Proceedings of the 7th International Conference of Recent Trends in Environmental Science and Engineering (RTESE'23)
Canada – June 04 - 06, 2023
Paper No. 128
DOI: 10.11159/rtese23.128

Coagulation and Filtration Combined to Treat Paint Factory Wastewater: Empirical Insights from Uganda

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ABSTRACT - Treatment of wastewater from different sources such as agricultural and industrial facilities is one of the world's challenges to improving people's health, livelihoods, and well-being, especially in developing nations like Uganda. The main purpose of this research was to investigate the quality and quantity of the wastewater from a case study factory in Uganda and design a treatment system that could treat it to dischargeable standards. Sampling of the wastewater was carried out at the factory; its quality and quantity were determined by conducting both in situ and laboratory tests. The study provides an engineered design of the proposed treatment system which consists of a mixing unit, sedimentation tank, and filtration unit. I [1]utilized coagulation/flocculation with alum in the mixing unit and a sedimentation tank to enable the settling of solids. In the filtration unit, I employed commercial granular activated carbon to adsorb contaminants, and placed sand below it to capture other suspended solids that were left after sedimentation. The findings of my research suggest that the coagulation/flocculation and filtration process combination is effective in treating paint wastewater. I varied the contaminant concentration to examine the performance of the integrated system at different effluent qualities. For initial contaminant concentration of Chemical Oxygen Demand (COD) of 6,200mg/L, Biological Oxygen Demand (BOD) of 489 mg/L, colour of 39,000 mg/L, Total Phosphorus of 2,453 mg/L, Total Nitrogen (TN) of 1,800 mg/L. The removal reached up to 98.6% of COD, 91.4% of BOD, 99.6% of colour, 99.2% of TN, and 99.8% of total phosphorus.

Keywords: Industrial wastewater treatment, wastewater characteristics, flow rate, sedimentation tank, filtration unit, integrated system

1. Introduction

When applied to various surfaces for ornamental or protective purposes, paint is referred to as a liquid solution made up of various pigments and solvents [1]. Paint comes in two varieties: oil- and water-based paints. For the former, oil is utilised as a solvent, whilst water is used for the latter.

Paint wastewater is known to contain toxic compounds that can inhibit bacterial growth [2]. The main issue with paint and paint wastewater is their improper disposal into the environment, which introduces toxic waste and creates health hazards. This problem is particularly severe in Kampala City, where surface and groundwater are polluted, putting the city's inhabitants at high risk of waterborne diseases. For example, a recent typhoid outbreak was partly attributed to polluted water sources [3]. These challenges underscore the need for effective wastewater management and treatment to promote public health and protect the environment.

As a developing country, Uganda is experiencing an increasing demand for architectural paints due to the construction of new infrastructure. This trend has led to the emergence of new paint manufacturing industries, creating opportunities for economic growth [4]. However, with the rise in paint production comes an increased risk of paint wastewater contamination, requiring appropriate measures to prevent environmental damage and health risks.

Paint manufacturing industries are among the most regulated industries globally. Various countries have set minimum standards for effluent disposal to prevent environmental pollution. As a result, paint manufacturers have been compelled to adopt low-solvent and solventless technologies in the past four decades, and this trend will likely continue in the future [5]. The regulations are in place because of the significant threat that paint wastewater poses to the environment.

This paper, therefore, contributes to the scientific knowledge of wastewater management and treatment which is a key theme in promoting the health, livelihood and well-being of the public. It also contributes to environmental conservation and

[1] 'I' used to refer to the corresponding author especially in respect to her identity as principal researcher

the protection of biodiversity underwater in support of the key demands recently presented at the 15th conference of parties (COP 15).

The paper is based on findings from a case study of a water-based paint factory in Kampala City, Uganda, and was guided by the following specific objectives.

a. Determining the characteristics of the wastewater and the volume of wastewater generated.
b. Designing a treatment system for the wastewater from the case study factory.
c. Examining the performance of the designed integrated treatment system in eliminating specific water contaminants.

1.1 Problem statement

The factory had an inefficient wastewater treatment system, resulting in the discharge of untreated wastewater into an underground pit and on land (shown in Fig. 1). According to Part 5(1) of the National Environment Regulation for Discharge of Effluent into water or onto land, all industries are required to have a treatment facility and regulate the amount of waste generated to meet environmental standards [6]. The current management of the factory's wastewater presents a significant risk of leakage into the surrounding environment, including water channels and downstream streams that people rely on [7].

