RESEARCH ARTICLE

Removing copper, chromium and nickel in industrial effluent using hydroxide precipitation versus sulphide precipitation

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Abstract:

Rapid growth of industries, such as the electroplating industry has led to large scale water pollution, due to the release of wastewater containing high concentration of heavy metals such as chromium (Cr), copper (Cu) and nickel (Ni) that does not comply with the Industrial Effluent Regulation (IER) 2009. This experiment was conducted to determine the efficiency of removal heavy metals by using hydroxide precipitation and sulphide precipitation. The optimum condition, which is pH and coagulant dosage were determined by jar test. Jar test was conducted on two different types of chemical precipitation, which is hydroxide precipitation using sodium hydroxide (NaOH) and sulphide precipitation using sodium sulfide (Na_2S). The result shows the optimum condition of removal Cr, Cu and Ni in hydroxide precipitation was at pH 8.5 while for sulphide precipitation was at pH 10. The optimum coagulant dosage (ferric chloride = $FeCl_3$) for hydroxide precipitation and sulphide precipitation was 0.8 mL. For hydroxide precipitation, Cr = 98.65%, Cu = 2.81% and Ni = 99.90% were removed while for sulphide precipitation Cr = 91.29%, Cu = 99.99% and Ni = 99.97%. From the results, it showed that sulphide precipitation was more effective to remove Cr, Cu and Ni compared to hydroxide precipitation as it can remove heavy metals at broad range of pH.

Keywords: hydroxide precipitation, sulphide precipitation, turbidity removal

1. INTRODUCTION

Wastewater discharged by industrial activities is usually contaminated with a variety of foreign substances that can be toxic and harmful to environment and public health. One of the common substances that is used in industrial activities is heavy metals, especially in electroplating industry. Electroplating is a branch of the metalworking industry in which metal surfaces are treated by means of chemical and electrochemical processes involving a sequence of pre-treatment, coating and surface conversion baths to provide the manufactured products with various properties and characteristics such as protection from corrosion, increases aesthetics values and surface hardness enhancement. [1]. The process of plating involves various types of heavy metals. This leads to the discharge of wastewater containing heavy metals such as chromium (Cr), zinc (Zn), cyanide (Cn), copper (Cu) and nickel (Ni) [1,2] that can cause pollution to water bodies, resulting in water that is no longer consumable and safe for drinking and daily use [3]. Due to the excessive amount of heavy metals that have been discharge from the electroplating activities, there are a few methods that have been applied for heavy metal removal. The most common method used is chemical precipitation as it is the simplest method in removing heavy metals from aqueous solutions (4-6]. However, there are a few limitations in treating mixed metal effluents, as the process is affected by the optimum pH and coagulant dosage.

The most common method used in chemical precipitation is hydroxide precipitation and sulphide precipitation [7,8]. According to Lewis [9], hydroxide precipitation is widely used in industry for removing heavy metals including Cr, Cu and Ni. However, through a research by Nur et al., [8], it is stated that sulphide precipitation gives a better performance in removal of heavy metals as it can remove mixed heavy metals due to the lower solubility of metal sulphide over a broad pH range. In general, the treatment of wastewaters containing heavy metals for Cr, Cu and Ni involve coagulation process that uses chemical to enhance the process and as it is most effective [10]. Chemical precipitation is the process of adding other chemicals or coagulant to enhance the removal of heavy metals by significant increment in particles size of precipitates [11]. Coagulant is mainly used for separation of small molecules or suspended solid contents from solution by destabilizing the particles, which inhibit the bond between water particles [10,12]. Additionally, the process of adding precipitant influence the formation of bond. The reaction of hydroxide precipitation is shown in Equation 1 while reaction for sulphide precipitation in Equation 2:

