Article

Integrated Microbial Fuel Cells with Chemical Coagulation Technique for Advanced Industrial Wastewater Treatment

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Abstract: This study develops into the application of a combined MFC unit with chemical coagulation for total treatment of inert contaminants in complex substrates. Microbial Fuel Cell (MFC) technology converts chemical energy in the form of organic matter, into bioelectricity in an environmentally friendly and efficient manner, reducing carbon emissions and increasing bioenergy production. An evaluation of a laboratory scale chemical coagulation using an aluminum and poly-based coagulant on how effective it can remove bulk impurities such as particulate COD and turbidity to obtain the purest and most cost-effectively treated wastewater using a jar test is being conducted in this current study. This study aims to find the most effective treatment technologies for wastewater recovery in breweries in order to achieve zero liquid effluent discharge (ZLED). The preliminary results showed that adding a modest amount of poly and a 50 % alum alone treatment improved COD, color, and turbidity reduction. The turbidity removal efficiency achieved after chemical coagulation treatment was 90.50 % and 59.36 % COD removal, demonstrating the benefits of adopting an alum/poly based technique. To determine ZLED, this study clearly advised a combined treatment technique, specifically the MFC-flocculator unit for efficient organics and inorganics removal.

Keywords: chemical oxygen demand *(COD);* zero liquid discharge *(ZLED);* poly-aluminum chloride; chemical-coagulation; jar-test; Microbial Fuel Cell *(MFC)*

1. Introduction

Environmental degradation caused by released industrial effluent has increased in South Africa and around the world, [1]. Due to its extensive changes in high strength organics such as TOC, alkalinity, turbidity, acidity, COD, BOD, and volatile fatty acids, brewery wastewater is one of the major industrial effluents contributing to these impacts, [2]. Various efforts have been made, and some are still being made, to identify new approaches for treating and reusing industrial wastewater, [3].

Due to the abundance of organic compounds such as sugars, soluble starches, ethanol, and organic acids, as well as particulate matter from barley and hops, brewery wastewater typically has high Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), and Total Suspended Solids (TSS), [4]. The amount of TSS, BOD, COD, and the concentration of nitrogen and phosphorus in the form of orthophosphate characterize untreated brewery effluent, [4]. Previous studies have shown that the brewery effluent temperature ranges from 18-40 ^{o}C with average to high operational temperatures, [5].

Chemical coagulation is a critical component in most traditional water and wastewater treatment plants. It occurs in a physical purification system that comprises transportation operations, coagulant injection for chemical reactions, charge neutralization, and the formation of tiny flocs for agglomeration into bigger flocs. This improves downstream processes' ability to effectively remove recalcitrant pollutants, [6]. Double layer compression, sweep flocculation, adsorption and charge neutralization, and adsorption and inter-particle bridging are the four coagulation mechanisms or particle aggregation mechanisms that can occur. The colloids and the additional coagulant react to destabilize and neutralize the electric charges in the particles, while flocculation aids the agglomeration of flocs in the colloidal solution, [7]. The coagulant is responsible for the formation of small-scattered particles that eventually coalesce into bigger, more stable particle flocs, [7]. As a result, the flocs become heavier than the water, settling as sediments that can be removed. About 90% of the suspended stuff is removed because of this process, [8].

MFCs are evolving into a simple and reliable technology. In the realm of wastewater treatment, middle-term application may undoubtedly be foreseen at market-value pricing. The electrochemical improvement of the MFC is critical, if the biological expertise is properly obtained; the thermodynamic stability and favourability of this technology would result in cheaper prices of construction materials indicated by Logan et al.,[9-14]. The system's economic convenience and reliability would lead to full-scale industrial application of this technology, which is based on a simple, reliable, and renewable clean operating technique for converting carbs *(chemical energy)* to renewable energy *(Bioelectricity)*,[17-20]; [21-23]. As a result, the proposed research study will look into the extremely high possibility of using a co-treatment setup as the next novel blue energy technique for both electricity production and efficient industrial wastewater treatment, in order to fill the knowledge gap on these bioelectrical treatment methods.

The study main aim is to test the efficacy of an aluminium-based chemical coagulant and poly in a lab scale flocculator for removing turbidity and inert strength contaminants from brewery wastewater to achieve zero liquid effluent discharge. The following particular objectives will be accomplished: demonstrate laboratory scale chemical coagulation treatment on brewery wastewater using a jar test method. More specifically, assess the impact of two chemical coagulants ***(ALUM and Poly)*** on the removal of inert and high-concentration organic contaminants. As aforementioned, this study will be done in a bench top jar test method using a Lovibond six piece flocculator unit with variables stirring speeds. More operation sequence on this unit has been presented in details in the following methods sections.