The high levels of pollutants in water channels, such as Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), and Total Dissolved Solids (TDS), make the water unsuitable for drinking, home use, irrigation, and aquatic life. This negatively affects people's health and livelihood, as they become more susceptible to diseases. In addition, the runoff from paint wastewater can lead to the slow breakdown of organic solvents and inorganic compounds in water, depriving aquatic organisms of the oxygen they need to survive. These toxic chemicals can also cause tumors to form in animals such as fish.

About 35% of the world's population depends on shallow aquifers for their water needs [8], exposing them to the poisonous pollutants in the factory's wastewater. Moreover, some of the waste components may infiltrate and percolate into the subsurface environment upon discharge, accumulating in the soil pores [9]. Surface and groundwater quality has been declining due to industrialization and human activities [10].

This study aimed to design a treatment system for the factory by conducting wastewater sampling, field and laboratory tests, analysis, and design.

Fig 1: Showing the underground pit

1.2 Justification of the problem

The wastewater generated by the paint factory is not disposed of properly, as it lacks an efficient effluent disposal management system. Instead, the factory uses an underground pit which is not sustainable and can have negative effects on soil productivity and concentrations [11], thereby posing risks to plant life in the long run. Moreover, these pits cannot effectively remove inorganic waste; nitrogen and phosphorus compounds that could lead to algal blooms in waterways in case of leakages [12].

Despite the existence of regulatory bodies such as the National Environment Management Authority (NEMA) tasked with ensuring proper wastewater disposal, the paint factory does not conform to these regulations for effluent discharge.

There is a need for an appropriate wastewater treatment design to be implemented to ensure the proper treatment of effluent before discharge. This will reduce the risk of contamination of underground water and land, protecting both human and plant life. Moreover, implementing an appropriate wastewater treatment design will be a crucial step in achieving the UN Sustainable Development Goals (SDGs), particularly Goal 14: Life underwater.

2. Methodology

This chapter outlines the methodology that was used to achieve the first specific objective. Sampling of the wastewater was carried out through field and laboratory tests. Field tests were carried out at the case study factory and the laboratory tests at the National Water and Sewerage Corporate (NWSC)-Central Laboratory (Kampala, Uganda).

2.1 Field tests

Field/in situ tests were carried out for some of the wastewater parameters to determine its characteristics and flow rate to determine the quantity of wastewater generated.

2.1.1 Flow Rate measurements

The flow of wastewater fluctuates based on the day, week, or month. Wastewater was mainly produced during the evening, specifically during floor and mixing tank cleaning, resulting in elevated wastewater volumes during this time. To determine the flow rate at the wastewater outlet from the factory, the bucket method was employed (refer to Figure 2). The bucket method was chosen over other methods because it is appropriate for small flows and irregular channels and also because the necessary equipment for its implementation was readily available.

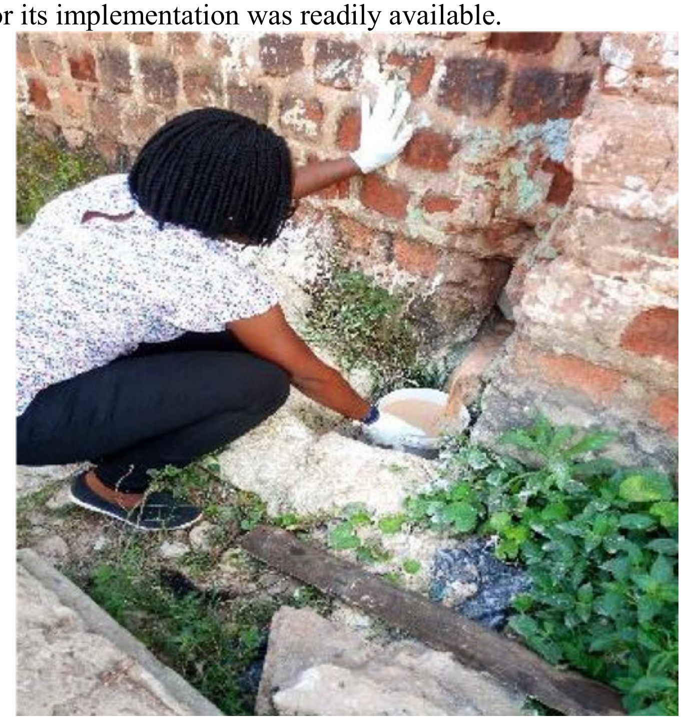


Fig 2: Determining the flow rate using the bucket method

2.1.2 Wastewater Characteristics

The wastewater characteristics were analyzed through field and laboratory measurements. Preliminary tests were performed by collecting wastewater samples at two sampling points. The first sampling point was located at the factory's wastewater outlet before the screening, and the second sampling point was in the underground pit after the screening. The wastewater was screened before being directed to the underground pit to reduce the number of suspended solids.

