COAGULATION IN TREATMENT OF SWINE SLAUGHTERHOUSE WASTEWATER

Bui Manh HA[1], *Duong Thi Giang HUONG* [1]
[1] *Department of Environmental Science, Sai Gon University*
273 An Duong Vuong Street, Ward 3, District 5, Ho Chi Minh City 700000, Vietnam
e-mail manhhakg@yahoo.com.vn

Abstract

In this study, wastewater taken from the Nam Phong swine slaughterhouse, Ho Chi Minh City, was used to evaluate the treatment efficiency of common coagulants, including Alum (Aluminum Sulfate - Al2(SO4)3.18H2O), Poly-Aluminum Chloride (PAC), and Ferrous Sulfate (FeSO4.7H2O), using a jar-test system. The experiments were conducted using the one-factor-at-a-time method to examine three variables which are pH, stirring speed, and coagulant dosage. The results showed that both Alum and PAC perform over 90% removal of colour, turbidity, COD, and total phosphorus (TP) from slaughterhouse wastewater at pH 7 with a stirring speed of 75 revolutions per minute (RPM) and average coagulant dosages of 450 mg/L for Alum and 550 mg/L for PAC. Meanwhile, under the appropriate conditions of pH equal to 10 and 75 RPM with a chemical dosage of 350 mg/L, COD and TP removal efficiencies by Ferrous Sulfate exceed 87%, but those of turbidity and colour only reach 25%. This finding could be a promising coagulation method as a pre-treatment for the swine slaughterhouse wastewater.

Key words: alum; ferrous sulfate; PAC; swine slaughterhouse wastewater

1 INTRODUCTION

Pork plays a key role in protein contribution to human nutrition, accounting for approximately 70% of meat consumed by Vietnamese people. Besides, the swine sector is one of fastest growing sub-sectors in Vietnamese agriculture. However, this sector is a major source of environmental pollution. The vast majority of pollution comes from slaughterhouse processing, which usually consists of several stages to get the fresh meat from pigs (i.e. stunning, exsanguination, evisceration, etc.) and requires high usage of water (around 400 litters/a pig) [1]. The wastewater typically contains manifold impurities and a high organic matter level, including blood, fat, fur as well as detergents, preservatives and pathogenic microbes, etc., presenting high chemical oxygen demand (COD), biochemical oxygen demand (BOD), nitrogen, phosphorus, total solids that threaten the environment and human health [2].

Due to such high organic level in the wastewater, most of BOD and some of COD in the swine slaughterhouse process are normally eliminated by a biological treatment such as upflow anaerobic sludge blanket reactor [2], upflow anaerobic filter reactor [3], and anaerobic fixed-film reactor [4]. However, the organic values (COD or BOD) after these processes did not meet current water quality standards [1]. This fact implies that a complete degradation of organic matter in the slaughterhouse wastewater could not be achieved by using solely biological treatment. Therefore, certain methods such as coagulation, adsorption, and advanced oxidation should be added to the treatment process so as to remove the residual pollutants from the wastewater. Among the mentioned methods, coagulation seems to be an effective one to remove remaining pollutants from the slaughterhouse wastewater. The coagulation process has been successfully practiced to treat textile wastewater [5], pulp and paper wastewater [6], pesticide wastewater [7], landfill leachate [8] as well as drinking water [9]. Nevertheless, there have been no studies done on the treatment of the swine slaughterhouse wastewater in Vietnam by using the coagulation method. As a result, the objective of this study was to apply a jar-test experiment to study the pollutant removal capacity of different coagulants (such as Alum, Ferrous Sulfate, and Poly-Aluminum Chloride) on the Vietnamese swine slaughterhouse wastewater based on three selected parameters including pH, stirring speed, and coagulant dosage. The changes in COD, colour, turbidity, and total phosphorus concentrations before and after the process were captured.