2. Materials and Methods

The main study beyond this article specifically focuses on **MFC technology**; a novel approach of removing high strength organic and biological pollutants synchronously to bioenergy production in a laboratory scale sequential double chamber Microbial Fuel Cell (MFC) which will be integrated with an Electrochemical coagulation process in the cathodic chamber for enhanced substrate removal. This Bio-electrochemical method will be tested for Scaling -up the production of electricity whilst treating industrial and brewery wastewater specifically removing; phosphates, chemical oxygen demand **(COD)** and Biological oxygen demand **(BOD)** and total suspended solids **(TSS)**. This method will be employing specially screened mixed cultured microbes in the form of "***electrogens***" as an anodic mediator therefore will be referred to as a mediator less MFC. Its key advantages and constraints will also be evaluated and investigated in comparison to an existing predictive optimum operating energy model of Gibbs free energy which will thermodynamically measure the ability of the MFC in producing electricity in the form of overall cell electromotive force **(E_{emf})** (V). In simply terms, this is the work done between the Anodic and Cathodic Chambers expressed Volts.

The main aspects of this study will critically attempt in resolving the currently experienced complications with the MFC method in treating industrial and brewery wastewater at the same time producing electricity. Categorically stated; this study will focus on the; electrochemical energy "scaling-up' production, through increasing the anodic surface area design and also modifying the electrodes material of construction most preferable use carbon material quoted with carbon nanotubes. The theoretical unique design of having a permanganate chloride solution as a Catholyte mediator is believed to significantly enhance the potential of easy electron acceptance in the Cathode chamber and therefore improving the overall **E_{emf}** generation more than an ordinary MFC using oxygen as electron acceptor. The second research question will be to investigate the possibility of minimising the activation losses in the MFC. Improving the bioenergy production of the MFC will be achieved through increasing the electrodes surface areas, increasing the bioreactor operating temperature. The above key aspects will be attainable following these listed several specific objectives: (i) Generate efficient amount of Electricity from the MFC technology (ii) Monitor the production of CO_2 during COD efficient removal in the Anode MFC treatment system (iii) Develop a viable co-treatment (Bio electrochemical) method of the permanganate MFC technology with a flocculator unit (chemical coagulation) to enhance advanced organic /non-organic substrate removal (v) Investigate the effect of Electrochemical coagulation on the effect of particulate COD removal and Phosphates.

On these particulate inorganics or inert removal, special chemical poly coagulants will be evaluated to ensure that the total chemical oxygen demand is entirely removed. The capacity of these viable chemical coagulants to extensively treat the undesirable phosphates and p-COD that would be accumulated throughout the electrochemical processing in the MFC will be investigated. Previous study on poor phosphate and inorganic constituent removal from complex substrates in a standard MFC system has resulted as a research gap, which will be filled by this combined bio-chemical treatment approach.

This section explains the planned, analytical emphasis, and experimental setup methods used in this study to achieve the effect of chemical coagulation in the Jar test method. This study aims to answer the above-mentioned problems and make recommendations for a co-treatment strategy that combines the MFC and chemical coagulation techniques. In light of these study goals and objectives, a more fundamental and step-by-step strategy has been provided as a categorical technique to cover the influence of chemical coagulation of inerts removal on improving the overall performance of an MFC unit. Based on existing MFC and flocculator units, a more robust methodological sequence is expected to be built. Factorial Design in Design Expert Version 7 accurately predicted the study's experimental number of runs to be approximately 14 runs.

This section of the article presents into details, the materials and methods that were instigated to conduct the experimental runs in this study of the significance of chemical coagulation towards inetrt removals from brewery wastewater. All experiments were conducted at Mangosuthu University of Technology Research Laboratory over a period of 14 days. Given the varying dose ppm levels of the two coagulants in PAC, this aspect was confirmed using Response Surface Methodology (RSM). In order to optimize the primary experimental runs in the MFC unit, an overall Design of Experiment (DOE) in RSM was done, which projected a number of runs while taking into account all of the operating and design characteristics.

Below is a precise and detailed Jar test Unit experimenal set up, which covers all essential operational components of the bench top jar test procedure that was carried out as a pre-experimental runs towards integrating it with the MFC unit as per the aim of achieving ZLED.

2.1. Sample Harvesting and Storage and Characterisation

2.1.1. ample Harvesting and Storage

Samples were collected using the composite sampling method at the South African Brewery *(SAB)*, which is located in Durban Ispingo-Prospecton with respect to the APHA 2004 sampling standard method. The targeted sampling point for brewery wastewater was at the final treated effluent point before it is sent to the trade effluent discharge stream; samples were harvested using a 25 liters poly-can. After sampling runs were conducted within four hours, if not, the samples were preserved by storing them in the Chemical Engineering Laboratory at Mangosuthu University of Technology, at 4°C, to minimize microbiological deviations on the sample.