To determine some of the wastewater characteristics such as temperature and dissolved oxygen, field tests were conducted. The Mettler Toledo and a DO MRC were used by a technician to measure the above parameters. Each of the above parameters was measured in triplicate at both sampling points.

2.2 Laboratory Tests

The collected samples from the field were examined for various parameters, including colour, BOD, COD, TSS, TN, total phosphorus, alkalinity, and sulphate. The purpose of these tests was to assess if the wastewater parameters complied with the standards set by the National Environmental Management Authority (NEMA) for effluent discharge into the environment.

In addition to the aforementioned tests, the jar test was performed to identify the optimal coagulant dosage needed to purify the wastewater.

3. Results and Discussion

After carrying out field and laboratory tests, the following results were obtained, represented and interpreted as shown below.

3.1 Wastewater quality characteristics

Table 1: Preliminary characteristics of the wastewater from the factory.

PARAMETERS	UNITS	BEFORE SCREENING	AFTER SCREENING	NATIONAL STANDARDS OF EFFLUENT DISCHARGE
SAMPLE No.		K5983/2018/C/B	K5984/2018/C/B	
Alkalinity: Total	mg/L	1500	300	800
B.O.D	mg/L	519	372	50
C.O.D	mg/L	5000	5700	100
Colour(apparent)	PtCo	47300	33700	500
Dissolved Oxygen	mg/L	5.53	0.23	>2.0
EC	µS/cm	347	570	1500
Sulphate	mg/L	0	0	500
Temperature(C)		23	23	20-35
TKN	mg/L	1750	2721	20
Total phosphorus	mg/L	14375	16525	10
pH		8.06	7.23	6.0-8.0
TDS	mg/L	223.36	364.8	1200
TSS	mg/L	11700	6000	100
Turbidity	NTU	14425	9025	300
Lead	mg/L		0	0.1
Chromium	mg/L		0	1
Cadmium	mg/L		0.025	0.1

This study found that the levels of BOD, COD, Colour, Total Phosphorus, TKN, TSS, and Turbidity in wastewater were higher than effluent discharge standards both before and after the screening. The high levels of BOD and COD were attributed to the use of various organic materials such as titanium dioxide, calcium carbonate, magnesium silicate, and cellulose in the manufacture of paint [13]. The colour was due to the presence of dissolved organic material, which also contributed to the high turbidity values [14].

The alkalinity and pH of the wastewater were also above the discharge standards before the screening, but within the acceptable range after the screening. This was because the wastewater still contained paint before the screening, whereas after the screening, some paint was removed by the screen, resulting in a lower pH.

The study found that water-based paints, which use water as a solvent, had lower levels of heavy metals, as sulphate, lead, and chromium were not detected in the wastewater.

Finally, the study found that the dissolved oxygen (DO) levels were within the discharge range before the screening but out of range after the screening. This was due to the underground pit storage of the wastewater, which limited oxygen supply [15], thereby posing a threat to aquatic life and contributing to offensive odours. Adequate levels of dissolved oxygen are essential for the survival of aquatic life and odour control.

3.2 Wastewater flow rates from Chromatic Paints Factory

Below are the results obtained during the production days (weeks days) and the days when cleaning activities take place (Saturdays) for the month of February 2019.

Table 2: Flow rates of the wastewater

Day	**Flow Rate (m^3/day)**
Monday (4th)	135
Wednesday (13th)	140
Friday (22nd)	130
Saturday (9th)	180
Saturday (16th)	190
Saturday (23rd)	185
Average flow rate	**160**

The production days had a flow rate between 130-140 m3/day while Saturdays had a flow rate between 180-190m3/day, as indicated in Table 2. The peak flow rates occurred on Saturdays during cleaning activities. There was no constant flow rate, so the average flow rate of 160m3/day was calculated to facilitate the appropriate design of the treatment system.

The flow rate measurements varied depending on the day and time due to the factory's batch process. Wastewater only flows mainly during production and cleaning activities, which occur at different times. Monday to Friday are typical production days with more paint production than cleaning. Therefore, the flow rate values are lower. Saturday is when the factory performs general cleaning, leading to more wastewater generation and peak flow rate values.