2 MATERIALS AND METHODS

2.1 Reagents and apparatus

The experimental wastewater was collected from the Nam Phong Food Processing Enterprise (Ho Chi Minh City, Vietnam) in a mid-slaughtering-process from 12:00 a.m. to 1:30 p.m. The wastewater samples were then stored in a 30L plastic can and transported to the laboratory for the experiment. The jar-test experiments were performed within 24h with parameters described in Table 1.

Tab. 1 Characteristics of Nam Phong wastewater samples

Parameters	Value intervals	Mean values	*QCVN 40 (Column B)
pH	6.05 - 7.01	6.53	5.5 -9.0
Conductivity (mS/cm)	4.57 - 6.98	5.78	-
Turbidity (NTU)	148 - 320	234	-
Color (Pt-Co)	786 - 1940	1363	150
COD (mg/L)	3200 - 5100	4150	150
TP (mg/L)	9.13 - 22.21	1567	6

* Vietnam national standard requirement, column B (QCVN 40:2011/BTNMT)

The coagulants used in the experiment were: Alum ($Al_2(SO_4)_3 \cdot 18H_2O$ – 14.5% Al_2O_3), Ferrous Sulfate ($FeSO_4.7H_2O$ - 20% Fe), and PAC (Poly-Aluminum Chloride – $[Al_2(OH)_nCl_6.nH_2O]_m$ - 15% Al_2O_3) produced by the Bien Hoa Chemical Company, Viet Nam. As the main equipment of the experiments, the Stuart-SW6 Jar-tester (England) which could operate 6 beakers simultaneously with a digital regulator as shown in Figure 1 was used.

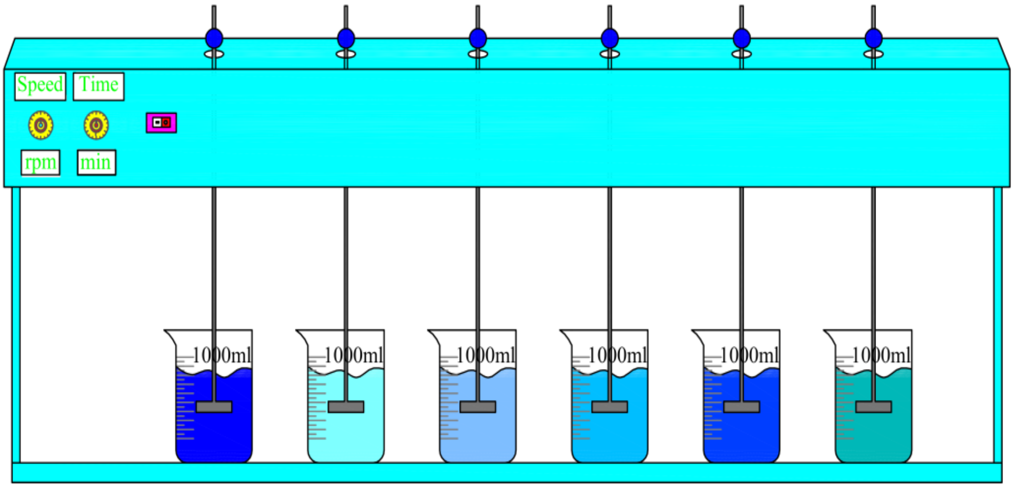

Fig. 1 Jar-test apparatus used in experiments

2.2 Procedure and analysis

The experiments were carried out by applying the one-factor-at-a-time method. The data of three main factors, which are stirring speed, pH, and coagulant dosage are summarized in Table 2.