2.1.2. Industrial Wastewater Samples Characterisation

The Industrial Wastewater samples were collected for two purposes: first, to characterize the wastewater generated by industry in order to determine the strength of its organic pollutant, and second, to send the Industrial Raw Wastewater samples to a laboratory-scale Flocculator Unit for advanced substrate removal. **Figure 1** shows the usual organic content of three different types of complex wastewater substrates that were collected from a local Biorefinery, Brewery and dairy plant. This effluent was set up for chemical coagulation in a Jar test operation, which comes as a post-tretment or polishing stage in a typical wastewater palnt. Due to the ever-changing nature of the complex industrial substrates, more characterisation analysis will be carried out.

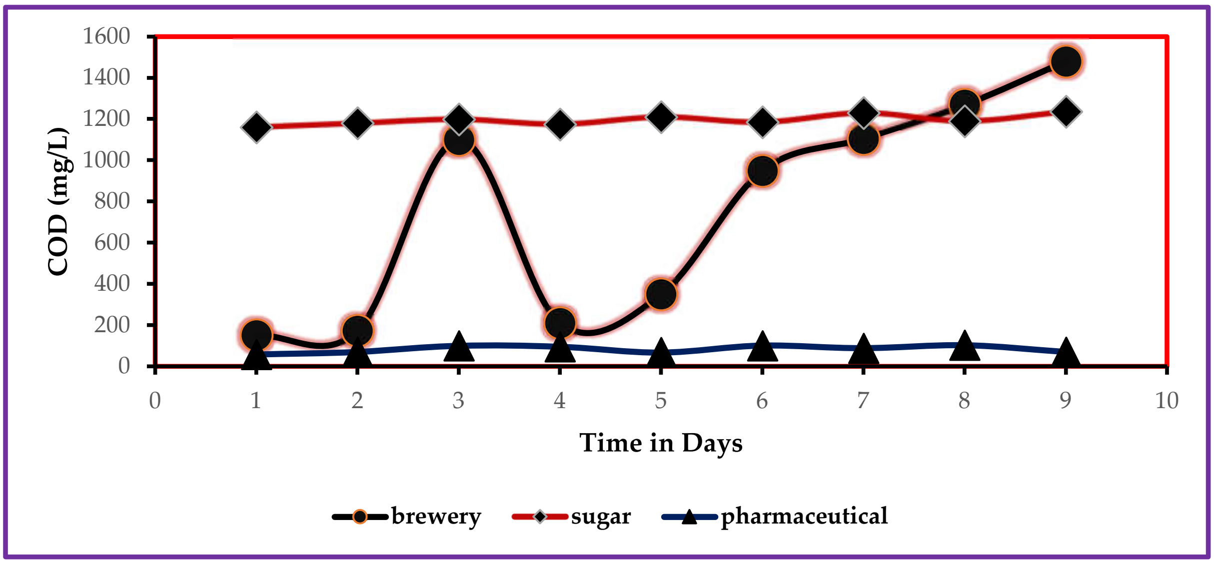

Figure 1. Presents the 3 different wastewater sources that will be harvested as complex substrate sources in this study.

2.2. Design of Experiments for Lab Scale Jar Test Method prior MFC Integration

The Design Expert software version 7 was used to design the experiments. This aided in determining the exact number of runs to be performed in executing this Jar test method, which will later be combined and merged with the MFC unit in the main research study to evaluate and improve the removal of particulate COD in the Microbial Fuel Cells while they generating Bioelectricity. The design expert analysis is presented in **Table 1** and is based on Response Surface Methodology (RSM) and the 2-2 factorial approach for run projection.

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Table 1. DOE for Jar Test Experiments.

	Factor 1	Factor 2
No. of Runs	A:Aluminium Chloride-Dose	B:Poly Based-Dose
	ppm	ppm
1	40	40
2	60	82.2487
3	80	75
4	60	57.5
5	31.7157	57.5
6	60	57.5
7	60	57.5
8	40	75
9	60	57.5
10	80	40
11	60	32.7513
12	60	57.5
13	88.2843	57.5

2.3. Jar Test:

The jar test is a standard laboratory technique used to assess the optimum water or wastewater treatment operating conditions. This method allows changes in pH, coagulant or polymer dose variability, exchange of mixing speeds or small-scale testing of different types of coagulants or polymers to predict the activity of a large-scale treatment plant. This method will be instigated as a post treatment stage after MFC biodegratdation of industrial complex saustrates and possible bioelectricity production. At this point, the emphasis is to investigate the feasiblity of the PAC coagulants on the removal efficacy and its significance in achieving ZLED hence complete removal of particluate and inert contamintants contanined in brewery wastewater (BWW).