$$\mathrm{M2+} + 2(\mathrm{OH})- \rightarrow \mathrm{M(OH)2} \tag{1}$$

$$\mathrm{M2+} + \mathrm{S2-} \rightarrow \mathrm{MS} \tag{2}$$

Basically, the rinsing process of plating activities contains a high concentration of hexavalent chromium, Cr (IV). Cr (IV) is more toxic than trivalent chromium, Cr (III) as it has been defined as very toxic and harmful based on its characteristics of mutagenicity, teratology and carcinogenicity [13,14]. Due to the higher toxicity level, Cr (VI) need to undergo reduction process in order to removed it and meet the standard. The reduction of Cr (IV) to Cr (III) must be conducted in low pH by using chemical reducing agents such as sulfur dioxide (SO_2) or sodium metabisulfite ($Na_2S_2O_5$) [13-15]. Based on research by Volesky [16] and Mo *et. al* [17] the hydroxide precipitation is done under alkaline condition. According to Nur *et. al.*, [8], sulphide precipitation process should be conduct in an alkaline condition to prevent H_2S gas formation and it stated that the performance of sulphide precipitation treatment was better than hydroxide precipitation as it removes a high amount of nickel and copper. Therefore, pH selection plays important role in making improvement on removal rate.

In this research, the pH range was selected based on the Theoretical Metals Solubility Curve in order to identify at which pH that the all heavy metals listed achieved maximum removal rate. Figure 1(a) showed the metals hydroxide solubility curve graph. From the graph, it indicated that Cr, Cu and Ni can be removed between pH 6.5 to 10.5 as pH 8.5 – 9.5 for copper [8], for chromium is pH 7.5 – 8.5 [18] and for nickel pH 9.0 - 10.0 [5] while for sulphide precipitation as stated above, it can remove heavy metals at broad pH but to avoid the production of H_2S gas, sulphide precipitation was conducted in alkaline condition. The pH between 8.0 until 10.0 is chosen. Daud *et al.*, [12] indicated that there are several factors affecting the effectiveness of the coagulation-flocculation process in chemical precipitation. This includes types of coagulants, chemical dosage, initial pH, mixing speed, settling time and coagulant aid addition. Therefore, this study aimed to determine the best way in removing the mixed heavy metals in plating industrial effluent.

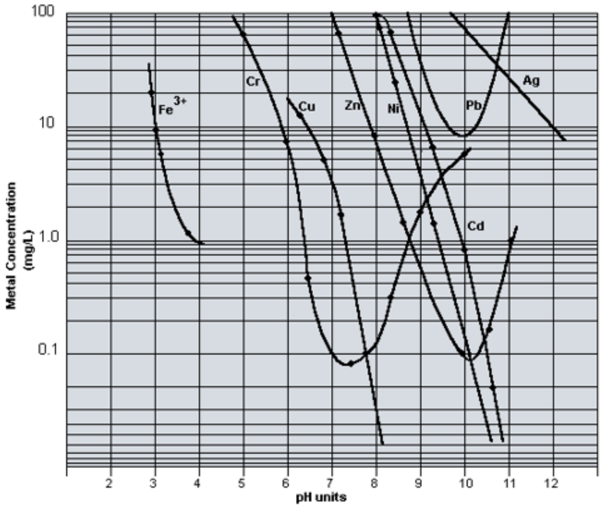

Figure 1: Metals hydroxide solubility graph
(Source: United States Environmental Protection Agency, 1983)

2. MATERIALS AND METHODS

In this experiment, there were several steps that needed to be carried out before running the experiment, which includes calibration of apparatus for initial reading. All the data were recorded from raw effluent preparation until the final result. The materials and apparatus used are also stated below. The initial parameters were taken and recorded to compare with the final result.

2.1 Raw effluent preparation and materials

The raw effluent samples were obtained from plating company in Klang, Selangor that contains nickel, chromium and copper. Approximately 15 liters of sample were needed for the experiment.

2.2 Heavy metals characterization

The effluent samples underwent several measurements, including measurement for heavy metals concentration, pH value, chemical oxygen demand (COD), turbidity value and total suspended solid. These measurements were taken before and after experiments.