Tab. 2 Examination sequences in treatment process with coagulants

No.	Factor	Surveyed intervals (mg/L)		
		Alum Sulfate	Ferrous Sulfate	PAC
1	pH	5-8	7-12	5-8
2	Stirring speed, RPM	60-120	60- 20	30-120
3	Coagulant dosage, mg/L	400-650	100-500	350-600

The method D2035-13 published by the American Society for Testing and Materials [10] was used by adding 500 mL of wastewater into each of the six beakers numbered correspondingly. The NaOH solution (0.1N) and HCl solution (0.1N) were used to adjust the pH value of the wastewater. The same volume but a different concentration of the coagulant solution was added to each beaker. The six beakers were placed in the jar-tester which was then operated at high RPM of 180 for 2 minutes. The stirring speed was then reduced to desired speed values and maintained for 15 minutes. Afterwards, the samples were left for settling for 30 minutes, and the treated water was collected for the analysis of pH, conductivity, turbidity, colour, COD, and total phosphorus concentration. The optimal values were selected based upon the lowest COD.

The data was analysed with the Excel-2007 software. The values used were: the averages of those from two trials. The Standard methods presented by Clesceri et al. [11] were used for the data analysis.

3 MATERIALS AND METHODS

3.1 Effects of pH

The pH value determines the chemical forms of coagulants and organic matters in the wastewater. Both "too high" and "too low" pH values cause a low treatment efficiency [12]. In order to determine the optimal pH value for treatment, pH values in the interval of 5-8 were investigated in the experiments with Alum and PAC. However, we extended it to an alkali environment with a pH interval of 7-12 for ferrous sulfate because of its distinct characteristics [5]. The concentrations of coagulants were fixed as follows: Alum 400 mg/L, Ferrous Sulfate 200 mg/L, and PAC 500 mg/L, while the stirring speed was 60 RPM.

It can be seen in Figure 2 that the removal efficiencies of slaughtering pollutants are highly influenced by pH changes corresponding with each coagulant.

