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Chemical coagulation of coffee wastewater for smallholder coffee agro-industry

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Abstract— **Water minimization for processing Robusta coffee has improved the green coffee quality. However, this approach leads to increase color and organic matter concentrations in the downstream process. In this study, different chemical coagulations were proposed to reduce color and organic matter (measured as chemical oxygen demand, COD) contained in the coffee wastewater. This study aimed to determine the optimum coagulant dose and operating pH conditions. Two commonly used and inexpensive coagulants, i.e. $Al_2(SO_4)_3$ and $FeCl_3$ were evaluated. Samples were collected from smallholder coffee processing. The best performance was achieved by adding 7.5 g/L of $FeCl_3$ at pH 5 with the removal of COD and color was 71.9% and 97.8%, respectively. Yet, resulted final effluent with low pH means new problem for disposal.**

Keywords; coagulation; coffee wastewater; $Al_2(SO_4)_3$; $FeCl_3$.

I. INTRODUCTION

Coffee is one of Indonesia's main export commodities that has an important role to the national economy, thus placing Indonesia as the fifth coffee-producing countries in the world [1]; [2]. Approximately 86.4% of Robusta coffee is planted in Indonesia in which 96.6% of production comes from smallholder plantation [3]. Nowadays, smallholder coffee plantation suffers from a low quality of green coffee that comes from post harvest processing. One method to improve and support the smallholder coffee sustainability is wet coffee processing.

Application of wet coffee processing could increase green coffee quality and hence increase its price on the farmer level. However, this wet technology requires a lot of water and generates large quantity of wastewater that leads to environmental problems. While a modified wet process by water minimization on specific level could decrease the wastewater quantity as organic matter in coffee wastewater more concentrated [4].

Therefore, to reduce the organic matter chemical coagulation-flocculation was evaluated as pretreatment. It is considered to be effective, low cost and easy to handle at the optimum process conditions [5]. The main purpose of this study was to determine the optimum process conditions of chemical coagulations for the removal of colour and organic matter.

II. METHODOLOGY

2.1. Wastewater

The study conducted at the Advance Water Management Center (AWMC), The Queensland University, Australia. The wastewater were synthetic coffee wastewater made from instant coffee solution with consideration of material availability and the ease making of coffee wastewater in specific range COD concentration. The characteristics of synthetic coffee wastewater were similar with the wastewater from the discharge outlet of Sidomulyo smallholder coffee processing, Jember Region, East Java. The effluent quality is highly coloured, typically has a pH of 4.5, and contained high organic matter (5,000 mg/L COD). The wastewater parameter includes pH, COD, colour and absorbance.

2.2. Jar tests

Experiments were conducted using 500 ml effluent in 1 L erlenmeyer flasks on a Peterson Candy International jar testing apparatus, enabling six jars to be stirred simultaneously by direct driven blade stirrers (180 rpm). Samples were flocculated thirty minutes and settled for one hour. The samples were taken after settled and analysed for absorbance and colour (Varian Cary 50 Bio Light Spectrophotometer), and COD (Merck Spectroquant). The absorbance range was taking based on previous study.

The coagulants that used are aluminium sulfate ($Al_2(SO_4)_3$) that known as alum and ferric chloride ($FeCl_3$). Those coagulants are used to treat water or wastewater. The range of pH and dose of coagulants carried out based on study literature. NaOH, H_2SO_4, and Ca^{+2} solution were use to adjust the optimum pH.

III. Results And Discussion

The multivalent characteristic of the cations, Al and Fe, strongly attracts them to charged colloidal particles and their relative insolubility ensures their removal to a high degree. Aluminium salts work best in a pH range of 5.5 – 6.3, whereas ferric salts are most effective around a pH range of 4.5 – 5.5 [6]. Two factors that affect optimum process in removal organic matter of wastewater are pH and dose of coagulant. Excessive use of coagulant will result in destabilization of colloid complex in wastewater [5].