2.2.1 Heavy metals measurement by using Inductively Coupled Plasma- Optical Emission Spectrometers (ICP-OES)

Inductively Coupled Plasma-Optical Emission Spectrometers (ICP-OES) (Thermo Scientific iCAP 6000 series) was used. 10 ml of wastewater was utilized to achieve the first objective, which is characterization of element content in the wastewater.

2.2.2 Chemical oxygen demand measurement

To determine the chemical oxygen demand (COD) for the sample, DRB200 reactor and HACH DR2800 was used. Before the usage of DRB200 Reactor, it needed to be heated from ambient temperature to 150ºC. The sample vial was filled with 2 mL of sample while for blank sample, 2 mL of deionized was filled by using pipet. Both vials were put in the DRB200 Reactor for preheating for 2 hours. After the heating process was completed, the vials were left in the reactor that had been switched off. Both vials were allowed to cool for about 20 minutes until the temperature reaches 120ºC or less. Both vials were inverted few times in warm condition, and were then placed in tube rack to cool until they reach room temperature. The blank sample was cleaned and inserted into cell folder. Button ZERO was pushed to ensure screen displayed the value 0.0 mg/L COD. This step was repeated as the sample was inserted into the cell holder. Both results for initial and final readings were recorded.

2.2.3 Total suspended solid measurement

The suspended solid was measured by using Whatmann 1 filter paper. The weight of filter paper was measured using electronic analytical balance (ADAM Nimbus Analytical Balance) and recorded before usage (initial weight). After the jar test processes were carried out, the sample was filtered and dried in the oven (MMM Medcenter Venticell Drying Oven) at 35^0C – 40^0C to evaporate the moisture. When the sample was totally dried and the weight become constants, the oven was switched off and let the sample cool down before weighed (final weight). The weight of sample was obtained from the subtraction of filter paper final weight minus initial weight divided by total volume of the sample. It is shown in Equation 3 below (APHA 2540 D Method).

$$\text{Total suspended solid (mg/L)} = \frac{(A - B)}{V} \qquad (3)$$

Where: A = mass of filter paper + dried residue (mg)
B = mass of filter paper (mg)
V = total volume of the sample (L)

2.3 Jar test

To evaluate the optimum pH and coagulant dosage for the precipitation process, a few sequences of jar test was carried out using flocculator (Stuart SW6 Flocculator). The adjustment of pH was varied to five different pH which is 6.5, 7.5, 8.5, 9.5 and 10.5 in each beaker respectively by adding sulphuric acid (H_2SO_4) or sodium hydroxide NaOH. In this experiment, ferric chloride ($FeCl_3$) was used as the coagulant. Firstly, the samples of 300 mL of raw effluents were poured into five different unit of 500 mL beakers by using measuring cylinder. To get optimum pH, each beaker was set to five different pH levels as stated above and the coagulant dosage ($FeCl_3$) was set at a constant 0.5 mL. Meanwhile, for the optimum coagulant dosage, the five beakers were set to a same optimum pH but different coagulant dosages which 0.2 mL, 0.4 mL, 0.6 mL, 0.8 mL and 1.0 mL for each beaker. The process involved rapid mixing, 150 rpm by using flocculator. At the end of the experiments, the turbidity was measured and recorded. Besides, the mass of the suspended solid produced by each test also was measured by the gravimetric method and the result was recorded.

2.4 Reduction of hexavalent chromium (IV) to trivalent chromium (III)

For converting Cr (IV) to Cr (III), the sample of effluent was filled in a beaker where the pH was determined and sulfuric acid was added until a pH value of 2 was reached. The justification for the pH setpoint of 2 has been selected as the most cost-effective. At the same time, the oxidation reduction potential (ORP) of the solution was measured, and sodium metabisulfite [13-15] was added until an ORP value of approximately 280 mV was achieved. Reactions that occurred reduced hexavalent chromium to trivalent chromium (Cr^{+6} to Cr^{+3}).