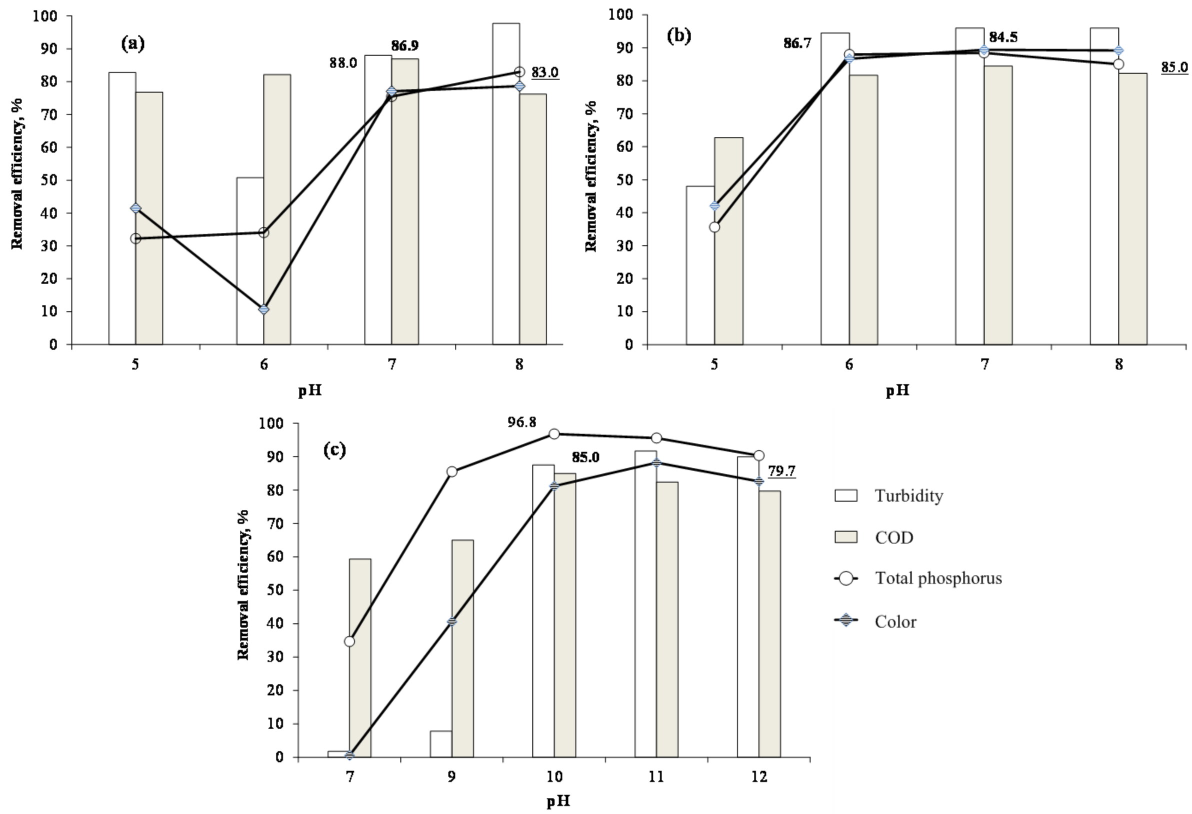

Fig. 2 Effects of pH on treatment efficiency at stirring speed of 60 RPM (a) Alum 400 mg/L; (b) PAC 500 mg/L; (c) Ferrous Sulfate 200 mg/L

For Ferrous Sulfate (Figure 2c), the COD removal rate increases rapidly (60% to 85%) when pH rises from 7 to 10, but decreases when pH continues to increase. This trend is also observed in the changes in turbidity, total phosphorus level, and colour. These results quite agree with the explanation by Lakshmanan et al. [13] that the coagulation of ferrous ion reaches the maximum efficiency at pH range from 8.8 to 11.5; at the pH values, ferrous ions mainly exist in the form of $Fe(OH)_2$ and show effectiveness in treatment (Figure 3). The pH value also quite matches with the earlier research by Sanghi et al. [12] on textile wastewater treatment at pH 9.5.

The experiments with Alum and PAC show similar trends. At pH 7, maximum COD removal rates are achieved (86.9% for Alum and 84.5% for PAC); colour, turbidity, and total phosphorus removal rates are approximately 80% for both Alum and PAC.

This is explained by the formation of $Al(OH)_3$ in neutral environment, in which it could easily coagulate the pollutants as illustrated in Figure 3. In addition, the experiment indicates that the PAC efficiency interval is wider, higher, and more stable than that of Alum, as seen in the fluctuation of removal efficiencies of colour and total phosphorus. While PAC experiments show a distinct increase in colour and total phosphorus removal rates when pH changes from 5 to 6, the Alum experiments indicate the opposite. This finding is coherent with the study by Zouboulis et al. [14], which compared the use of Alum and PAC in municipal wastewater treatment, and the higher efficiency of PAC than that of Alum is explained by its polymeric structure and its ability to form soluble Chloride radicals.

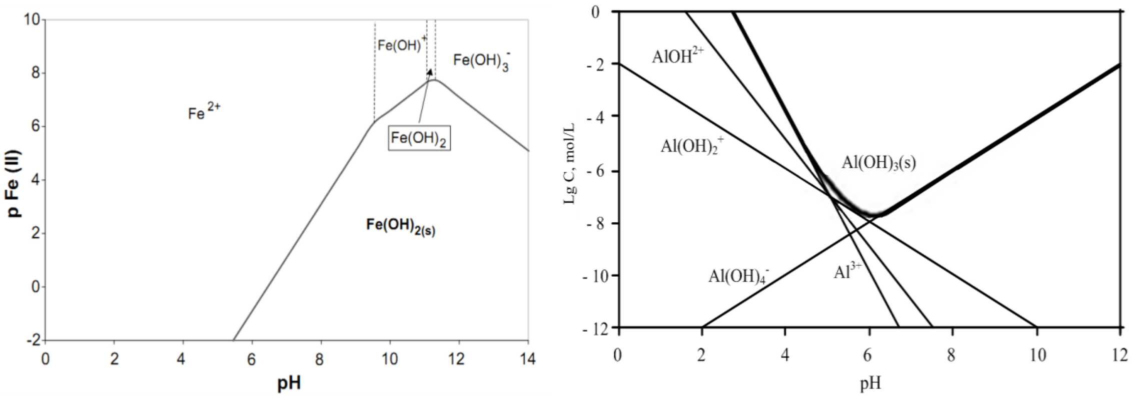

Fig. 3 Existing forms of ferrous and aluminum ions in solution under various pH conditions [15]

