that removed only about 51% of turbidity under acidic conditions [26] and with coagulation optima at pH 6–7 [6]. The raw water here was only about 20 NTU, so the instrument floor or a residual fine fraction (Section 3.2) may mask a pH effect that a more turbid water would show. The two runs with the highest pH after soda ash (7.52 and 7.61 on Days 8 and 9) gave the lowest turbidity (2.88 and 3.55 NTU), but they also received the highest alum doses (13–14 mg/L). Their result is therefore attributable to alum dose, in line with the stronger sweep flocculation expected at higher dose [1].

3.2. Turbidity Removal by Aluminum Sulfate and Profloc

Turbidity fell from a mean of 20.6 NTU to a mean of 4.74 NTU across all runs, a mean removal of 76.5% (final range 2.88–5.57 NTU). At the selected doses, the mean final turbidity was 4.85 NTU and 9 of 12 values were below the 5 NTU standard of the mill. The three exceedances (5.53–5.54 NTU) occurred on Days 1, 5, and 11, and all three were at the lowest alum dose tested (10 mg/L). All nine selected runs at 11–12 mg/L alum met the target, including the low-turbidity days 6 and 10. The exceedances therefore follow alum dose, not only the low raw turbidity (18–19 NTU) of those days. Low-turbidity days remain the critical case, because omitting rapid mixing impaired removal only in low-turbidity water [27] and raw turbidity is a control variable in coagulation studies [19].

Across all 36 runs, final turbidity fell stepwise with alum dose: 5.55 NTU at 10 mg/L (n = 7), 4.86 NTU at 11 mg/L (n = 11), 4.47 NTU at 12 mg/L (n = 15), 4.21 NTU at 13 mg/L (n = 2), and 2.88 NTU at 14 mg/L (n = 1), with r = □ 0.92. All 7 runs at 10 mg/L stayed above 5 NTU, and all 29 runs at 11 mg/L or more were below it. On six of the seven days on which alum varied within the day, the higher dose gave lower turbidity, and the exception (Day 7, 13 versus 11 mg/L) differed by only 0.02 NTU. This agrees with dose-dependent charge neutralization and sweep flocculation [1] and with higher dosage raising floc collision efficiency and strength [28]. Because doses were chosen day by day, alum dose is partly confounded with raw turbidity (r = 0.57), which also explains why final turbidity correlated negatively with raw turbidity (r = □ 0.61) and removal efficiency positively (r =

0.88). The data therefore show that 10 mg/L alum is too low for this water, and they do not show that removal efficiency is limited by raw turbidity as such.

The mean removal of 76.5% is lower than the 99.05% reported for alum on water intended for human consumption [21]. The difference mainly reflects the low raw turbidity here, because a residual of 4–5 NTU is a small absolute value but a limited percentage removal when raw water is only 18–26 NTU. Under optimized conditions, benchmark studies report residual turbidity of 2 NTU or lower [6,10], and our best run (2.88 NTU at 14 mg/L alum) shows that such values are within reach. A blended coagulant that included 13% alum met WHO potable-water limits at 45 mg/L [22], which indicates that dose and coagulant combination, not alum alone, determine the achievable residual. Alternative coagulants such as calcium ferrate (97–99% turbidity removal [29]) and tannin-based polymers (up to 90% [23]) could be evaluated if alum dosing cannot meet the target on low-turbidity days. Ultrasonic pretreatment raised turbidity removal by 25–35% and allowed lower doses, with the greatest benefit for aluminum sulfate [30].

Within an alum level, final turbidity was nearly constant although raw turbidity ranged from 18 to 26 NTU and final pH from 4.75 to 6.96: 5.53–5.57 NTU at 10 mg/L, 4.83–4.89 NTU at 11 mg/L, and 4.42–4.47 NTU in 14 of 15 runs at 12 mg/L. This suggests a dose-controlled residual fraction of fine particles that the applied alum and a fixed Profloc dose do not remove, and the coarse resolution of the DR-900 at this low range probably adds to the discrete clusters. Floc size and strength depend on coagulant dose and shear, and aluminum flocs broke up and then compacted under constant shear, leaving fewer fragments at the optimum dose [31].

A polymer flocculant such as Profloc is meant to bridge these fragments, and combined inorganic–polymer systems outperformed single components [9] and reached 1.19 NTU in sewage [10]. Overdosing the polymer, however, was linked to pipeline blockage [12], which is consistent with the mill's practice of dosing Profloc at a constant low rate (0.3 kg/day), because excessive doses degrade water quality. A constant Profloc dose cannot show whether Profloc is limiting, so jar tests with a Profloc series (mg/L) are needed to test whether a different dose would lower the 4.4–5.5 NTU residual.