2.5 Comparison hydroxide and sulphide precipitation

Before the completion of the jar test, the pH was set to optimum level by adding H_2SO_4 or NaOH. Then the optimum dosage of coagulant, $FeCl_3$ was added into the sample. After dosing the sample, the speed of stirrer was set to 150 rpm for 3 minutes. Following that, the precipitant, which is hydroxide or sulphide, was added into the sample and while stirring continues. This is then followed by the addition of coagulant booster. Once mixed well, the mixer was turned off and the beaker was left for 30 minutes to allow the flocs to settle. Finally, the concentration of Cr, Cu and Ni were measured using ICP-OES and the sludge produced was observed. The steps were repeated using different precipitant, NaOH and Na_2S. The result from both precipitants was compared

2.6 The analysis of variance (ANOVA)

The results of the hydroxide and sulphide precipitation were analyzed using two-factor with replication ANOVA in Excel Microsoft Software.

3. RESULTS AND DISCUSSION

Wastewater effluent from any industry activities included electroplating industry need to be comply with the Industrial Effluents Regulations 2009 (IER 2009) which included the parameters such as pH value, COD, and heavy metal concentration. Table 1 showed the standard parameter that needed to be comply with IER 2009. The initial result of the wastewater indicates that a few parameters does not comply with the standard as the result obtain for pH was acidic (4.46), COD = 128 mg/L and the heavy metals (Cr = 15.1509 mg/L, Cu = 6.8128 mg/L, Ni = 63.8948 mg/L) were exceeded the standard. The initial turbidity value was 89.7 NTU. This study seeks to analyze the comparison between hydroxide precipitation and sulphide precipitation.

Table 1: The parameter that needed to be comply based on Fifth Schedule and Eight Schedule in IER 2009.

Parameters	**Standard B**
pH value	5.5 – 9.0
COD, mg/L	200
Chromium trivalent (Cr^{3+}), mg/L	1.0
Copper (Cu), mg/L	1.0
Nickel (Ni), mg/L	1.0

3.1 Effect of optimum pH

The efficiency of heavy metals removal was significantly affected by pH alteration. From the metal solubility graph, it is indicated that Cr, Cu and Ni can be optimally removed at a pH range of 6.5 to 10.5, with a pH range of 8.5 – 9.5 for copper [8], pH 7.5 – 8.5 for chromium [18] and pH 9.0 - 10.0 for nickel. Meanwhile, sulphide precipitation can remove heavy metals at broad pH but to avoid the production of H_2S gas, sulphide precipitation needed to be conducted in alkaline condition [8]. Therefore, a pH range between 8.0 until 10.0 was selected. The pH of wastewater varied between pH 6.5 until 10.5 for hydroxide precipitation while for sulphide precipitation, it was between pH 8.0 until 10.0. Both were conducted at constant $FeCL_3$ dosage of 0.5 mL (coagulant) and PAC dosage of 0.5 mL (coagulant booster).

Figure 2 shows the result of pH value vs percentage of turbidity removal, %. For the hydroxide precipitation, the bar graph showed a decrease from pH 6.5, 7.5 and 8.5. There was a slight increase at pH 9.5 but it decreases again at pH 10.5. The lowest turbidity removal was 49.05% (45.7 NTU) which the pH 6.5 while the highest turbidity removal was 75.14% (22.3 NTU) which at pH 8.5. As stated by Volesky [16] and Mo et. al [17], the hydroxide precipitation should be carried out in alkaline condition. The optimum pH for hydroxide precipitation was pH 8.5 as it showed the highest percentage of turbidity removal, out of all five different pH. Therefore, this supports the evidence presented by Volesky [16] and Mo et. al [17].

The line graph showed a slightly increase from pH 8 to pH 8.5 and decline from pH 9 and 9.5 for sulphide precipitation. Observation also showed a slight decrease for pH 10. The lowest turbidity removal was 52.40% (42.7 NTU), in which the pH was 8.5 while the highest was 88.41% (10.4 NTU) at pH 10. Based on the research by Nur *et. al.,* [8], sulphide precipitation should be done under alkaline condition to avoid the production of hydrogen sulphide gas. From the experiment, it showed that the optimum pH for sulphide precipitation was at pH 10. It indicated that efficiency of sulphide precipitation increases as the pH increased. This showed, that sulphide precipitation can remove heavy metals at alkaline condition. A research by Shahad [19] also stated that the condition of alkaline sample which is the higher pH can reduce the turbidity value. This is due the opposite charge of an ion of the colloid that affect the sedimentation process.