3.2 Effects of stirring speed

In jar-test experiments, stirring speed plays an important role in the formation and settling of the "flocs". An optimal speed helps enlarge the size of the flocs and maintain their interactions without breaking the texture [5]. Aiming at finding the suitable stirring speed, the value of speed was increased from 60 to 120 RPM for Sulfates testing (Alum and Ferrous) and from 30 to 120 RPM for polymeric – PAC testing, with fixed coagulant dosages (Alum 400 mg/L, Ferrous Sulfate 200 mg/L and PAC 500 mg/L) at pH 7 for Alum and PAC, and pH 10 for Ferrous Sulfate. The results are shown in Figure 4.

Figure 4 shows that for inorganic coagulants such as Alum and Ferrous Sulfate, the studied stirring speed has minor effects on the removal capacity as these are insignificantly affected and the flocs formed by these chemicals are quite stable. However, when the stirring speed exceeds 75 RPM, the COD removal efficiency slightly decreases in the case of Alum, which indicates instability (maybe due to limited solubility) of using Alum in the process treatment pilot. The optimal stirring speed in this series of testing for all 3 coagulants is found to be 75 RPM, which agrees with the RPM value recommended by Aziz et al. [8], and, therefore, chosen for coagulant dosages experiments.

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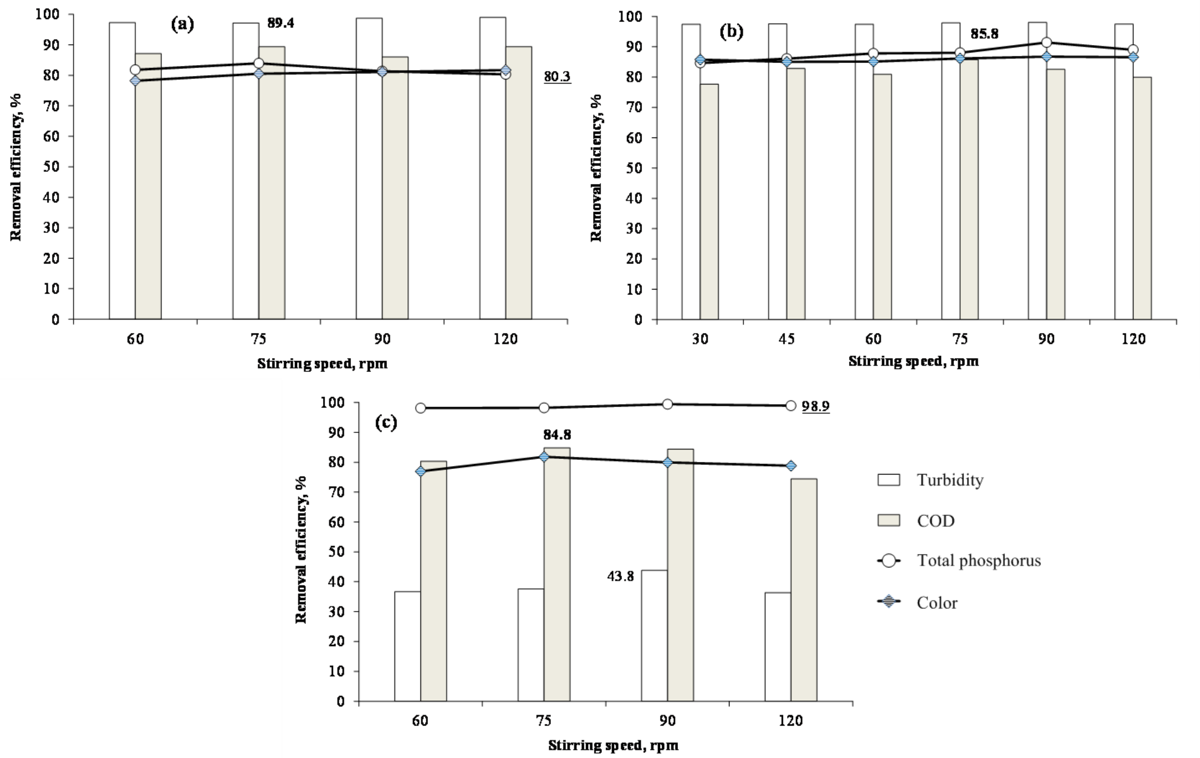