2.3.1. Jar Testing Apparatus: Lovibond Flocculator

The jar testing apparatus consists of six paddles, which stir the sample on the six 1000 ml beakers. One beaker is used as a control while the operating conditions are varied among the remaining five beakers. A stirring gage on the top-left of the device allows for the control of the mixing speed in all of the beakers. The instrument is also equipped with the automatic time, which used to time the running intervals in order to do away with human errors as presented in **Figure 2**.

Figure 2. Six paddle Lovibond - flocculator used at the laboratory.

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2.3.2. Solution Preparation

Aluminium based stock solution of 1.0% by weight is not on hand, the solution was prepared at the lab as follows. Liquid Products: Liquid aluminium based coagulant (alum) is sold at 48.5% and accounted for on a dry basis. Using its specific gravity 1.335 ± 0.005. 10.0 grams / (1.335 x 0.485) = 15.4 mL liquid, for a 10 g/L (1.0% by weight) dry basis solution. 1 mL of this solution in a 1 L jar test beaker equates to 10-ppm dry salt. Poly came in a liquid form 50% concentrated with a specific gravity of 1.216 ± 0.005. 10 grams/ (1.216 x 0.50) = 16.4 mL liquid, for a 10 g/L (1.0% by weight) dry basis solution. 1 mL of this solution in a 1 L jar test beaker equates to 10-ppm dry poly. The above stated method is based on basic solution chemistry that is used for preparation of these standard solution based coagulants.

2.3.3. Jar test operational procedure

The following sequential proceedure was developed and precisely carried out for this labscale Jar Test method inview of envestigating the effect of the Poly based and ALUM based chemical coagulants significance in inerts constiuents removal.

- Measure turbidity, pH and COD.
- Using a 1,000 mL graduated cylinder, add 1,000 mL of raw effluent water to be flocculated to each of the jar test beakers.
- Using a prepared stock solution (1.0% by weight), dose each beaker with increasing amounts of solution shown in **Error! Reference source not found.**. One beaker used as a control, while the other 5 beakers were adjusted at different doses.
- After the coagulant dose, stir at approximately 160 rpm for 2 minutes. The rapid mix stage helps to disperse the coagulant throughout each beaker.
- Reduce the stirring speed to 60 rpm and continue mixing for 15 minutes. This slower mixing speed helps promote floc formation by enhancing particle collisions, which lead to larger flocs.
- Turn off the mixers and allow the beaker to settle for 30 minutes. Then measure the final turbidity in each beaker.

Table 2 underneath presents the catagorical dosing intervals that were varied and increased in fixed amounts from the least ppm assay as per starting dosing concentration accoriding to the design of experiments, RSM suggested set points. These concentrations were increased towards the maximum set point that was also projected by factrial design. These projected range were prjected through RSM as design values sufficient to test effect of each chemical coagulant simultaneous to presenting its significance in particulate COD and inerts removal.

Table 2. Increasing dosages chemical coagulant.

Jar number #	Chemical added (mL)	Chemical dose (ppm)
Control #1	0.0	0.00
2	3.0	30.0
3	4.0	40.0
4	5.0	50.0
5	6.0	60.0
6	7.0	70.0

Figure 3 below presents a sample of the treatment outcomes that were achieved after a typical experimental sequence in a Jar test method. This pictorial result is evidence of the significance of chemical coagluation as an imperative post treatment means by biuological operation in this case from a typical brewery anaerobic digester vessel. In essence, this clealry shows why the Jar test is a critical step to be merged with the double chamber

MFC which soley does biological degradation of organics but limited towards removal of inorganics and phosphates.