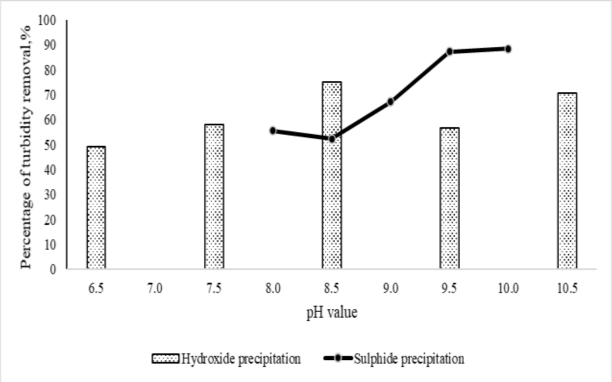

Figure 2: The result of pH value vs percentage of turbidity removal, % for hydroxide and sulphide precipitation.

3.2 Effect of coagulant ($FeCl_3$) and coagulant booster (PAC) dosage

The efficiency of turbidity removal from wastewater is significantly affected by the dosage of coagulant added to the wastewater. By varying the coagulant dose between 0.2 mL until 1.0 mL with interval of 0.2mL and at constant optimum pH of 8.5 for hydroxide precipitation, pH 10.0 for sulphide precipitation and constant flocculant dosage of 0.5 mL, the graph of optimum coagulant dosage, mL vs percentage of turbidity removal, % was plotted. Observations revelead the optimum coagulant dose for maximum removal of turbidity was obtained for hydroxide and sulphide precipitation.

Figure 3 shows the result of the optimum coagulant dosage, mL vs percentage of turbidity removal, %. In this experiment, ferric chloride ($FeCl_3$) was used as the coagulant. For the hydroxide precipitation, the bar graph showed an increase of turbidity removal from 0.2 mL, 0.4 mL, 0.6 mL and 0.8 mL. However, there was slightly decreased at 1.0 mL. The result for the 0.2 mL of $FeCl_3$ showed the lowest turbidity removal which 23.86% (65.3 NTU) while the highest turbidity removal was 75.92% (21.6 NTU), which the $FeCl_3$ dosage was 0.8 mL. From the result it showed that, as the coagulant increased, the percentage of turbidity removal also increased. However, when the amount of coagulant increased to 1.0 mL, the percentage of turbidity removal was decreased. The alteration of pH by NaOH can cause the metals inside the water to ionized into metals ions which were considered stable in water. These metals ions considered hard to eliminate by a little amount of $FeCl_3$ dose. Therefore, the solubility of the metals inside the water increases at this point. From the trend, the result can indicate that the increment of coagulant dosage at certain amount can enhance the removal of turbidity but as the amount exceed, the efficiency of coagulant was decreased.

The graph showed an unstable result for sulphide precipitation. The $FeCl_3$ dosage of 0.4 mL showed the lowest turbidity removal of 99.29% (0.63 NTU) and the highest turbidity removal at 99.73% (0.24 NTU), in which the $FeCl_3$ dosage was set at 0.8 mL. Therefore, 0.8 mL of $FeCl_3$ dosage was chosen as the optimum coagulant dosage for hydroxide and sulphide precipitation. From the trend, the addition of dosage of $FeCl_3$ in sulphide precipitation showed varied result. This may happen due to the ionization of metals. Na_2S was used as precipitant. Therefore, there was no addition of hydroxide ions that can affected the turbidity removal and easily to remove. Overall sulphide precipitation showed better results compared to hydroxide precipitation by adding varied amount of $FeCl_3$ dosage.

