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Properties of Laboratory Wastewater Having Influence Heavy Metals Treatment Efficiency by Chemical Precipitation

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ABSTRACT

The influence of laboratory wastewater properties on heavy metals treatment efficiency by the chemical precipitation included aluminium sulphate ($Al_2(SO_4)_3$) and poly aluminium chloride (PAC) using a stepwise multiple regression method. The laboratory wastewater properties showed high acidity approximately 0.75 and a highly turbid approximately 667.41 NTU that TSS (705.48 mg/L), COD (480.00 mg/L) and heavy metals such as Zn did not exceed the standards while Cu, Mn and Cr have levels exceeded the standards. Aluminium sulphate $Al_2(SO_4)_3$) coagulant has treatment efficiency for reducing heavy metals at a pH of 9.00 to 73.62%, 99.94%, 98.43%, 68.76% and 99.25% for various heavy metals (Cu, Fe, Mn, Zn and Cr) respectively with original laboratory wastewater properties that parameters of laboratory wastewater include TSS, BOD, and pH having the highest influence on heavy metals treatment efficiency. The parameters of laboratory wastewater having the highest influence on heavy metals treatment efficiency when using poly aluminium chloride (PAC) were pH, COD, DO, and BOD when at a pH of 9.00 has treatment efficiency for reducing heavy metals to 73.67%, 99.94%, 98.45%, 69.76%, and 99.26% for various heavy metals (Cu, Fe, Mn, Zn, and Cr) respectively.

Keywords: chemistry laboratory wastewater, chemical precipitation, heavy metals.

INTRODUCTION

The study of environmental science and various analyses such as water quality assessment, soil quality evaluation, and other chemical-related analyses are escalating issues of environmental pollution (Iqubal et al., 2020; Saxena et al., 2020). Currently, laboratory wastewater, despite being a significant source of hazardous pollutants, receives minimal attention within educational institutions. Laboratory wastewater poses a challenge due to its diverse composition, including heavy metals, COD, BOD, TSS, TDS, and varying pH levels. Laboratories, especially those conducting tests involving heavy metals, can contribute to environmental contamination if proper disposal measures are not in place. This oversight poses risks to human health and that of other living organisms. Heavy metal contamination can have economic ramifications at both local and global levels. Reduced productivity of goods from contaminated areas can lead to loss of income and damage to local economies (Zaynab et al., 2022). Therefore, effective treatment methods such as coagulation, adsorption or a combination of these approaches are necessary to manage this wastewater effectively. Combining multiple methods is often required to ensure comprehensive removal of contaminants and achieve regulatory compliance.

The coagulation process is highly efficient in removing high molecular weight organics from wastewater. It effectively targets contaminants of various origins and is commonly used as a primary treatment method (Kyrii et al., 2020). This method is straightforward, allowing for the utilization of different coagulants tailored to specific wastewater characteristics. Furthermore, the combined application of coagulation and adsorption processes has demonstrated particular effectiveness in eliminating organic substances from wastewater (Dąbrowska, 2021). Chemical precipitation emerges as a preeminent technique for immobilizing hazardous waste, acclaimed for its efficacy in mitigating environmental risks (Chen et al., 2021; El-eswed, 2020; Shrestha et al., 2021). This method induces transformative alterations in wastewater properties by precipitating toxic substances into solid forms, facilitating their subsequent separation and treatment, thus averting environmental contamination (Wang et al., 2022). The resultant effluent, post-precipitation, not only demonstrates diminished environmental hazards but also aligns with regulatory standards, thereby fostering cost-effective wastewater treatment and efficacious risk mitigation. Moreover, chemical precipitation enhances the overall quality of treated wastewater by purging it of harmful contaminants through precipitate formation, rendering it safer for discharge or reuse (Benalia et al., 2022; Pohl, 2020). This refinement not only streamlines downstream processing and disposal operations but also enhances operational efficiency and diminishes associated costs (Saleh et al., 2022). In this study, chemical precipitation was used for wastewater treatment to eliminate toxic waste in the laboratory. The investigation will focus on assessing changes in wastewater quality parameters such as pH, dissolved oxygen (DO), total dissolved solids (TDS), total suspended solids (TSS), chemical oxygen demand (COD), biochemical oxygen demand (BOD), and heavy metal concentrations including copper (Cu), iron (Fe), manganese (Mn), zinc (Zn), and chromium (Cr) before and after immobilization of high-toxicity waste via chemical precipitation. This aims to determine optimal conditions for treating laboratory wastewater using chemical precipitation methods with varying ratios of precipitant and pH conditions. Such an approach provides an alternative for reducing toxicity in laboratory wastewater and saving costs associated with its treatment.

METHODOLOGY

Scope and steps of study

This study is divided into 3 parts, the first part was an analysis of laboratory wastewater quality, the second part was a study of the efficiency of chemical removal and the last part was a study of the influences that affect the removal of heavy metals in laboratory wastewater (Figure 1).