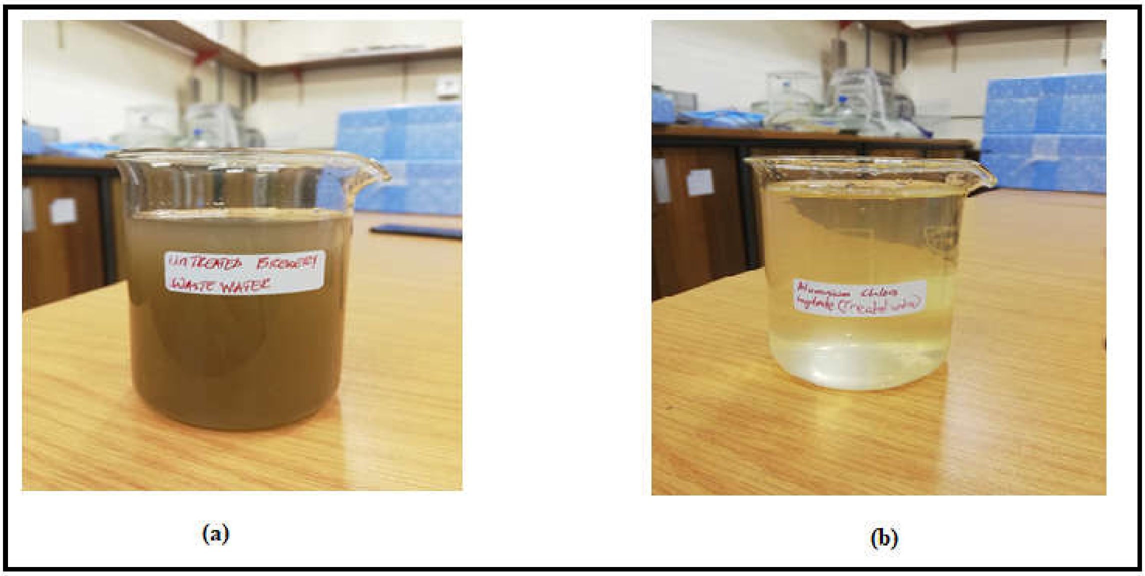

Figure 3. (a) Presents a sample of an untreated BWW substrate. **(b)** Presents a sample of treated BWW substrate after coagulation.

2.4. Analytical Methods and Data Analysis

Concentrations were analysed before and after treatment sequence as part of the performance monitoring step, COD quantities were analysed using high-range ampoules (HACH Chemical) with a spectrophotometer (HACH, DR5000), turbidity quantities were analysed using TL23 Benchtop HACH turbidimeter which uses ratio nephelometric measurement technology to provide reliable measurement. The grab sampling method was also used to analyse effluent characteristics, which are; BOD: COD, pH levels and conductivity. All data were sampled and analysed in replicates to achieve the replicability analyses hence eradicating the propagated human error during processing. More so, further statistical analysis was implemented using the advanced excel to analyse the smaple population standard deviation ,projected the sample Meadian and also analysed the overall distributaion of the sample in terms of Skweness test. For future work in the MFC unit, full experimetal runs with enough population size for the student *t-test* method on unpaired data with unequal variances at 95 % confidence interval will be implemented to gather the population size confidence inteval levels. For the purpose of this research article, basic statistical analysis to determine the significance levels of the results was done by linear regression on advance excel. Here an empirical predicticve model with a corresponding root-mean square factor was ascertained to show the significance of the coagulant in terms of inorganics removal as the value of R2 approaches 1. Clealry the results demonstrated a high significance and criticalness of merging chemical coagulation with the MFC treatment for succesful WWT treatment and Bioelectricity production. The results section details the above statistical parameters by plots and data tables. Moreso, R-Studio statistical Software was embarked on and presented in the following subsection. Its statistical findings on the ALUM, POLY and PAC chemical coagulants significance test is scrutinised.

2.4.1. Advanced Statistical Analysis on R-Studio

Advanced R-studio was undertaken to elucidate on the criticalness of the raw data harvested from the experimental runs. These analysis underpinned the relevence, significance, median ,mean, minimum and maximum values from the raw data tables presented in the results section. The statistical insight shown here was the complete balance and margin around the main operating variables like COD and Turibidity that was observed when using these two distinctive chemical coagulants , ALUM and POLY. Poly proved more viability compared to Alum though when these two cogulants are combined to form PAC, they even proved more higher significant removal of inorganics and chemical coagulation capacity as preseneted in **Table 5**, here all the perfomance monitoring factors COD and turbidity reomoval efficiencies are more steeper and visible marginal difference incomparison to the other two coagulants. **Tables 3, 4** and **5** presents the detailed findings further:

Table 3. Presents R-Studio Statistical analysis on ALUM Coagulant Profile.

Statistical Parameters	Dosage ALUM	COD *(mg/L)*	COD % Removal	NTU	NTU % Removl	pH	Temperature
Minimum value	30	106	0.2648	18	0.3026	8	24
1st Quarter	40	111	0.3470	25	0.4737	8	24
Median	50	133	0.3927	30	0.6053	8	24
Mean	50	130	0.4027	33	0.5631	8	24
3rd Quarter	60	143	0.4931	40	0.6710	8	24
Maximum Value	70	161	0.5160	53	0.7631	9	25

Table 4. Presents the R-Studio Statistical analysis on Poly Coagulant Profile.

Statistical Parameters	Dosage POLY	COD *(mg/L)*	COD % Removal	NTU	NTU % Removal	pH	Temperature
Minimum value	30	89	0.4384	10	0.6579	7	24
1st Quarter	40	92	0.4703	11	0.7237	8	24
Median	50	102	0.5342	17	0.7763	8	24
Mean	50	104	0.5233	17	0.7763	8	24
3rd Quarter	60	116	0.5799	21	0.8553	8	24
Maximum Value	70	123	0.5936	26	0.8684	8	25

Table 5. Presents the R-Studio Statistical analysis on PAC Profile.