Fig. 4 Effects of stirring speed on treatment efficiency (a) Aluminum Sulfate 400 mg/L, pH 7; (b) PAC 500 mg/L, pH 7; (c) Ferrous Sulfate 200 mg/L, pH 10

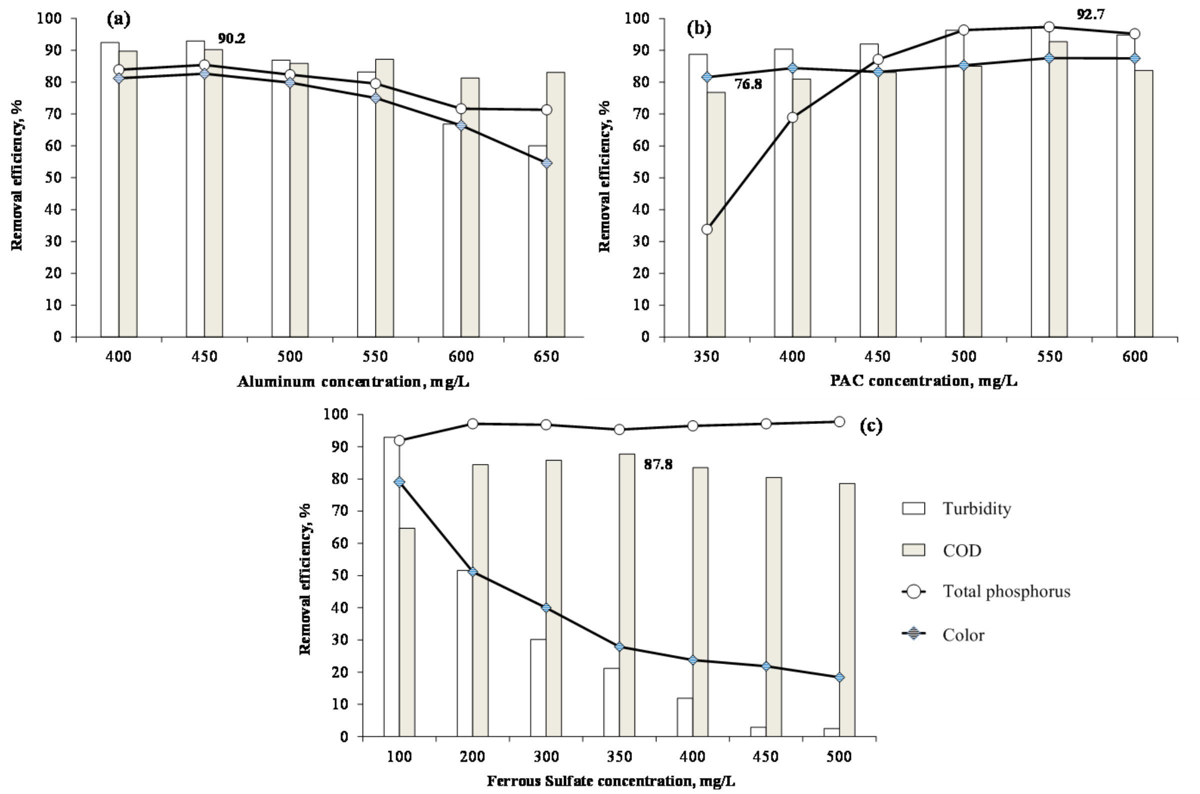

Fig. 5 Effects of coagulant dosages on treatment efficiency at 75 RPM (a) Aluminum Sulfate, pH 7; (b) PAC, pH 7; (c) Ferrous Sulfate, pH 10

3.3 Effects of stirring speed

In practice, overfeeding inorganic coagulants causes devastating effects on the systems. The higher the coagulant concentrations, the higher sludge content and the more metal residue (aluminum, iron) concentrations in the water which increases the treatment cost. Hence, establishing sufficient dosages for reactions is one of the important determinants in coagulation treatment. To solve the issue, in this experiment, coagulant dosages are altered (Alum: 400-650 mg/L; Ferrous Sulfate: 100-500 mg/L; PAC: 350-600 mg/L), while other factors such as pH (7 for Alum and PAC, 10 for Ferrous Sulfate) and stirring speed (75 RPM) are kept the same. The results are presented in Figure 5.

Figure 5 shows that the COD removal efficiency depends a lot on coagulant dosages. As for Alum (Figure 5a), the removal rate rises from 87% to 90% when the dosage increases from 400 to 450 mg/L. Nevertheless, when the dosage keeps on increasing, the COD removal rate drops slightly. Observations reveal that the "breaking" of the flocs reduces the efficiency of eliminating colour and turbidity dramatically. This phenomenon is also observed in the Ferrous Sulfate experiment (Figure 5c), in which the removal rates of colour and turbidity decline more rapidly when the dosages exceed 300 mg/L. It is due to the fact that iron ions, in contact with water, are oxidized and form yellow precipitate.