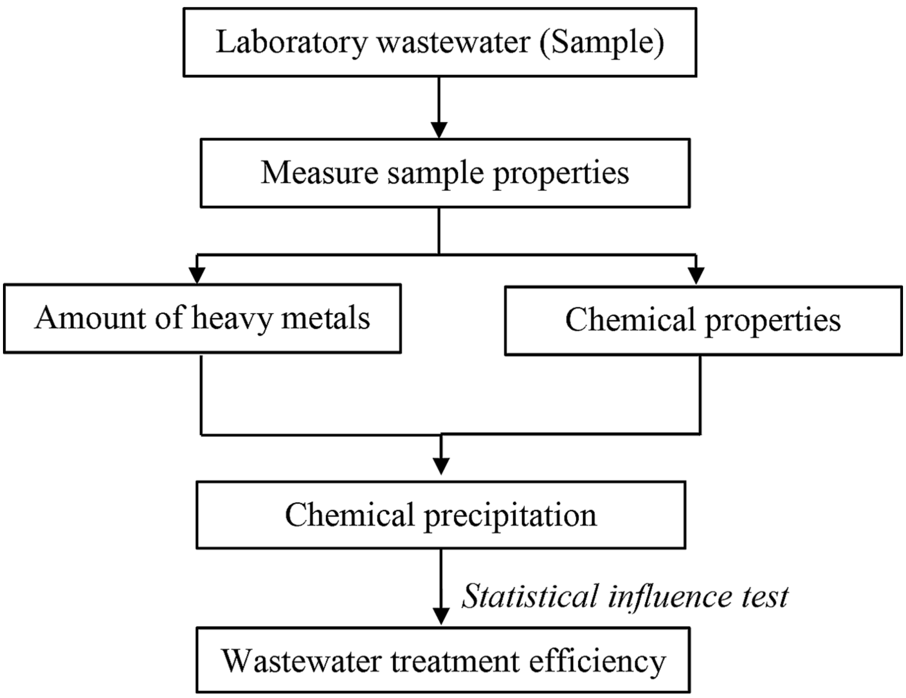

Figure 1. Flow of research

Study of properties of laboratory wastewater

The coagulants and chemicals used to enhance the removal efficiency were aluminium sulphate ($Al_2(SO_4)_3$) and poly aluminium chloride (PAC). Chemicals used for water quality analysis were potassium dichromate digestion solution ($K_2Cr_2O_7$), sulfuric acid (H_2SO_4), ferroin indicator, ferrous ammonium sulfate ($Fe(HH_4)_2(SO_4)_2 \cdot 6H_2O$), manganese sulfate monohydrate ($MNSO_4 \cdot H_2O$), sodium hydroxide (NaOH), sodium iodide (NaI), sodium azide (NaN_3), soluble starch, salicylic acid ($C_7H_6O_7$), sodium thiosulfate pentahydrate ($Na_2S_2O_3 \cdot 5H_2O$). The pH value of the solution was adjusted with 0.1M H_2SO_4 or 0.1 M NaOH, and deionized water was used to prepare solutions. All chemicals used in the study were of analytical grade.

Comparative studies of precipitation efficiency of iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), and chromium (Cr) ions from wastewater were conducted using $Al_2(SO_4)_3$ and PAC. The Jar test (VELP Scientifica Model: JLT6) was used in precipitation tests, a mechanical mixing motor with a six-bladed disc turbine agitator as the impeller. The heavy metals content was determined using a microwave digestor (Anton Paar Model: Multiwave 5000) and the residual heavy metal ion concentrations were analyzed by inductively coupled plasma-optical emission spectrometry (ICP-OES: Shimadzu Model, ICPE-9820: sample uptake rate 1.00 mL/min, carrier gas flow rate 0.70 L/min, auxiliary gas flow rate 0.60 L/min, plasma gas flow rate 10.00 L/min, and temperature 25°C). The water properties analysis (pH, DO, and TDS) was measured using multiparameter water quality meter (YSI Model: ProQuatro). The turbidity of the samples was measured using turbidity meter (VELP Scientifica Model: TB1). The TSS was measured using gravimetric method. The BOD was measured using azide modification (20 °C, 5 days) and COD was measured using closed reflux.

Study of heavy metals treatment efficiency

To find optimal coagulants and chemicals used to enhance the removal efficiency, $Al_2(SO_4)_3$ and PAC at concentrations 0.00 (control), 100.00, 150.00, 200.00, 250.00, and 300.00 mg/L were used. Place sample water into 2 sets of 1,000.00 ml. beakers, with 6 beakers in each set. Proceed to modify the initial pH to 5.00, 7.00, and 9.00 respectively. Then, the mixtures were centrifuged at 100.00 rpm for 1 min for phase separation with Jar test, the next step is to add 0.00 (control) 5.00, 7.50, 10.00, 12.50, and 15.00 mL of $Al_2(SO_4)_3$ and PAC solution of flocculent to 1,000.00 mL of sample water. Then the mixture was centrifuged at 100.00 rpm for 1.00 min for phase separation and the mixture was centrifuged at 40.00 rpm for 30.00 min, let it settle for 3.00 hours. Then the supernatants were collected to measure the water quality and metalion concentrations (Figure 2).

Data analysis for testing statistical influence

Data were tested for normality, and then the stepwise multiple regression method at p-value $\leq$ 0.050 and standardized coefficients (β) were