3.3. Plant-Scale Dose and Injection Rate

The selected jar-test doses were converted to plant dosing with Eqs. 1–4 and checked by pump calibration (Table 2). Pump rates were 19.47–22.55 L/h for the soda ash, alum, and Profloc lines and 14.56 L/h for the Soda Ash B line on 30 September, and 19.71–21.98 L/h and 14.91 L/h on 7 October. Between the two calibrations the pump rates changed by less than 3% for every chemical, whereas the selected doses rose from 9 to 11 mg/L for Na_2CO_3 and from 10 to 11 mg/L for $Al_2(SO_4)_3$. With a nearly constant pump rate, the delivered dose can change only through the strength of the stock solution, and Eq. 2 puts the required strength of Na_2CO_3 at 37.0 g/L on 30 September and 44.6 g/L on 7 October ($Al_2(SO_4)_3$: 36.6 and 41.4 g/L).

These strengths are estimates from the equation and not measurements, and they imply that the operators adjusted dose mainly by changing the stock concentration rather than the pump speed. Over the 12 days the consumption of Na_2CO_3 was 15–22 kg/day (mean 17.6), $Al_2(SO_4)_3$ 17–21 kg/day (mean 19.4), and Soda Ash B 11–17 kg/day (mean 13.6), while Profloc stayed at 0.3 kg/day (Table 3). Soda Ash B accounted for about 44% of all soda ash used, so its function needs a clear technical rationale.

Table 2. Jar-test dose, calibrated pump rate, estimated stock strength, and plant dose on two calibration days

Chemical	30 September 2025				7 October 2025			
	Dose (mg/L)	Pump rate (L/h)	Stock (g/L)	Dose (kg/day)	Dose (mg/L)	Pump rate (L/h)	Stock (g/L)	Dose (kg/day)
Na_2CO_3 (soda ash)	9	19.47	37.0	15	11	19.71	44.6	18
$Al_2(SO_4)_3$	10	21.86	36.6	18	11	21.26	41.4	19
Profloc	0.15	22.55	0.53	0.3	0.15	21.98	0.55	0.3
Na_2CO_3-B (Soda Ash B)	9	14.56	49.5	11	11	14.91	59.0	14

Pump rate from the triplicate calibration (Eq. 3). Stock strength is estimated as D × Q / q (Q = 80 m^3/h; Eq. 2). Plant dose is from the mill's calculation sheet (Eq. 4), rounded up to whole kg except for Profloc.

3.4. Chemical Cost

Daily chemical cost ranged from Rp251,218 to Rp337,701, with a mean of Rp288,410 (Table 3). Na_2CO_3 from the two lines made up 61% of the mean daily cost, $Al_2(SO_4)_3$ 23%, and Profloc 16%. Profloc costs Rp47,553 per day although only 0.3 kg is used, because its unit price is 28 times that of soda ash and 46 times that of aluminum sulfate. The most expensive days (Days 3 and 4: 22 kg of soda ash, 21 kg of alum, and 17 kg of Soda Ash B) cost 34% more than the cheapest day (Day 11: 15, 17, and 11 kg), and the two Na_2CO_3 lines explain 84% of that difference. This spread shows how strongly soda ash dosing drives the cost of the plant, which is why dose control, rather than coagulant choice, is the main cost lever here. The same cost sensitivity was reported for lime- and alum-based treatment [13], and AI-based dose optimization reduced median chemical cost by 49% in a drinking-water plant [14].

Table 3. Daily chemical consumption and cost

Day	Consumption (kg/day)				Cost (Rp/day)				
	Na_2CO_3	$Al_2(SO_4)_3$	Profloc	Soda Ash B	Na_2CO_3	$Al_2(SO_4)_3$	Profloc	Soda Ash B	Total
Unit price (Rp/kg)					5,603	3,411	158,510	5,603	
1	15	18	0.3	11	84,045	61,398	47,553	61,633	254,629
2	16	21	0.3	13	89,648	71,631	47,553	72,839	281,671
3	22	21	0.3	17	123,266	71,631	47,553	95,251	337,701
4	22	21	0.3	17	123,266	71,631	47,553	95,251	337,701
5	18	18	0.3	13	100,854	61,398	47,553	72,839	282,644
6	19	20	0.3	14	106,457	68,220	47,553	78,442	300,672
7	18	19	0.3	14	100,854	64,809	47,553	78,442	291,658
8	18	21	0.3	14	100,854	71,631	47,553	78,442	298,480
9	18	19	0.3	14	100,854	64,809	47,553	78,442	291,658
10	15	19	0.3	11	84,045	64,809	47,553	61,633	258,040
11	15	17	0.3	11	84,045	57,987	47,553	61,633	251,218
12	15	19	0.3	14	84,045	64,809	47,553	78,442	274,849
Mean	**17.6**	**19.4**	**0.3**	**13.6**	**98,519**	**66,230**	**47,553**	**76,107**	**288,410**

Days as in Table 1. Costs were recalculated as consumption × unit price (Eqs. 5–6), so Profloc is Rp47,553/day (0.3 kg × Rp158,510). Soda Ash B is described in Section 2.3.