Using alum and ferry chloride at optimum pH and dose showed maximum removal of organic colloids of coffee wastewater as depicted in Fig. 1. The optimum pH of alum and ferric chloride was 6.0 and 5.0, respectively (Fig 1.a and Fig 1.b). The optimum dose of alum and ferric chloride at the optimum pH was 5.0 g/L and 7.5 g/L, respectively (Fig 1.c and Fig. 1d). Coagulation process of alum is the reaction between positively charged aluminium ion and negatively charged dissolved organic matter. The optimum pH of aluminium sulfate depends on the dose and acid-base affinity of the organic compound. At low pH conditions (pH 5 - 6) and optimum dosing of 5 g/L, the positively charged alum works better. Alum addition leads to decrease pH of the effluent (e.g. with final of pH 5.0 was observed).

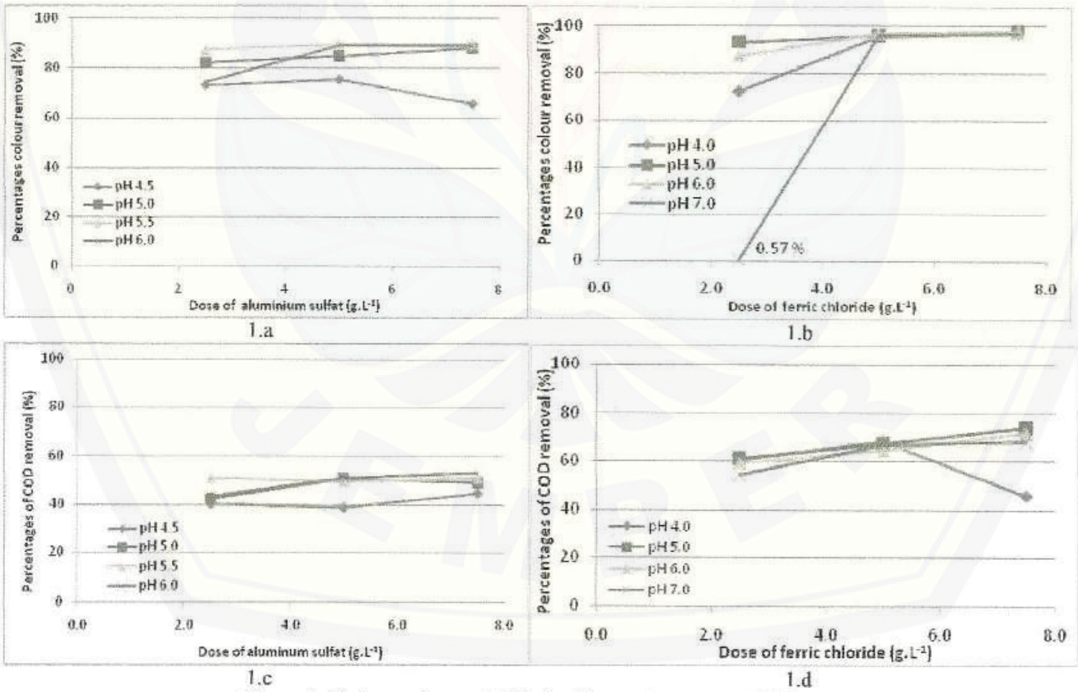

Figure 1. Optimum dose and pH of coffee wastewater coagulation

The range of optimum pH for ferric chloride was lower than alum (pH 4 – 5) with optimum dose of 7.5 g/L. At the end of flocculation process, positively charged ferric chloride bounded with negatively charged of organic compounds to settle down, and causing pH decrease to pH 4.1. It appears that aluminium sulfate was more applicable coagulant for coffee wastewater because the final pH and dosing level were more feasible to apply at smallholder coffee industry. Furthermore, ferric chloride will generally produce larger volume of sludge than in the case of aluminium sulfate, which creates another issue to handle (Fig. 2).