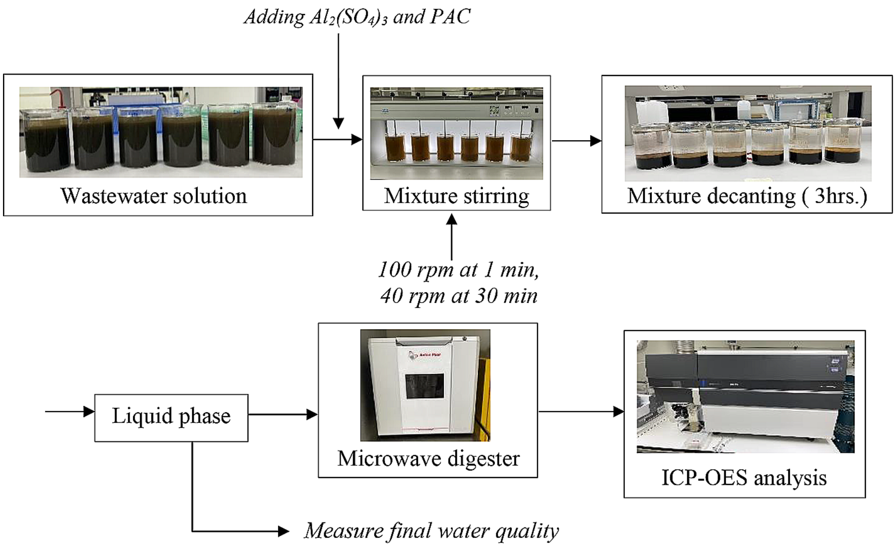

Figure 2. Wastewater analysis process

utilized for the regression coefficient analysis, examining the relationship between wastewater properties with heavy metal. To calculate metal removal efficiency, use the following Equation (Intissar et al., 2024)

$$R\ (\%) = \frac{C_i - C_f}{\mathrm{Ci}} \tag{1}$$

where: R–metal removal efficiency, C_i–initial concentration of the metal, C_f–final concentration of the metal

RESULTS AND DISCUSSION

The properties of laboratory wastewater

The wastewater from the environmental laboratory exhibits characteristics showed high acidity approximately 0.75, indicating a high level of acidity in the wastewater, which could have adverse effects on living organisms and the environment. The wastewater was highly turbid, with a turbidity value of approximately 667.41 NTU, suggesting the presence of large dissolved or suspended particles. The TDS value is 705.48 mg/L, indicating the concentration of dissolved substances in the water, such as mineral salts and organic solutes. The COD value is 480.00 mg/L, indicating the amount of organic substances requiring oxygen for decomposition in the water. Color of the wastewater was yellowish, indicating the presence of dissolved yellowish substances, possibly originating from chemicals or other dissolved solutes. Heavy metal contents (Cu, Fe, Mn, Zn, and Cr), the concentrations of Cu, Fe, Mn, Zn, and Cr are 0.83, 431.25, 6.35, 0.32, and 77.60 mg/L respectively suggesting the presence of these heavy metals in the wastewater. Therefore, the wastewater from the environmental laboratory exhibits characteristics of high concentration and various substances. This could have implications for the environment and human health. Thus, proper management and treatment of wastewater from laboratories are essential to minimize potential impacts.

When compared to the surface water standards of Thailand (Table 1), the pre-treatment water quality parameters within the parameters, including TSS, COD, and heavy metals such as Zn, did not exceed the Thailand Pollution Control Department standards. However, parameters such as Cu, Mn and Cr should not exceed 0.10, 1.00, and 0.05 mg/L. The properties of laboratory wastewater found Cu = 0.83 mg/L, Mn = 6.35 mg/L, and Cr = 77.60 mg/L that their levels exceeded the standards set by law in regard to surface water quality. According to WHO (2014), Cr and Mn should not exceed 0.10 and 0.20 mg/L in wastewater used for irrigation, the study result found that laboratory wastewater found Cr = 77.60 and Mn = 6.35 mg/L, that levels have exceeded WHO standard (Aftab et al., 2023). Furthermore, upon comparing water quality parameters with databases from other countries and the US.EPA, it was evident that most parameters exceeded the set standards. This serves as a clear indication that the water quality before treatment within these parameters would severely impact the environment if not properly managed.

The heavy metals treatment efficiency by chemical precipitation

Precipitation with aluminium sulphate ($Al_2(SO_4)_3$)

This study investigates the use of aluminum sulfate in treating heavy metal-containing wastewater. It provides clear insights into the efficiency of the treatment process using aluminum sulfate under different conditions of solution concentration and pH levels of the wastewater tested. From the Figure 3 showing the surface graph of the removal efficiency at various conditions, divided into shades according to the removal efficiency, it was found that the optimum conditions for using aluminum sulfate as a coagulant occur at a pH of approximately 9.00 and with an aluminum sulfate concentration of 250.00 mg/L. Under these conditions, the following parameters were observed TDS was 376.58 mg/L, TSS was 0.55 mg/L, turbidity was 41.82 NTU, COD was 128.00 mg/L, BOD was 4.72 mg/L, Cu concentration was 0.09 mg/L, Fe concentration was 0.26 mg/L, Mn concentration was 0.10 mg/L, Zn concentration was 0.10 mg/L, and Cr concentration was 0.58 mg/L. The treatment efficiency for reducing heavy metals in the wastewater using aluminum sulfate at a pH of approximately 9.00 was calculated to be approximately 73.62%, 99.94%, 98.43%, 68.76% and 99.25% for various heavy metals, respectively. The efficiency of heavy metal removal through the process of coagulation-flocculation with aluminum sulfate at pH around 9.00 demonstrates significant effectiveness in reducing TDS, TSS, turbidity, COD, BOD, and various heavy metal concentrations in wastewater. Generally, the process exhibits the highest efficacy in reducing heavy metal concentrations when using aluminum

