Evaluation of Cationic Inorganic Coagulants for a Local South Africa Paint Industry Wastewater Treatment using Coagulation - Floatation Process

Thanashnie Pragasen*, Emmanuel Kweinor Tetteh and Sudesh Rathilal

Abstract— A significant source of environmental contamination associated with industrial growth is the discharge of industrial effluent pollutants into waterways. These pollutants have altered the environmental water quality, rendering vast quantities of water unsuitable to be used. In the industrial sector, this has raised urgent environmental concerns due to the detrimental impact of wastewater on human health and aquatic life. Herein, wastewater from a Paint industry with high chemical pollutants discharge to the environment has a significant negative influence on the receiving water bodies. Therefore, this study evaluated the performance of cationic inorganic coagulants for the pre-treatment of a local South Africa Paint industry wastewater. Coagulants such as Aluminum Sulphate (Alum), Ferric Chloride, and Ferric Sulphate dosage (10-50 mg/L) were investigated for the removal of chemical oxidation demand (COD), turbidity, total suspended solids (TSS), and total dissolved solids (TDS). This was done with a laboratory Jar tester operated on a constant condition of mixing speed (250 rpm) and settling time (15 min). Alum was found to be the best coagulant at an optimum coagulant dosage of 50 mg/L with over 75% removal of COD, turbidity, TSS and TDS. It was deduced that Alum had great potential to be used for the pre-treatment of the paint wastewater. Thus, it aggregated and coalesced the chemical pollutants to form larger flocs to be removed via the post-floatation process.

Keywords—Aluminum Sulphate; Chemical Oxygen Demand, Coagulation; Floatation Process, Turbidity

I. Introduction

This study evaluates the effects of three coagulants on the treatment of paint industry wastewater using a coagulation dissolved air flotation (DAF) mechanism. The purpose of this study was to enhance the operational effectiveness of a paint effluent facility located in South Africa.

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The coagulants employed in the study were aluminum sulphate (commonly known as alum), ferric chloride (FC), and ferric sulphate (FS). The efficiency of coagulants and their various doses was assessed by evaluating water quality measures, including chemical oxygen demand (COD), turbidity, total dissolved solids (TDS), and total suspended solids (TSS). The discharge of wastewater from paint factories is a significant environmental issue because of the often-low quality of effluents resulting from heavy pollution. These effluents are characterized by high levels of chemical oxygen demand (COD), turbidity, and total suspended solids (TSS), among other pollutants. However, if wastewater is discharged without undergoing treatment, it can result in significant pollution, depletion of oxygen levels, disruption of the ecosystem's equilibrium, and pose threats to human health. This has prompted several researchers to explore potential physio-chemical processes for the treatment of wastewater prior to its release [1].

Generally, paint production is known to use high amount of water ends up generating untreated or partially treated wastewater. This presents significant environmental and public health concerns, especially with underdeveloped countries which are water stressed to induce waterborne illnesses [2]. Furthermore, the presence of untreated paint industry wastewater has a detrimental impact on the overall water quality of aquatic ecosystems, which give rise to potential hazards to human well-being through its integration into the food chain [3].

South Africa, as a rapidly advancing developing nation, places significant emphasis on the efficient usage of energy and water resources due to their crucial role in fostering social, economic progress, and long-term sustainability. A multitude of treatment strategies have been extensively established as reliable methods for decontaminating paint wastewater. The methods encompass a variety of therapeutic approaches that span across physical, biological, and chemical domains. A range of techniques have been utilized in the treatment of wastewater, such as membrane filtration, biological aerated filters, hydro cyclone, evaporation pond, adsorption, and coagulation-flocculation, among other approaches [4].

The utilization of coagulation and flocculation techniques is prevalent in the treatment of wastewater that contains suspended particles, colloids, and metal ions. During the process of coagulation, a coagulant is introduced to counteract the ionic charges present to induce destabilization of colloidal substances [5]. This destabilization leads to the aggregation of microscopic particles, resulting in the formation of bigger flocs that can settle. Nevertheless, the processes of coagulation and flocculation are interconnected and necessitate the use of agitation to promote the agglomeration of the produced floc into bigger masses within the solution [6]. The process entails both quick and slow mixing. During rapid mixing, the coagulants are evenly distributed throughout the system, while slow mixing facilitates the formation of inter-particle bridges, leading to the aggregation of floc particles in the aqueous suspension. The efficacy of coagulation is influenced by several aspects, such as the kind and dosage rate of the coagulant, pH levels, mixing rate, and the duration of settling or flotation [7]. According to the studies conducted by Altaher, 2011, it has been shown that optimal mixing is achieved when the rotational speed of the mixer is set at 250 revolutions per minute (rpm).