3.3 Determining the optimum dosage of alum.

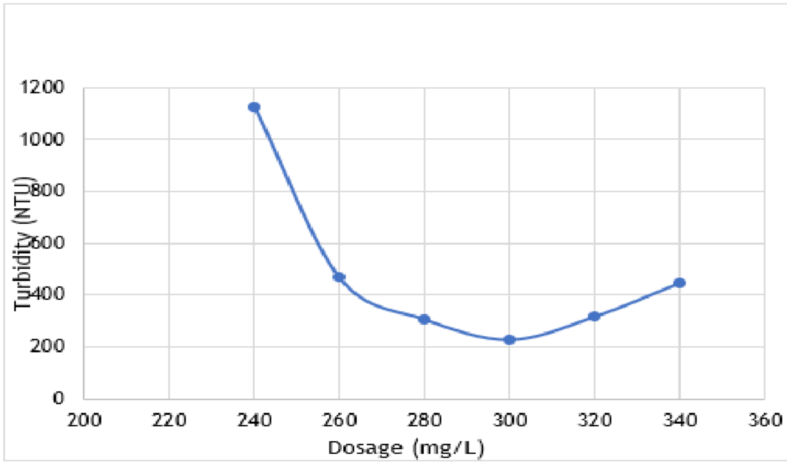


Fig 3: A graph of turbidity against the dosage of Alum

The research experiment conducted involved the measurement of turbidity and dosage of alum. Figure 3 displays the average values obtained from two jar tests with identical dosages, and the graph of turbidity against the dosage plotted based on the results. The data indicates that the optimal dosage of alum to achieve the lowest turbidity level is 300 mg/L, and this value was obtained at a pH of 7.68.

The pH of the wastewater was observed to increase between the range of 7.5-7.8 as the dosage of alum increased. This is attributed to the reaction between the different salts present in the paint manufacturing process, such as calcium carbonate and magnesium silicate, and alum. However, the pH did not exceed the neutral range of 7.8, and hence, no adjustments were necessary.

3.4 Laboratory scale design

The design of the wastewater treatment system was informed by the results obtained from tests. A prototype or laboratory scale design was established, and the wastewater was processed through the system, which is illustrated in Figure 4. Testing was conducted on the influent, coagulated wastewater, and effluent after filtration. The efficiency of the system was evaluated based on the results. The second specific objective was achieved through the design

Fig 4: Design prototype of the treatment unit

The wastewater underwent several stages of treatment. Initially, it flowed from the mixing unit, where agitation of the wastewater and alum facilitated the coagulation-flocculation process. Next, the wastewater was directed to the sedimentation tank to allow the suspended solids to settle. Lastly, the wastewater was filtered through the filtration unit, where Granular Activated Carbon (GAC) adsorbed the contaminants, and sand below. The placement of the GAC above the sand was advantageous because it has a large surface area for molecules to stick, facilitating the adsorption process [16].

In addition, sand was placed below the GAC to capture any remaining suspended solids and prevent the breakthrough of flocs [17]. To support the filter media, gravel was used as the base layer, following recommendations from [18].

3.5 Sampling of the design/prototype

3.5.1 Chemical treatment

Tests were carried out on the coagulated wastewater from the sedimentation tank and the results obtained are shown below in table 3. As shown in Figure 3, coagulation/flocculation, and sedimentation effectively reduces the pollutants and allows slight improvement for wastewater characteristics. 90%, 69.3, and 74.3% of COD, BOD and colour removal efficiencies respectively. The results are attributed to the organic pollutants being soluble. Despite the improvement in the wastewater characteristics for BOD, COD, Colour, TN, TP, TSS and Turbidity were still above the discharge standards of effluent. Therefore, a subsequent treatment was required to fully improve the wastewater characteristics and be within the discharge standards.