Table 1. Properties of laboratory wastewater

Parameters	Measured values	Standard score of each country				
		Thailand[1,2]	Kuwait[3]	Jordan[3]	Oman[3]	US.EPA[4]
pH	0.75	5.00-9.00*	6.50-8.50	6.00-9.00	6.00-9.00	6.00-9.00
DO (mg/L)	5.42	6.00**	2.00	1.00	–	1.00
TDS (mg/L)	705.48	500.00*	1,500.00	1,500.00	2,000.00	1,500.00
TSS (mg/L)	3.29	40.00*	15.00	60.00	30.00	50.00
COD (mg/L)	480.00	–	100.00	150.00	200.00	250.00
BOD (mg/L)	19.15	30.00*	20.00	60.00	20.00	50.00
Cu (mg/L)	0.83	0.10**	0.20	0.20	1.00	0.20
Fe (mg/L)	431.25	–	5.00	5.00	5.00	5.0 0
Mn (mg/L)	6.35	1.00**	0.20	0.20	0.50	0.20
Zn (mg/L)	0.32	1.00**	2.00	5.00	5.00	2.00
Cr (mg/L)	77.6 0	0.05**	0.15	0.10	0.05	0.10

Note: *Building effluent standards (Type 2), **Standard value of surface water for class 2, [1]Notification of the Ministry of Natural Resources and Environment (2005), [2]Notification of the National Environment Board (1994), [3]World Health Organization (2006), [4]Environmental Protection Agency (2012)

sulfate at optimal concentrations and under suitable pH conditions. These findings align with the experimental and analytical data obtained from the wastewater characterized as described earlier. Therefore, the coagulation-flocculation process with aluminum sulfate proves to be an efficient method for mitigating the pollution of wastewater containing heavy metals, particularly under conditions of pH around 9.00 and optimal solution concentrations, show in Figure 3. Overall, the results demonstrate the effectiveness of the aluminum sulfate treatment process in reducing TDS, TSS, turbidity, COD, BOD, and various heavy metal concentrations in wastewater when applied under suitable pH conditions. Typically, the highest efficiency in reducing heavy metal concentrations is achieved when aluminum sulfate is used at the appropriate concentration and under optimal pH conditions. The pH serves as an indicator for assessing the acidity or alkalinity level of a solution. It plays a critical role in the coagulation process. When positively charged ions from the coagulant come into contact with negatively charged ions under specific pH conditions, particles or flocs are created. These particles gradually grow in size and weight, leading to the settling of the floc. The formation of flocs during this process typically results in a decrease in pH value (Susila Arita et al., 2022).

Precipitation with poly aluminium chloride

The results of the experiment using poly aluminium chloride, with the concentration of the solution set at 0.00 (control), 100.00, 150.00, 200.00, 250.00, and 300.00 mg/L, and controlled at pH 5.00, 7.00, and 9.00 revealed that the optimal condition for using poly aluminium chloride as a coagulant was at a pH of approximately 9.00 with a concentration of 100.00 mg/L. From the experiments conducted under these conditions, it was found that the TDS value was 211.88 mg/L, TSS was 0.35 mg/L, turbidity was 10.12 NTU, COD was 96.00 mg/L, BOD was 4.12 mg/L, Cu was 0.09 mg/L, Fe was 0.26 mg/L, Mn was 0.10 mg/L, Zn was 0.10 mg/L, and Cr was 0.57 mg/L. This translates to an efficiency of heavy metal removal of approximately 73.67%, 99.94%, 98.45%, 69.76%, and 99.26%, respectively show in Figure 4. The experimental results suggest that the use of poly aluminium chloride for wastewater coagulation is suitable and effective. The coagulation process aims to destabilize colloidal particles in water. It involves careful consideration of factors such as stirring speed, stirring time, and coagulant dose to achieve optimal results. It was found that the optimal conditions for using this substance as a coagulant occur at a pH of approximately 9.00 with a concentration of poly aluminium chloride at 100.00 mg/L. The experimental results demonstrate the ability to efficiently reduce TDS, TSS, turbidity, COD, BOD, and various heavy metal concentrations in wastewater when using poly aluminium chloride at pH around 9.00. In the coagulation process using PAC coagulant, floc formation occurs more rapidly compared to with ordinary coagulants. This is attributed to the effective binding of colloids by the aluminate active group. The bonding is further