Numerous research has been conducted to investigate the coagulation process of wastewater derived from the paint industry, employing various coagulants such as iron and aluminum sulfates [10]. The study conducted by Daud, 2015 also assessed the removal efficiencies of chemical oxygen demand (COD) and the operational expenses linked to coagulants, including alum, ferric chloride, and ferric sulfate. In their study, Dovletoglou, 2022 discovered that aluminum sulphate exhibited the most favorable outcomes when the pH was roughly 9.7. The removal efficiencies at coagulant dosage of 2 g/L for chemical oxygen demand (COD) was from 30% to 80%, while for turbidity, ranged from 70% to 99%. In the study conducted by Eremektar, 2006, it was shown that pH modification was not required for aluminum sulphate. The optimal coagulant dosage was determined to be 25 g/L, leading to process efficiencies ranging from 70% to 95% for COD removal and 90% to 99% for turbidity reduction. According to a study conducted by Daud, 2015, it was proposed that an excessive amount of coagulant may have a role in the restabilization of oil droplets. This phenomenon is attributed to the reversal of surface charge on the particles and the subsequent chain reaction of the coagulants. To address the conflicting reactions caused by alkalinity, pH, trace elements, and other compounds present in wastewater, the determination of the appropriate coagulant dosage for the removal of COD, turbidity, TDS, and TSS is typically conducted through jar tests, occasionally supplemented by pilot-scale tests [6]. Herein, this study employed the DAF jar tester to evaluate the efficacy of coagulants (alum, FC and FS) for wastewater treatment. The detailed approach is highlighted in section (II), results obtained is discussed in section (III) and findings obtained is concluded in section (IV).

II. MATERIALS AND METHODS

A. Industrial effluent and coagulants

The coagulants used were alum, FS and FC, obtained from Sigma Aldrich. The wastewater used was collected from a local South African paint industry wastewater treatment plant, in the Kwazulu-Natal Province. The wastewater was characterized according to standard protocols and results presented in Table 1. The standard methods for examining water and wastewater were used (APHA 2012). The TSS/TDS and turbidity were measured with a Hach DR890 portable colorimeter and Hach 2100N turbidimeter, respectively. Calibrations were done with standard samples prior to analysis. In accordance with standard method EPA 410.4, COD was determined with a Hanna HI 83099 COD and multiparameter photometer.

TABLE I
INDUSTRIAL EFFLUENT CHEMISTRY

Water Parameter	Effluent Sample
pH	7
Turbidity (NTU)	496
TSS (mg/L)	1064
COD (mg/L)	4485
EC (mS/m)	636
TDS (mg/L)	11052

B. DAF Jar tester and analytical procedure

The ECE DBT6 dissolved air flotation batch (jar) tester system provides a simple, rapid, economical method of evaluating dissolved air flotation processes on a bench scale. Base unit. The DAF jar tester consists of the jar support base with end housings, mixer drive motor, mixer speed controls and indicator, fluorescent lamp, cooling fan, 16V DC power supply, and controls. Sample containers (jars). Six individual sample containers are supplied with the DBT6. Each jar is graduated at the 1 L mark and with 5% volume increments. Sample ports, with removable stopcock, cap, adapters, and tubing, are provided. Dosing/baffle module served for two functions. The first is to provide baffling in the jars, to prevent vertexing at high mixer speeds. The second is to provide a holder for chemical dosing syringes, so that chemicals can be added simultaneously and accurately to all jars.

Mixer module consists of six paddle/shaft assemblies, with drive system and coupling. It is placed on the base unit during the mixing stage of the test procedure, and automatically coupled to the mixer drive motor. The recycle module contains six individuals recycle injection systems, one for each jar station. Each system includes a solenoid valve controlled by a timer, to allow preselected amounts of recycling to be added. A selector switch provides a choice of three different recycle injection modes. The recycle module is automatically connected to 16-volt DC power when the module is placed on the base unit. The stainless-steel saturator vessel provides the supersaturated water used for recycling injection. It is provided with a fill hatch and cover, air inlet

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and water outlet connections, pressure gauge, and pressure relief valve. The air compressor is used to pressurize the recycle saturator to 200 to 550 kPa typically used in DAF processes.