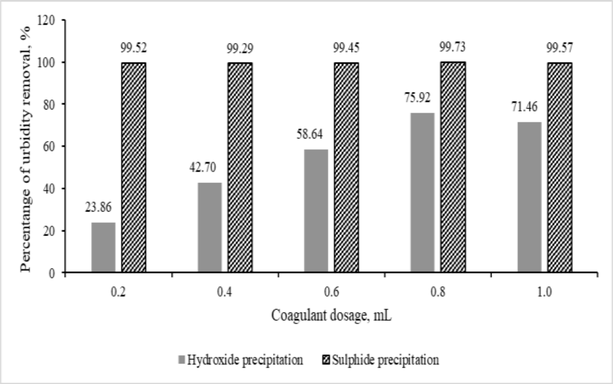

Figure 3: The result of coagulant, $FeCl_3$ dosage, mL vs percentage of turbidity removal, % for hydroxide and sulphide precipitation.

Figure 4 shows the result of coagulant booster (PAC) dosage, mL vs percentage of turbidity removal, %. In this experiment, the pH and $FeCl_3$ dosage was set to the optimum value. The optimum pH for hydroxide and sulphide precipitation was 8.5 and 10.0 respectively while the optimum $FeCl_3$ dosage was 0.8 mL for both. The results are presented in the bar chart below. The trend shows an increased percentage of turbidity removal, % from 0.2 mL, 0.4 mL and 0.6 mL. However, the results decreased for 0.8 mL and 1.0 mL. The lowest turbidity removal was 70.12% (26.8 NTU) for 0.2 mL of PAC and the highest turbidity removal was 89.52% (9.4 NTU) with 0.6 mL of PAC. For the bar graph of sulphide precipitation, the result was increased for 0.2 and 0.4 mL of PAC and decreased when more PAC was used. However, the result shows the lowest turbidity removal was 97.97% (1.82 NTU) for 0.8 mL of PAC dosage and the highest was 99.45% (0.49 NTU) for 1.0 mL of PAC dosage. Thus, for hydroxide and sulphide precipitation the optimum coagulant booster (PAC) dosage was 0.6 mL and 1.0 mL respectively.

Addition of PAC may affect the change of pH, which may also affect turbidity removal. PAC was added to improve coagulation process and reduces the amount of $FeCl_3$ used by increasing the amount of positive charges that help to create larger, heavier and easily settled particles [20]. From Figure 4, we can observe an improvement of performance of turbidity removal for hydroxide precipitation when PAC was added as it increased the basicity condition. However, in this experiment, sulphide precipitation are observed to be better at removing heavy metals by reduction of turbidity.

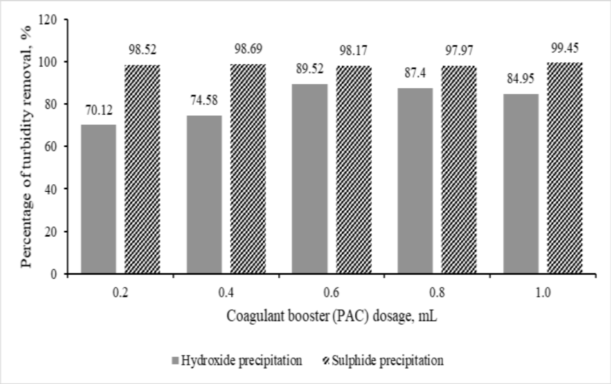

Figure 4: The result of coagulant booster, PAC vs percentage of turbidity removal, % for hydroxide and sulphide precipitation.

3.3 Effect of precipitant

The efficiency of turbidity removal can be affected by precipitant dosage. To conduct the hydroxide and sulphide precipitation, the pH was set to the optimum pH, which for hydroxide precipitation, was pH 8.5. Meanwhile, for sulphide precipitation the pH was 10.0. The coagulant dosage also was adjusted to the optimum dosage for each treatment. The precipitant dosage varied from 0.2 mL to 1.0 mL with an interval of 0.2. The graph of effect precipitant dosage to the turbidity removal was plotted. The precipitant used for hydroxide precipitant is NaOH, while sulphide precipitation used Na_2S.Thus, the optimum precipitant dosage for each treatment was obtained.