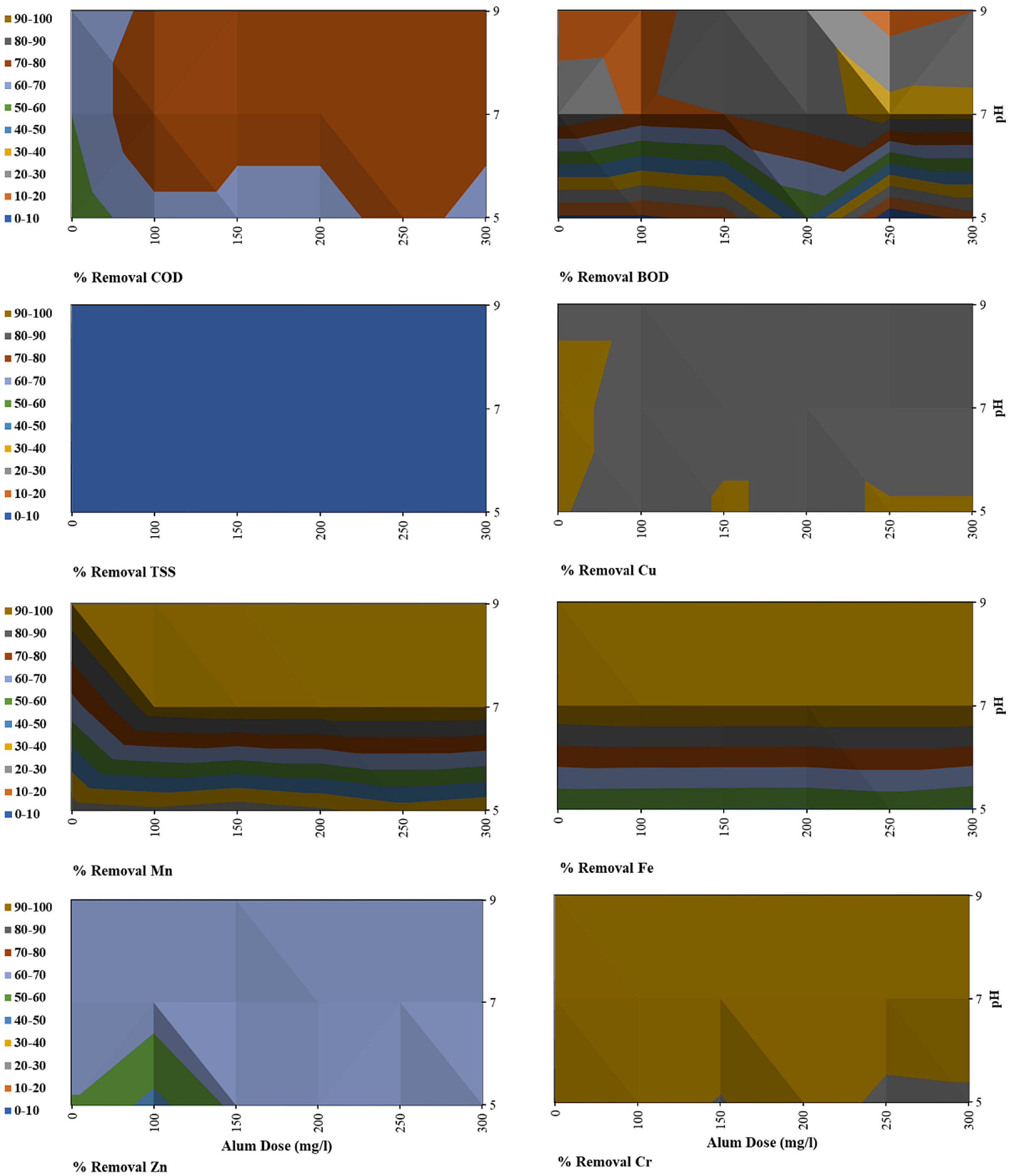

Figure 3. Efficiency of removal by coagulation-flocculation with aluminium sulphate ($Al_2(SO_4)_3$)

strengthened by polymer chains from the polyelectrolyte group, resulting in denser flocs. Additionally, the addition of hydroxyl groups to the hydrophobic colloidal chain increases its molecular weight. Following the addition of PAC coagulant, the pH value increases with the concentration of PAC. This rise in pH is attributed to the reduction in free hydrogen ions (H^+) resulting from the hydrolysis reaction when the coagulant reacts with water (Susila Arita et al., 2022). This controlled condition proves effective in removing heavy metals from wastewater, which is a significant outcome for the development of wastewater treatment processes in both industrial and environmental contexts in the future. However, it is essential to consider the limitations and applicability of these results in real-world scenarios. Further testing and refinement in future research are necessary to achieve comprehensive results and optimize the use