Statistical Parameters	Dosage ALUM	Dosage POLY	COD *(mg/L)*	COD % Removal	NTU	NTU % Removal	pH	Temperatur e
Minimum value	50	5	89	0.4977	7	0.7105	7	24
1st Quarter	50	10	93	0.5388	8	0.7500	8	24
Median	50	15	100	0.5434	17	0.7763	8	24
Mean	50	15	98	0.5498	14	0.8079	8	24
3rd Quarter	50	20	101	0.5753	19	0.8947	8	24
Maximum Value	50	25	110	0.5936	22	0.9079	8	25

The following graphical trends presents the an overall statitstical perception from R-studio when comparing the two chemical coagulats removal efficacies over and above the versatility of combining these two chemical coagalants with the option of varying Poly as its more chemically significant towards solids and color and inroganics treamnet in wastewater. The combined chemical coagulants refered to as PAC showed a more significant removal efficiency with convincing alpha values of 0.005 in the t-test paired analysis. The overall observation derived from this statistical exercise is that PAC is more convienient and highly effective for both particulate COD and Turbidity removal. This aspect is further presented in the results section underneath. **Figures 4** and **5** clearly elucidate of the graphical findings of R-Studio.

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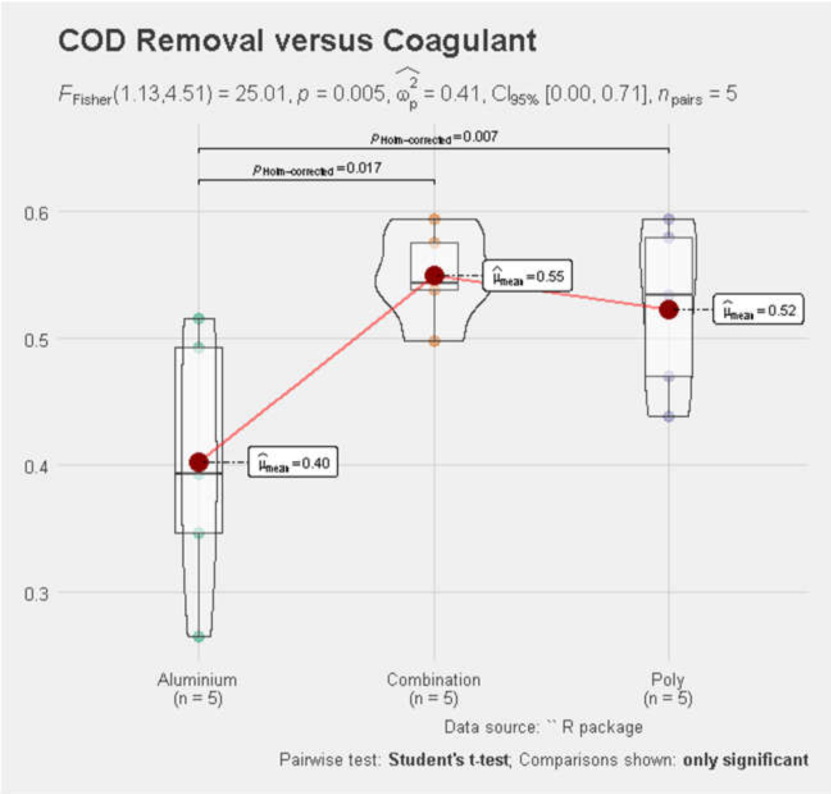

Figure 4. presents COD removal efficincies comapred to Coagulant doses.