C. Coagulation DAF mechanism procedure

To ascertain the appropriate coagulant type and dosage rate, a 1 L stock solution was made for each coagulant. The coagulant was administered in varying dosages of 0, 10, 20, 30, 40, and 50 mg/L to each 1 L sample, employing a syringe in a sequential manner. Each experiment was conducted under consistent operating circumstances, which involved fast mixing at a speed of 250 revolutions per minute for a duration of 2 minutes, followed by flocculation. Table 1: Characteristics of the influent chemistry the water quality parameters measured in this study are Total Suspended Solids (TSS) with a value of 1,064 mg/L, Turbidity with a value of 496 NTU, Chemical Oxygen Demand (COD) with a value of 4,485 mg/L, and Total Dissolved Solids (TDS) with a value of 11,052 mg/L.

The experiments were conducted under consistent operational parameters, including a quick mixing speed of 250 revolutions per minute (rpm) for a duration of 2 minutes, followed by flocculation at a speed of 30 rpm for 15 minutes. The experiments also involved a recycling ratio of 10% with a retention period of 3 seconds. The air saturator pressure was maintained at 350 kilopascals (kPa) or 50.7 pounds per square inch (psi). Finally, the flotation process lasted for 15 minutes. Following the conclusion of the flotation process, samples of 500 ml were gathered for the purpose of analysis. The same approach was employed for all coagulants.

III. Results and Discussion

The selection of coagulant is contingent upon the requirements of water chemistry and quality, as well as the dose of the coagulant [12]. The augmentation in dose results in a persistent stimulation and substitution of emulsion surface charges through the dissociation of Al^{3+} and Fe^{3+} ions. The application of this technique led to the consolidation of oil droplets inside the sludge, resulted in the creation of larger aggregates that ultimately ascended to the uppermost layer. Consequently, there was a proportional decrease in the concentration of pollutants present in the effluent, such as COD, TDS, TSS, and turbidity. Hence, the effectiveness of pollutant elimination from the effluent was improved with the increase in the dosage of coagulant. However, after the dosage reached its optimum level, subsequent increases in dosage did not yield significant enhancements in water quality. However, it led to an increase in the costs associated with chemicals [13].

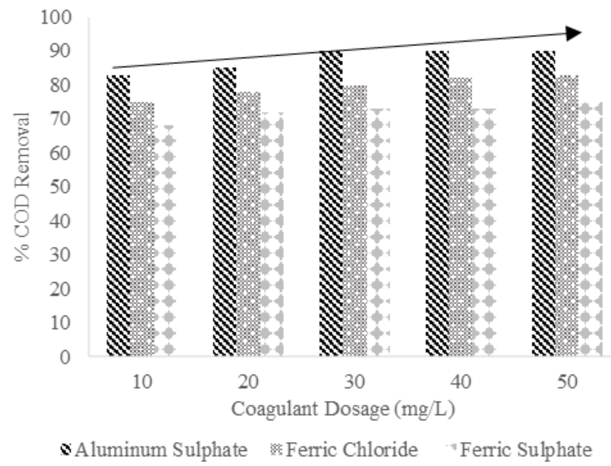

Fig. 1 Percentage COD vs coagulant dosage (mg/L); coagulating with alum at 30 mg/L dose rate removed 90% of the initial COD.

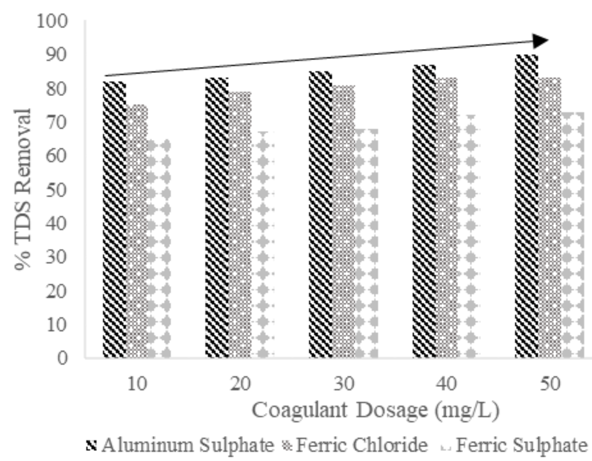

Fig. 2 Percentage TDS vs coagulant dosage (mg/L); coagulating with alum at 50 mg/L dose rate removed 83% of the initial TDS.