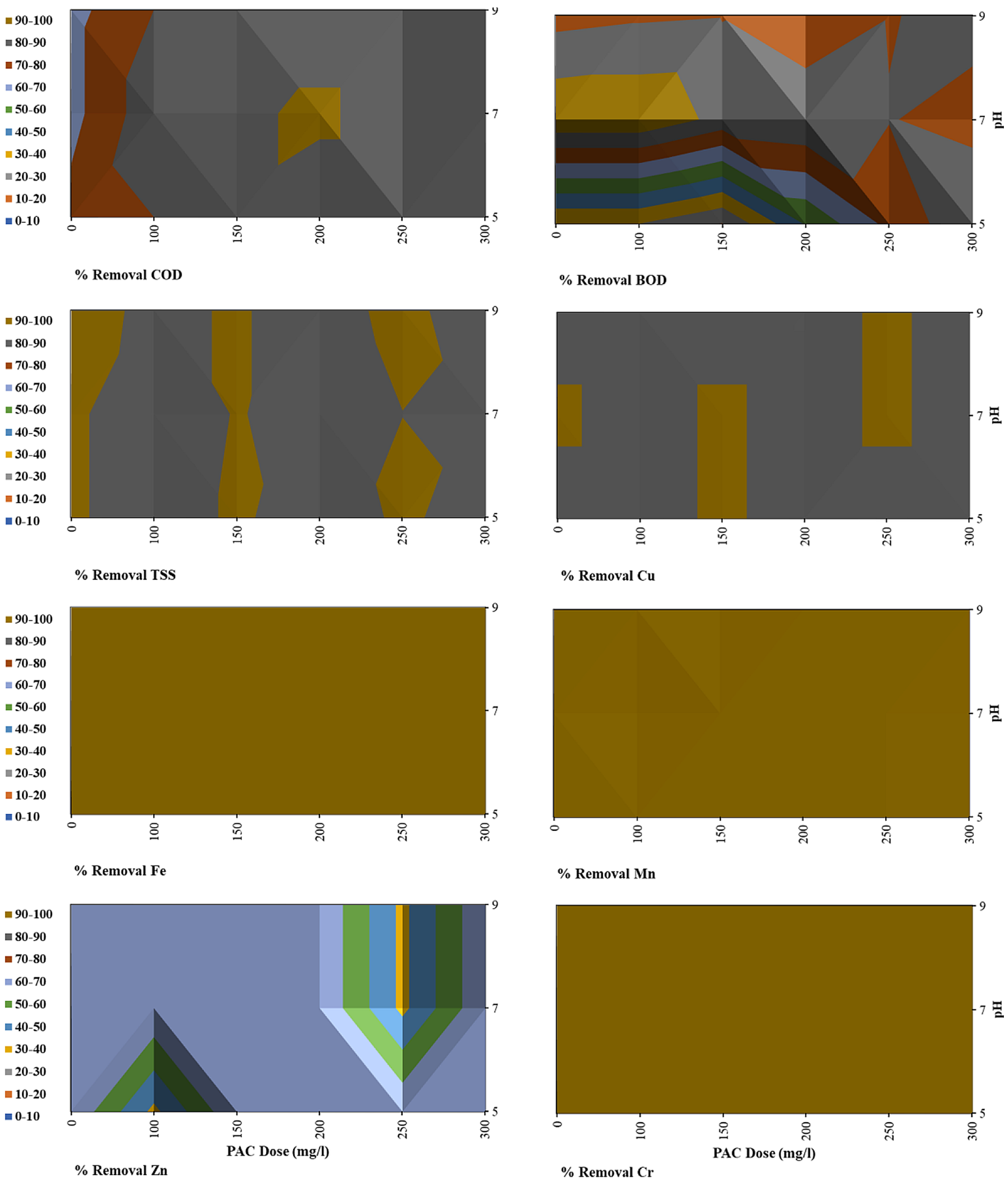

Figure 4. Efficiency of removal by coagulation-flocculation with poly aluminium chloride (PAC)

of poly aluminium chloride for improving water and environmental conditions simultaneously.

Influence of laboratory wastewater properties on heavy metals treatment efficiency

The study of wastewater properties form correlation between heavy metals includes Cu, Fe, Mn, Zn, and Cr with 5 parameters of laboratory wastewater properties through the use of 2 chemical coagulants and analyzed using Pearson correlation statistics. The results show in Table 2, aluminium sulphate ($Al_2(SO_4)_3$) coagulant found that pH has a high correlated value with 4 types of heavy metals include Fe (R = 0.895, p-value = 0.000), Mn (R = 0.897, p-value = 0.000), Zn (R = 0.592, p-value = 0.010), and Cr (R = 0.732, p-value = 0.001) as well as BOD were Fe (R = 0.937, p-value = 0.000), Mn

Table 2. Correlation of wastewater properties with heavy metals

Chemical precipitation	Parameters	Correlation	Types of heavy metals				
			Cu	Fe	Mn	Zn	Cr
Aluminium sulphate ($Al_2(SO_4)_3$)	pH	R	-0.265	0.895**	0.897**	0.592**	0.732**
		p-value	0.287	0.000	0.000	0.010	0.001
	DO	R	-0.150	-0.406	-0.425	-0.562*	-0.061
		p-value	0.554	0.095	0.078	0.015	0.809
	TDS	R	-0.191	-0.086	-0.027	0.067	-0.228
		p-value	0.448	0.734	0.914	0.791	0.363
	TSS	R	0.418	-0.007	-0.057	0.107	-0.246
		p-value	0.084	0.977	0.821	0.673	0.325
	COD	R	-0.567*	0.460	0.562*	0.274	0.242
		p-value	0.014	0.055	0.015	0.272	0.333
	BOD	R	-0.367	0.937**	0.901**	0.574*	0.852**
		p-value	0.134	0.000	0.000	0.013	0.000
Poly aluminium chloride (PAC)	pH	R	0.080	-0.047	-0.057	-0.019	-0.480*
		p-value	0.751	0.853	0.823	0.940	0.044
	DO	R	0.060	-0.079	0.315	-0.184	0.293
		p-value	0.812	0.756	0.202	0.466	0.238
	TDS	R	-0.033	0.059	-0.126	0.025	0.425
		p-value	0.897	0.816	0.618	0.922	0.079
	TSS	R	0.511*	-0.185	0.310	0.020	-0.040
		p-value	0.030	0.463	0.211	0.937	0.875
	COD	R	-0.069	0.180	-0.209	0.050	-0.100
		p-value	0.785	0.474	0.405	0.844	0.693
	BOD	R	0.037	-0.138	-0.333	0.163	-0.170
		p-value	0.883	0.584	0.178	0.517	0.501

Note: * Correlation at the 0.010 level of significance, ** Correlation at the 0.050 level of significance.

(R = 0.901, p-value = 0.000), Zn (R = 0.574, p-value = 0.013), and Cr (R = 0.852, p-value = 0.000). While TSS and COD have a high correlated value with Cu (R = 0.418, p-value = 0.084) and Mn (R = 0.562, p-value = 0.015) respectively.

In addition, the poly aluminium chloride (PAC) coagulant found that DO, TDS, TSS, COD, and BOD have a high correlated value with Mn (R = 0.315, p-value = 0.202), Cr (R = 0.425, p-value = 0.079), Cu (R = 0.511, p-value = 0.030), Fe (R = 0.180, p-value = 0.474), and Zn (R = 0.163, p-value = 0.517) respectively.