Figure 5 showed the result of precipitant dosage, mL vs percentage of turbidity removal, % for hydroxide and sulphide precipitation. The result observed from the bar chart for hydroxide precipitation showed an increased from 0.2 mL of NaOH dosage until 0.8 mL. at 1.0 mL of NaOH the result showed a slightly decreased. The lowest turbidity removal was at 0.2 mL of NaOH, which is 79.14% (18.71 NTU) while the highest was at 0.8 mL which 98.42% (1.42 NTU). Thus, 0.8 mL of NaOH was the optimum precipitant dosage as it showed the highest percentage of turbidity removal. For sulphide precipitation, the bar chart showed a significant increase from 0.2 mL of Na2S until 1.0 mL. The lowest percentage turbidity removal was 94.24% (5.17 NTU) while the highest was at 1.0 mL which 99.28% (0.65 NTU). Thus, 1.0mL of Na2S was the optimum precipitant dosage for sulphide precipitation.

Overall, the result indicated from the hydroxide precipitation showed that the increment of precipitant dosage can enhance the turbidity removal but at certain point when the precipitant was exceed, there was no reaction occur between the ions as the higher hydroxide group in the water made the ions become stable and not easily to remove [12]. This is due to the reaction between the ions in the water that was affected by factors such pH and coagulant dosage. As stated by Nur et al., [8] sulphide precipitation can remove heavy metals at broad pH. The result of the experiment aligned with the statement as the sulphide precipitation showed a better result for turbidity removal compared to hydroxide precipitation.

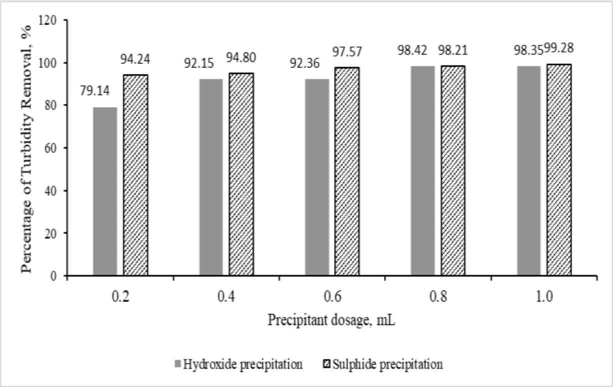

Figure 5: The result of precipitant dosage, mL vs percentage of turbidity removal, % for hydroxide and sulphide precipitation.

3.4 The removal concentration of chromium (Cr), copper (Cu) and nickel (Ni) of the effluent wastewater

Figure 5 shows the result for the percentage removal of heavy metals concentration of chromium (Cr), copper (Cu) and nickel (Ni) for hydroxide precipitation and sulphide precipitation. The line graph indicated the hydroxide precipitation while the bar graph indicated the sulphide precipitation. For the hydroxide precipitation, the result of removal was Cr = 98.65%, Cu = 2.81% and Ni = 99.90% while for sulphide precipitation Cr = 91.29%, Cu = 99.99% and Ni = 99.97%. From the result, it showed that Cr and Ni can be removed at the same pH (8.5) value as it was in the same range of solubility. However, at pH 8.5, it only removed Cu at minimum value while for the sulphide precipitation, the result showed more than 90% of heavy metal concentration were removed at same pH, which is pH 10.0. This showed that sulphide precipitation can remove heavy metals at broad range of pH.

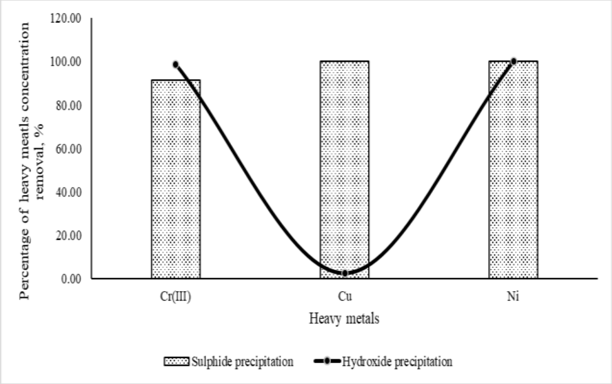

Figure 6: The result for percentage removal of Cr, Cu and Ni concentration, %.