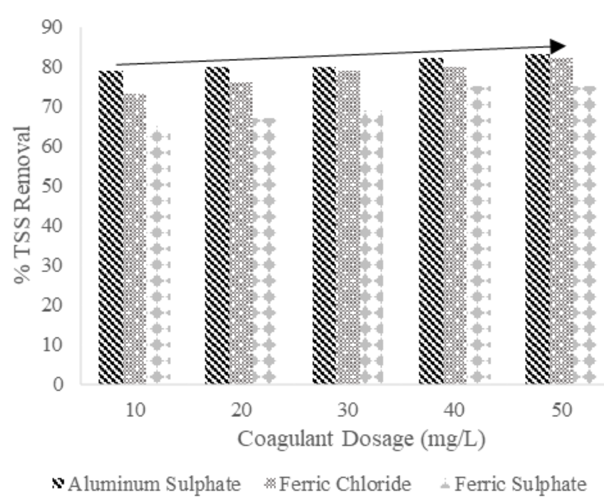

Fig. 3 Percentage TSS vs coagulant dosage (mg/L); coagulating with alum at 50 mg/L dose rate removed 80% of the initial TSS.

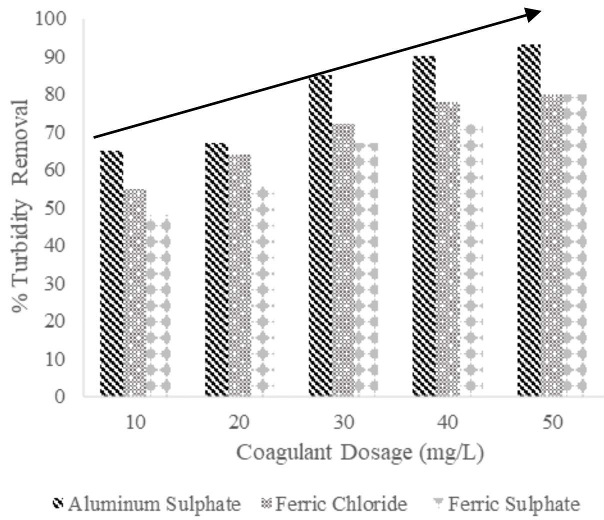

Fig. 4 Percentage turbidity vs coagulant dosage (mg/L); coagulating with alum at 50 mg/L dose rate removed 80% of the initial turbidity.

The data shown in Figures 1 and 2 indicate that the removal of COD and TDS is more efficiently achieved by alum compared to FC and FS. However, the superiority of alum is mostly attributed to its lower chemical consumption rate, resulting in reduced economic expenses. In addition, it can be shown from Figure 2 that the augmentation of the FC dose rate from 40 to 50 mg/L resulted in a marginal decrease in the efficacy of TDS removal, with the removal efficiency declining from 84% to 83%. Nevertheless, except from overdose, no significant impact on efficiency was seen. According to [12], excessive use of coagulants might result in the re-stabilization of oil droplets, hence diminishing the effectiveness of the coagulant and escalating chemical expenses. Figures 3 and 4 demonstrate the high efficacy of alum in the removal of turbidity and total suspended solids (TSS). Due to the stipulated water quality standards and environmental regulations, the utilization of Alum is deemed advantageous due to its ability to yield superior outcomes at a reduced dosage rate. The optimal dosage rate of the coagulant was determined to be 50 mg/L, resulting in a reduction in pollutant concentration in water by more than 85%. Aluminum sulfate (alum) shows superior effectiveness in comparison to the other coagulants.

IV. Conclusion

In this study three different coagulants (Alum, FC and FS) were evaluated for the pre-treatment of industrial paint wastewater, with the objective of identifying the effective coagulant. It was found that, increasing the coagulant dosage (10-50 mg/L) increased the water quality to a degree that excess dosage had no significant effect for the removal of COD, TDS, TSS and turbidity. At optimal dosage of 50 mg/L over 85% efficiency was achieved with alum been the best coagulant. Alum demonstrated the highest efficacy in removing COD, turbidity, TDS, and TSS from water. Specifically, at a dose rate of 50 mg/L, alum proved to be the most effective in reducing turbidity and COD, as well as removing TDS and TSS. The future prospect of pre-treatment of Paint industry wastewater is viable by using DAF coupled with alum under optimized conditions.

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