The Table 3 was analysis of laboratory wastewater properties having influence heavy metals treatment efficiency using a stepwise multiple regression method, which a high beta value (β) indicates a high influence of heavy metal treatment efficiency. The aluminium sulphate ($Al_2(SO_4)_3$) coagulant showed a high influence on heavy metals treatment efficiency if the laboratory wastewater parameters are controlled, the Cu type of heavy metal multiple regression showed the influence of wastewater parameters on the occurrence of treatment efficiency to 18.20% (R^2 = 0.182) with TSS (β = 0.258) having the highest influence on treatment. In addition, the Fe and Cr types of heavy metals multiple regression showed the influence of wastewater parameters on the occurrence of treatment efficiency to 92.20% (R^2 = 0.922) and 80.00% (R^2 = 0.800) with BOD (β = 0.644 and β = 1.027) has the highest influence on treatment as well. The pH value of wastewater influences the treatment efficiency of Mn (β = 0.445) and Zn (β = 0.898) heavy metals equal to 91.50% (R^2 = 0.915) and 32.60% (R^2 = 0.326) respectively.

The poly aluminium chloride (PAC) coagulant showed Cu multiple regression having the highest influence on treatment efficiency with pH (β = 0.996) to 3.70% (R^2 = 0.037) while the COD value of wastewater influences the treatment efficiency of Fe (β = 0.359) and Zn (β = 0.569). In addition, Mn type of heavy metal multiple regression showed

Table 3. Results of regression coefficient analysis between wastewater properties with heavy metals.

Heavy metals	Parameters	Un-Std. coefficients B	Un-Std. coefficients Std. Error	Std. coefficients Beta (β)	t	Sig.	R	R^2	Adj.R^2	Std. error of the estimate
Aluminium sulphate ($Al_2(SO_4)_3$)										
Cu	Constant	63.788	50.788	-	1.256	0.235	0.686	0.471	0.182	0.90738
	pH	0.066	0.205	0.203	0.323	0.753				
	DO	-0.039	0.074	-0.144	-0.529	0.607				
	TDS	0.472	0.800	0.246	0.590	0.567				
	TSS	0.064	0.060	0.258	1.065	0.310				
	COD	-0.089	0.053	-0.583	-1.679	0.121				
	BOD	-0.009	0.014	-0.305	-0.638	0.537				
Fe	Constant	-44.775	378.543	–	-0.118	0.908	0.974	0.949	0.922	6.76311
	pH	2.221	1.529	0.283	1.453	0.174				
	DO	-0.597	0.554	-0.091	-1.077	0.304				
	TDS	-2.715	5.962	-0.059	-0.455	0.658				
	TSS	0.193	0.451	0.032	0.429	0.676				
	COD	0.415	0.396	0.112	1.047	0.318				
	BOD	0.448	0.103	0.644	4.353	0.001				
Mn	Constant	-474.268	546.627	–	-0.868	0.404	0.972	0.945	0.915	9.76611
	pH	4.842	2.208	0.445	2.193	0.051				
	DO	-0.972	0.800	-0.107	-1.216	0.250				
	TDS	1.024	8.610	0.016	0.119	0.908				
	TSS	-0.055	0.651	-0.007	-0.085	0.934				
	COD	1.041	0.572	0.204	1.819	0.096				
	BOD	0.411	0.149	0.428	2.767	0.018				
Zn	Constant	-203.830	244.037	–	-0.835	0.421	0.751	0.564	0.326	4.36001
	pH	1.027	0.986	0.595	1.042	0.320				
	DO	-0.484	0.357	-0.335	-1.357	0.202				
	TDS	4.152	3.844	0.409	1.080	0.303				
	TSS	0.047	0.291	0.036	0.162	0.874				
	COD	-0.159	0.256	-0.196	-0.621	0.548				
	BOD	0.012	0.066	0.079	0.182	0.859				
Cr	Constant	287.716	109.370	–	2.631	0.023	0.933	0.870	0.800	1.95401
	pH	-0.291	0.442	-0.205	-0.658	0.524				
	DO	0.120	0.160	0.101	0.747	0.471				
	TDS	-3.435	1.723	-0.412	-1.994	0.071				
	TSS	-0.211	0.130	-0.194	-1.620	0.134				
	COD	0.027	0.115	0.040	0.235	0.819				
	BOD	0.129	0.030	1.027	4.337	0.001				
Poly aluminium chloride (PAC)										
Cu	Constant	-2.726	73.357	–	-0.037	0.971	0.614	0.377	0.037	0.54478
	pH	0.159	0.163	0.996	0.972	0.352				
	DO	0.050	0.061	0.373	0.820	0.430				
	TDS	0.852	0.886	0.789	0.962	0.357				
	TSS	0.203	0.100	0.570	2.032	0.067				
	COD	-0.012	0.033	-0.147	-0.357	0.728				
	BOD	-0.001	0.009	-0.030	-0.075	0.941				