Additionally, the COD result also decreased from 128 mg/L to 59 mg/L for hydroxide precipitation and 12.9 mg/L for sulphide precipitation. Apart from that, the sludge from sulphide precipitation (0.41 g) was more than hydroxide precipitation (0.02 g). Thus, from the results as shown in the Table 2, it can state that sulphide precipitation was better than hydroxide precipitation for removing heavy metals in the electroplating wastewater.

Table 2: The result of chemical oxygen demand (COD) and total suspended solid after hydroxide and sulphide precipitation treatment.

Parameter	Hydroxide precipitation	Sulphide precipitation
Chemical Oxygen Demand (COD), mg/L	59	12.9
Total suspended solid, g	0.41	0.02

3.5 Two-factor ANOVA analysis of the removal of Cr, Cu and Ni via hydroxide precipitation and sulphide precipitation

The comparison of performance on Cr, Cu and Ni removal for hydroxide precipitation and sulphide precipitation was analyzed using a two-factor ANOVA analysis. The two-factor with replication ANOVA analysis was conducted based on the experiment of chemical precipitation by using Excel Software. The ANOVA analysis for each chemical precipitation was presented in Table 3.

Table 3: The result of two-factor ANOVA analysis.

Source of variation	**dF**	**F**	**p-value**	**F crit**
Sample	2.80845	1	2.80845	1.530212
Columns	8.529636	2	4.264818	2.323729
Interaction	16.82971	2	8.414857	4.58492

Table 3 indicates the result of two-factor ANOVA analysis for the experiment. The sample row showed the F statistics and p-value for differences between hydroxide and sulphide precipitation. F critical value (1.530212) is bigger than F value of 1. This indicates the acceptance of null hypothesis, which means the observation for the hydroxide and sulphide precipitation are not the same in favor of the alternative. Since the p-value is greater than 0.05, it showed another evidence that the null hypothesis is accepted. The column row showed that F critical value, 2.323729 is bigger that F value, 2 which means of the observation by the columns called hydroxide and sulphide precipitation are not same in favor of alternative is that there is no difference between at two of them and the p-value is bigger than 0.05 which means the null hypothesis is accepted. The interaction row showed the F critical value (4.58492) is bigger than F value (2), which also means the null hypothesis is accepted. The p-value, which is also greater than 0.05, also indicates that the null hypothesis is accepted. The result from the interaction showed the differences of heavy metals (Cr, Cu, Ni) is independent of the chemical precipitation. However, it also indicates the reverse, in which the effect of hydroxide and sulphide precipitation on the turbidity removal is independent of the types of heavy metals (Cr, Cu, Ni).

4. CONCLUSION

In this experiment, the optimum pH, coagulant ($FeCl_3$) dosage and coagulant booster (PAC) dosage were determined through several sequences of jar test. The performance of hydroxide precipitation and sulphide precipitation was compared to evaluate which is the more effective method to remove Cr, Cu and Ni in the effluent of industrial wastewater. The result shows that hydroxide precipitation, Cr = 98.65%, Cu = 2.81% and Ni = 99.90% were removed while for sulphide precipitation Cr = 91.29%, Cu = 99.99% and Ni = 99.97%. Meanwhile, sulphide precipitation was more effective in removing Cr, Cu and Ni compared to hydroxide precipitation, as it can removed heavy metals at broad range of pH. As a conclusion, the performance of sulphide precipitation treatment was better than hydroxide precipitation. In future, the experiment can be improved for getting the better result to analyze the effectiveness of the performance. Not only that, it is also recommended to determine the heavy metals concentration based on the percentage of turbidity removal as it can show the exact interaction of the heavy metals reduction from the ions reaction with the pH alteration and coagulant dosage.

ACKNOWLEDGEMENTS

The authors would like to thanks to the Faculty of Chemical engineering and Faculty of Health Sciences for the facilities provided.

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