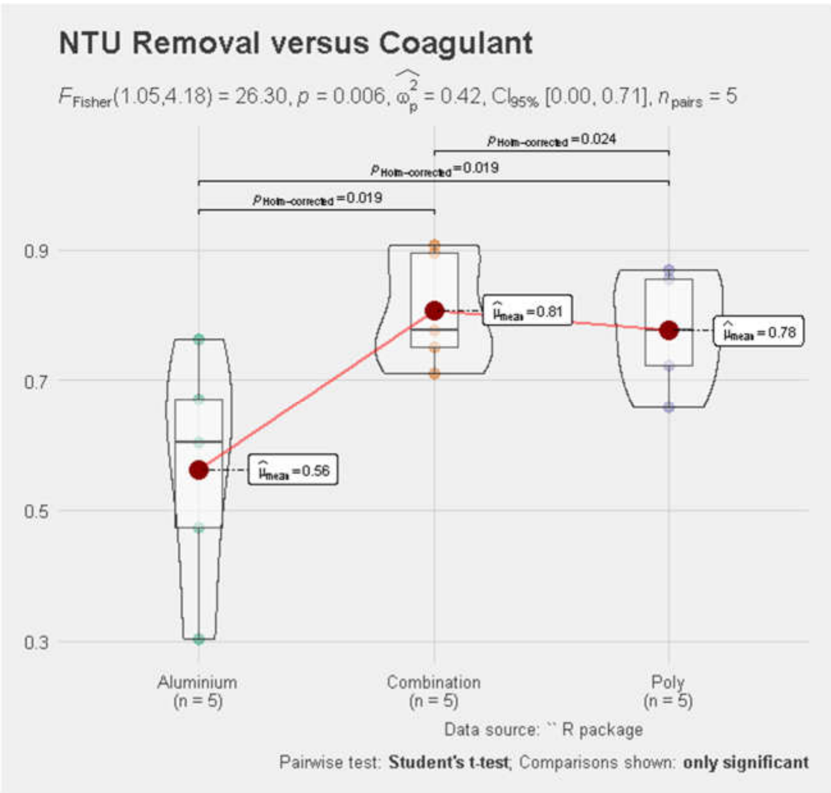

Figure 5. presents the NTU removal efficiencies compared to Coagulant doses.

3. Results and Discussion

3.1. Tables of Results

Trail runs were done over a period of 14 days; in order to tougher study the removal of these impurities by chemical coagulation and flocculation. Due to high quantities of turbidity, an initial dosage of 30ppm was ideal with an increment of 10pmm to 70ppm. Results presented on **Table 6** and **Table 7**.

are average results that were obtain over a period of two interchanging chemical dosages and analysis.

comprises of results attained using both chemicals at once in order to achieve desired reduction on bulk parameters.

Table 6. Aluminium based coagulant jar test results and analysis.

Aluminium based coagulant							
Dosage		Measured parameters average					
Jar #		**COD(mg/L)**	**COD % Removal**	**%NTU Removal**	**NTU**	**pH**	**Temperature (°C)**
1	Control	219	0	0	76	8	25
2	30 ppm	161	26	30	53	8	24
3	40 ppm	143	35	47	40	9	24
4	50 ppm	133	39	61	30	8	25
5	60 ppm	111	49	67	25	8	24
6	70 ppm	106	52	76	18	8	24
STDEV		41	19	28	21	0	1
MEAN		138	37	54	35	8	24
SKW		1	-1	-1	1	2	1

Table 7. Poly coagulant aid jar test results and analysis.

Poly							
Dosage		Measured parameters average					
Jar #		**COD(mg/L)**	**COD % Removal**	**NTU**	**NTU % removal**	**pH**	**Temperature (°C)**
1	Control	219	0	76	0	8	24
2	30 ppm	123	44	26	66	8	24
3	40 ppm	116	47	21	72	8	25
4	50 ppm	102	53	17	78	8	24
5	60 ppm	92	58	11	86	7	24
6	70 ppm	89	59	10	87	8	24
STDEV		44	20	23	30	0	0
MEAN		109	50	19	75	8	24
SKW		2	-2	2	-2	-2	2

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Table 8. Jar test analysis at constant dose of Coagulant and Varied dose of coagulant aid.

Aluminium based coagulant @50 ppm and Poly varied									
Dosage			Measured parameters average						
Jar #			COD(mg/L)	COD % Removal	NTU	NTU % Removal	pH	Temperature (oC)
1	Control	Control	219	0	76	0	8	24
2	50 ppm	5 ppm	110	50	22	71	8	24
3	50 ppm	10 ppm	101	54	19	75	7	24
4	50 ppm	15 ppm	100	54	17	78	8	25
5	50 ppm	20 ppm	93	58	8	89	8	24
6	50 ppm	25 ppm	89	59	7	91	8	24
STDEV			45	21	24	31	0	0
MEAN			101	54	18	76	8	24
SKW			2	-2	2	-2	-2	2

There is a clear outline in the removal efficiency of COD and turbidity in **Tables 6; 7;** and **8**. When applying a polymer-based flocculant, the chemical coagulation effect is seen to increase. Even with varying Poly dosages, the poly tends to have a greater influence on the removal of suspended solids, sparingly breaking then agglomerating them to create settleable flocs. Poly has a stronger flocculating capacity in principle than Alum base coagulant and demonstrated a better statistical distribution analysis when skewness values were taken into account, [7,13]. Poly can readily be recommended for industrial applications.