Compared to Alum and Ferrous Sulfate, polymeric PAC demonstrates a higher stability and solubility. Therefore, even when the PAC concentration surpasses its recommended value, the colour and turbidity would be unremarkably affected (Figure 5b). For slaughterhouse wastewater, while the types of coagulant do not significantly influence the COD removal efficiency, the PAC performance brings high effectiveness (92.7%) and is more stable than Alum and Ferrous Sulfate (90.2% and 87.8%, respectively), owing to its high stability and solubility [5]. Nonetheless, PAC requires a higher dosage of 550 mg/L compared to 450 mg/L of Alum and 300 mg/L of Ferrous Sulfate that may be due to the impurities in commercial polymeric PAC on the market.

4 CONCLUSIONS

After conducting the experiment using three common coagulants with the wastewater from the Nam Phong slaughterhouse, it can be concluded that coagulation is one of the effective methods to remove organic matter from slaughterhouse wastewater. Through the coagulation process, the reactions occurred promptly even at high pollutant concentrations (COD of 4150 mg/L). The coagulation efficiency depends on wastewater pH and chemical dosages: the peak COD removal rates were 92.7%; 90.2%, and 87.8% corresponding to the concentrations of 550 mg/L PAC, 450 mg/L Alum, and 350 mg/L Ferrous Sulfate at 75 RPM. Ferrous Sulfate coagulates the best in alkali medium (pH 10); meanwhile, Alum and PAC are the most effective in neutral environment (pH 7). Under optimal conditions, the removal rates of total phosphorus and turbidity exceed 80% for all three coagulants; however, the removal rates of colour are low (especially, only reached 25% in the case of Ferrous Sulfate coagulant) which may be due to the natural colour and insolubility of the reagents. These results prove the coagulation method to be a fast and effective method in a partial treatment of slaughterhouse pollution and could be an important step before biological methods.

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