Fe	Constant	99.997	0.140	–	715.286	0.000	0.423	0.179	-0.269	0.00104
	pH	0.000	0.000	-0.611	-0.519	0.614				
	DO	0.000	0.000	-0.611	-1.169	0.267				
	TDS	-0.001	0.002	-0.294	-0.312	0.761				
	TSS	0.000	0.000	-0.090	-0.279	0.786				
	COD	0.000	0.000	0.359	0.761	0.463				
	BOD	0.000	0.000	-0.278	-0.611	0.554				
Mn	Constant	81.720	88.458	–	0.924	0.375	0.620	0.385	0.049	0.65692
	pH	0.134	0.197	0.693	0.681	0.510				
	DO	0.123	0.073	0.763	1.685	0.120				
	TDS	-0.008	1.068	-0.006	-0.008	0.994				
	TSS	0.057	0.121	0.132	0.472	0.646				
	COD	-0.027	0.040	-0.274	-0.670	0.516				
	BOD	-0.007	0.011	-0.255	-0.649	0.530				
Zn	Constant	1913.777	1747.472	–	1.095	0.297	0.491	0.241	-0.173	12.97739
	pH	-5.841	3.887	-1.700	-1.503	0.161				
	DO	-2.045	1.448	-0.710	-1.412	0.186				
	TDS	-21.679	21.104	-0.930	-1.027	0.326				
	TSS	1.561	2.382	0.203	0.655	0.526				
	COD	0.999	0.798	0.569	1.253	0.236				
	BOD	0.216	0.224	0.422	0.966	0.355				
Cr	Constant	0.670	0.547	–	1.226	0.246	0.524	0.275	-0.121	0.00406
	pH	-0.001	0.001	-0.782	-0.708	0.494				
	DO	0.000	0.000	-0.158	-0.321	0.755				
	TDS	0.000	0.007	-0.048	-0.054	0.958				
	TSS	0.000	0.001	0.049	0.162	0.875				
	COD	0.000	0.000	-0.028	-0.064	0.950				
	BOD	0.000	0.000	0.205	0.481	0.640				

the highest influence of wastewater parameters on the occurrence of treatment efficiency with DO (β = 0.763) and Cr of heavy metal multiple regression showed the highest influence of treatment efficiency with BOD (β = 0.205).

The comparative analysis between aluminum sulfate ($Al_2(SO_4)_3$) and poly aluminum chloride (PAC) coagulants in wastewater treatment reveals nuanced insights that inform decision-making in real-world applications. While both coagulants demonstrate effectiveness in removing heavy metals from laboratory wastewater, notable differences emerge in their performance under varying conditions. Aluminum sulfate exhibits optimal heavy metal removal efficiency at a pH of approximately 9.00, achieving removal percentages ranging from 68.76% to 99.94% across different heavy metals. In contrast, poly aluminum chloride demonstrates comparable removal efficiencies, with optimal conditions observed at a pH of around 9.00 and a coagulant concentration of 100.00 mg/L. However, the choice between coagulants entails considerations beyond removal efficiency, including sludge generation, treatment costs, and environmental impact. Aluminum sulfate tends to generate higher volumes of sludge compared to poly aluminum chloride, potentially increasing treatment costs and posing challenges for disposal. Conversely, poly aluminum chloride may offer advantages in terms of reduced sludge production and lower treatment costs, making it an economically favorable option in some scenarios. In addition to removal efficiency and cost considerations, the environmental impact and sustainability of coagulant use play crucial roles in decision-making. While aluminum sulfate and poly aluminum chloride both contribute to sludge generation, the environmental implications vary depending on factors such as chemical usage and sludge disposal methods. Aluminum sulfate, despite its effectiveness, may raise concerns regarding its environmental footprint due to higher chemical consumption and energy requirements during production. In contrast, poly aluminum chloride may offer a more sustainable alternative with lower chemical usage and reduced energy consumption, aligning with objectives for environmental stewardship and resource conservation. However, practical considerations such as availability, handling requirements, and compatibility with existing treatment infrastructure also influence the choice between coagulants. Overall, the comparative analysis underscores the importance of considering multiple factors, including removal efficiency, cost-effectiveness, and environmental sustainability, to guide informed decision-making in wastewater treatment practices. Using high concentrations of coagulants in wastewater treatment can lead to increased production of sludge, posing environmental challenges. The concentrated sludge may contain heavy metals and require specialized disposal methods, but it will decrease wastewater volumes and save on treatment costs. Addressing these issues necessitates optimizing treatment processes to minimize sludge production, implementing advanced treatment technologies, and ensuring compliance with regulatory standards to prevent adverse impacts on ecosystems and avoid fines. In real-world settings, balancing the effectiveness of treatment with environmental sustainability and economic efficiency is essential for responsible wastewater management.

CONCLUSIONS

This study, the heavy metals in laboratory wastewater treatment to eliminate toxic by the chemical precipitation included aluminium sulphate ($Al_2(SO_4)_3$) and poly aluminium chloride (PAC). The wastewater from the environmental laboratory has a high acidity and a highly turbid that TSS, BOD, and heavy metals such as Zn did not exceed the Thailand Pollution Control Department standards while Cu, Mn, and Cr have levels exceeded the standards set by law in regard to surface water quality. The treatment efficiency for reducing heavy metals in the wastewater using aluminium sulphate ($Al_2(SO_4)_3$) at a pH of 9.00 was calculated to be approximately 73.62%, 99.94%, 98.43%, 68.76%, and 99.25% for various heavy metals (Cu, Fe, Mn, Zn, and Cr) respectively as well as the treatment efficiency for reducing heavy metals in the wastewater using poly aluminium chloride (PAC) 73.67%, 99.94%, 98.45%, 69.76%, and 99.26% for various heavy metals (Cu, Fe, Mn, Zn, and Cr) respectively. The influence of wastewater properties on heavy metals treatment efficiency found TSS, BOD, and pH having the highest influence on treatment efficiency when using aluminium sulphate ($Al_2(SO_4)_3$) while poly aluminium chloride (PAC) having the highest influence on treatment efficiency with pH, COD, DO, and BOD. Thus, the controlling of laboratory wastewater parameters before treatment will result in higher heavy metals efficiency.

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