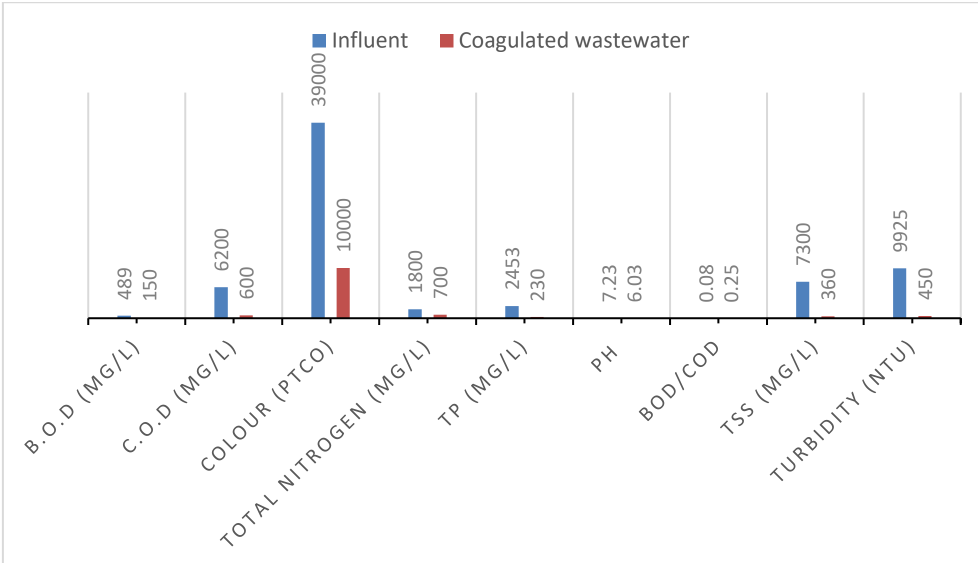
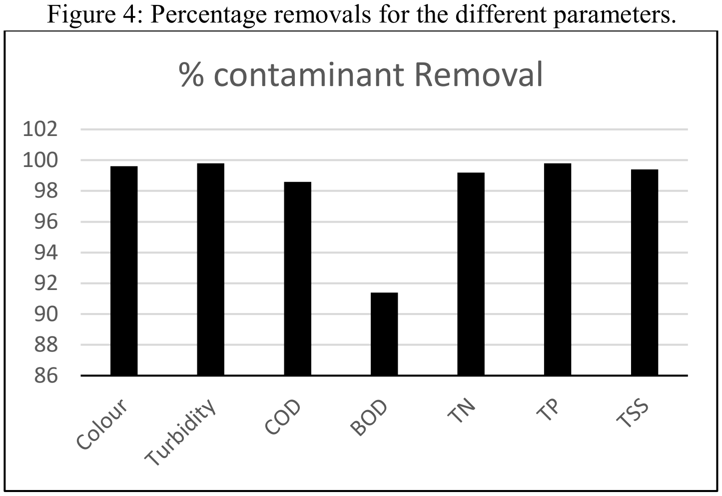


Fig 3: A graph of Influent and coagulated wastewater characteristics

3.5.2 Combination of chemical treatment and filtration

A composite sampling method was employed in obtaining the effluent sample. This involved collecting four individual samples of 2 liters each, at regular intervals after every two hours within 24 hours. The samples were combined in proportion to the rate of flow at the time of collection, resulting in a representative sample that was tested and analyzed.

Figure 4: Percentage removals for the different parameters.



The efficiency of the wastewater treatment system was evaluated by calculating the percentage removal of the different parameters. The results showed that the system had a percentage removal of over 90% for all the parameters, as seen in figure above. This was within the discharge standards, indicating that the system was efficient in treating the wastewater from the Factory.

The sedimentation tank was utilized to settle solids, leading to a reduction in BOD and TSS. The tank enhances the removal of approximately 50-70% of TSS and 25-40% of BOD, as supported by a study by [15]. The water was clearer after sedimentation, indicating a reduction in colour, turbidity, and BOD. The colour reduction was attributed to flocculation, which was a result of alum addition. The activated carbon in the system helped in the maximum removal of COD, TN, colour, and phosphorus [19]. The filtering unit also helped in retaining suspended solids in the wastewater, further reducing the turbidity and BOD.

The proposed wastewater treatment system was compared to other designs used in treating water-based paints, such as the combination of a chemical coagulation-flocculation step with an aerobic biological process [20]. This system removed 92% of COD, 97% of colour, and 44.5% of BOD [20]. It was observed that the proposed system was more efficient than that of [20] since it had a higher percentage of efficiency.

Figure 5: Samples of wastewater from the mixing, sedimentation and filtration units

4. Conclusion

The wastewater from the case study factory was found to have elevated levels of various parameters, including COD, BOD, TSS, color, turbidity, TP, and TKN. To address this issue, a treatment system was developed that combined coagulation, sedimentation, and filtration using activated carbon and sand. This system was found to be highly effective, resulting in an effluent that was clear and free of contaminants. The system also showed remarkable removal rates for various parameters, including 99.6% for colour, 98.6% for COD, and 91.4% for BOD.

The factory produces approximately an average flow rate of 160 m3/day. The optimum dosage of alum obtained from the jar test was 300 mg/L.

Urban development policymakers and implementers should with engineers together with business developers promote and enforce sustainable paint wastewater management using the integrated system of coagulation, and filtration using activated carbon and sand.

Acknowledgment

I would like to express my deepest appreciation to the co-author (Roice Bwambale) for his valuable contributions to this research paper. He played a critical role in reviewing and editing this paper, providing constructive feedback and suggestions that significantly improved the clarity, coherence, and overall impact of the paper.

I would like to also express my heartfelt gratitude to my father for his unwavering support and encouragement throughout my research journey. Without his financial assistance, this research would not have been possible.

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