Weekly cost was Rp1,795,018 in the first calibration week and Rp1,665,903 in the second (Table 4), a decrease of Rp129,115 (7.2%). Na_2CO_3 from the two lines accounted for 87% of the decrease, Soda Ash B alone for 30%, and $Al_2(SO_4)_3$ for 13%. The weekly consumption was 112 and 99 kg of Na_2CO_3, 119 and 114 kg of $Al_2(SO_4)_3$, and 85 and 78 kg of Soda Ash B. Profloc cost was identical in both weeks, reflecting its constant dose. Without a fixed-dose baseline, the savings attributable to jar-test-based dosing cannot be quantified from these data. The week-to-week change nevertheless shows that dosing followed raw-water conditions, in line with the view that dose should follow raw-water pH, turbidity, and alkalinity [3],[15].

Table 4. Chemical consumption and cost per calibration week

Chemical	Unit price (Rp/kg)	30 September–5 October		7–12 October	
		Consumption (kg)	Cost (Rp)	Consumption (kg)	Cost (Rp)
Na_2CO_3 (soda ash)	5,603	112	627,536	99	554,697
$Al_2(SO_4)_3$	3,411	119	405,909	114	388,854
Profloc	158,510	1.8	285,318	1.8	285,318
Na_2CO_3-B (Soda Ash B)	5,603	85	476,255	78	437,034
Total			**1,795,018**		**1,665,903**

Weekly totals were recalculated from the daily records. They differ from the mill's weekly summary (Rp1,758,677 and Rp1,607,155) because of arithmetic corrections for Day 3 soda ash, Profloc, and week-2 Soda Ash B.

3.5. Practical Implications and Limitations

In practical terms, the plant meets the turbidity target at 11 mg/L alum or more, but the final pH is below 6.5 in most runs, so soda ash should be dosed for the post-alum pH rather than for the pH after soda ash. The cost data show that Na_2CO_3 dosing, not Profloc or alum, offers the largest scope for savings, and Table 1 suggests that part of the pH adjustment did not improve turbidity within the range tested. Raising soda ash to reach a higher final pH would raise cost, so the benefit of meeting the pH specification must be weighed against the cost of the extra Na_2CO_3. Alum sludge should also be considered, because it is rich in Al, Si, and Fe and varies with raw-water turbidity [20]. The study has four limitations: it covers one mill over 12 days, it has no fixed-dose control for quantifying savings, it lacks alkalinity, stock-strength, and residual aluminum data, and its turbidity readings lie below the specified range of the colorimeter. Future work should add alkalinity and zeta potential measurements and test dose-prediction models of the kinds cited above [3],[15–17].

4. Conclusions

Jar tests on reservoir water of pH 5.06–5.51 and 18–26 NTU showed that soda ash (8–14 mg/L) raised pH to a mean of 6.77, but aluminum sulfate then lowered it by 0.57 units to a mean of 6.20, so only 5 of the 12 selected doses ended within pH 6.5–7.5. Aluminum sulfate with Profloc cut turbidity by 76.5% to a mean of 4.74 NTU, and final turbidity fell stepwise with alum dose from 5.55 NTU at 10 mg/L to 4.47 NTU at 12 mg/L. All 29 runs at 11 mg/L alum or more were below 5 NTU, whereas the 7 runs at 10 mg/L were not. The selected doses averaged 11.0 mg/L Na_2CO_3 and 11.2 mg/L $Al_2(SO_4)_3$, with Profloc held constant. Calibrated pump rates were 19.47–19.71 L/h for Na_2CO_3, 21.26–21.86 L/h for $Al_2(SO_4)_3$, 21.98–22.55 L/h for Profloc, and 14.56–14.91 L/h for Soda Ash B, and plant consumption was 15–22 kg/day Na_2CO_3, 17–21 kg/day $Al_2(SO_4)_3$, 0.3 kg/day Profloc, and 11–17 kg/day Soda Ash B.

Chemical cost averaged Rp288,410 per day (Rp251,218–337,701) and totaled Rp1,795,018 and Rp1,665,903 in the two calibration weeks, with the two Na_2CO_3 lines accounting for 61% of the cost. The 34% cost spread between the cheapest and most expensive days shows that routine jar testing,

rather than fixed dosing, is the main lever for cost control at this plant. The main contribution of this study is a documented chain from jar-test dose to plant injection rate to weekly cost for a palm oil mill water treatment plant. Alkalinity measurements, a Profloc dose series, a fixed-dose control, and model-assisted dosing should be tested next to quantify the savings.

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