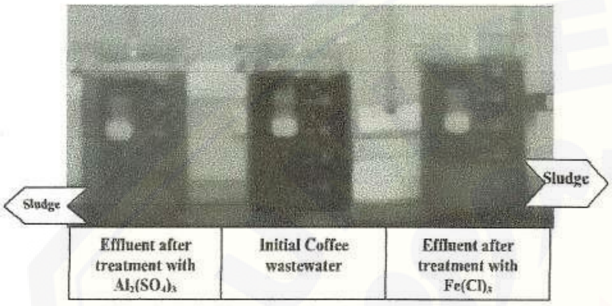

Figure 2. Sludge productions of the coagulation process

Determination of pH is essential in coagulation since this correlates to isoelectric point of colloid particles of aqueous waste. At the isoelectric point, ion will be neutrally charged leading to the formation of flocs (or flocculants) by the addition of coagulant [7]. The reaction of alum and ferric chloride is different in the water and resulted in different of strength to lose colloid particles. Alum reaction and ferric chloride reaction are [8]:

$$Al_2(SO_4)_3 + 6HCO_3^- \rightarrow 2\ Al(OH)_3 + 3\ SO_4^{-2} + 6CO_2$$

$$FeCl_3 + 3\ H_2O \rightarrow Fe(OH)_3 + 3H^+ + 3Cl^-$$

Alum is more stable than ferric chloride as the formed aluminium hydroxide floc has gelatine characteristics to absorb colloid particles. The ferric chloride works within two mechanisms; (i) Fe^{3+} ion neutralize colloid particle and (ii) the other parts be hydrolyzed. Hydrolyze reaction of ferry chloride is resemble with hydrolyze reaction of alum.

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Ferric chloride showed a higher percentage in removing organic matter and color than alum (Fig. 1b and Fig. 1fd). But, the technique has generated a lot of sludge at the end of the coagulation process and more acidic conditions than alum (Fig. 2 and Fig. 3). In order to increase pH in the final effluent, limestones (e.g. CaO and $CaCO_3$) can be used to substitute the relatively more expensive NaOH solution. Moreover, Ca^{+2} can work as a coagulant regardless the expected sludge which could be generated in larger quantities at the end of the process (Fig.3).

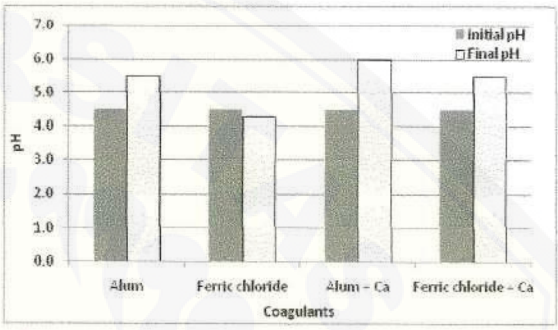

Figure 3. Comparison between initial and final pH of the coagulation process

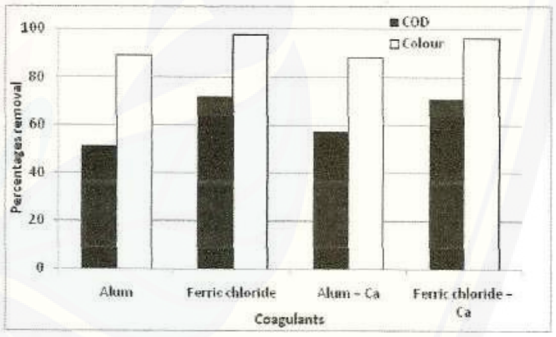

Figure 4. Percentages of organic and colour removals of the coagulation process

The use of ferric salts seemed more effective than alum in treating wastewater containing brown pigment (Fig 4.) But the resulted effluent has low pH and need other treatment before discharge to the environment [9]. The final sludge needs special treatment, and in most industries had used it to produce cone block or concretes for building.

Colour reduction was more pronounced than COD removal (Fig. 4). This is due to the fact that the coagulation was not strong enough to make organic complex matter of coffee wastewater lost their binding. However, the results suggested trying another treatment than chemical coagulations to remove the organic matter.

IV. CONCLUSION

The purpose of water minimization in modified wet coffee processing is to use the water as minimum as possible. However, this modified approach leads to an increase in organic matter concentration of coffee wastewater. Chemical coagulation with ferric chloride and aluminium sulfate was performed to remove colour and organic matters. The best performance was achieved by adding 7.5 g/L of ferric chloride at pH 5 with the removal of COD and colour was 71.9% and 97.8%, respectively. In addition, although colour reduction was achieved by ferric chloride, the removal of organic matter was ineffective. They also resulted in low pH and large sludge generation in the effluent. Further study is required to investigate a combined method (e.g. chemibiological) for the treatment of coffee wastewater.

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