3.1.1. Turbidity Removal Profile

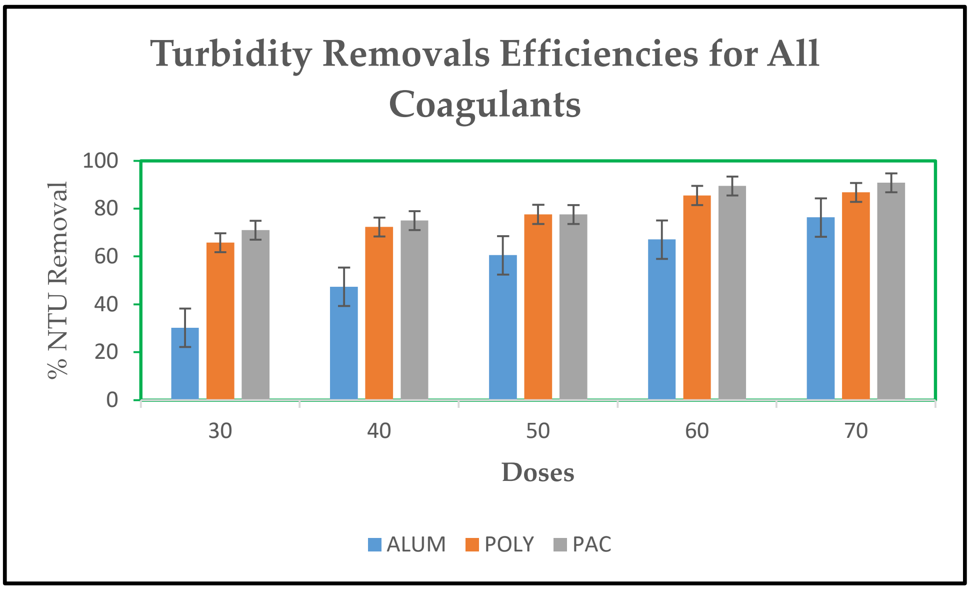

Figure 6. Turbidity removal assay profile in a Jar Test method.

Figure 6 displays a turbidity removal profile using two types of coagulants at different dosage. It can be observed from the graph that poly is more effective than alum although they both yield to quiet notable results with alum reaching a percentage removal of 75.85 % whereas poly remove about 85.95 % of turbidity. It can be clearly seen that poly is more effective. Poly based coagulant was able to bring down turbidity to 10.70 NTU from 76.20 NTU of the influent while alum gave 18.40 NTU. As indicated in **Figure 6,** the PAC coagulant had a balanced standard error from a statistical standpoint. This result corresponds to a 45-point standard deviation from a mean of 101. A positive skewness

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factor of 2 around the mean added to the statistical significance of the departure. The outliers were obviously dispersed positively around the mean value, as evidenced by this. **Figure 6** shows that the Alum and Poly mean values were 41 and 44, respectively. This is a tad less than the variance seen in the mixed coagulant. The skewness factor of 1 and 2 correspondingly revealed a clear and equitable distribution. Chemical coagulation's effect has been shown to be statistically significant once more, however it improves with the dosing configuration of the mix poly-alum coagulant.

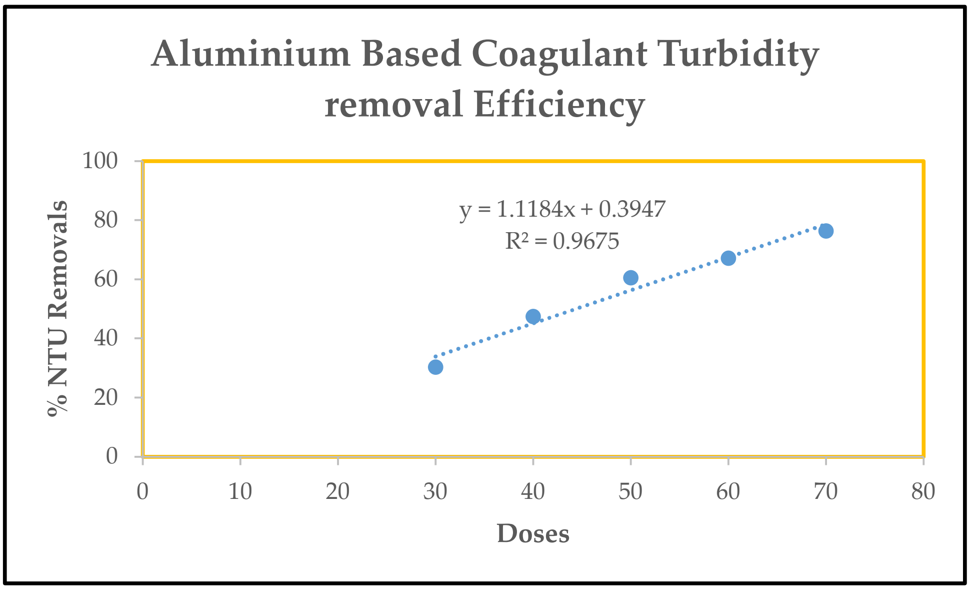

Figure 7. presents the Alum Based Coagulant for Turbidity Removal.

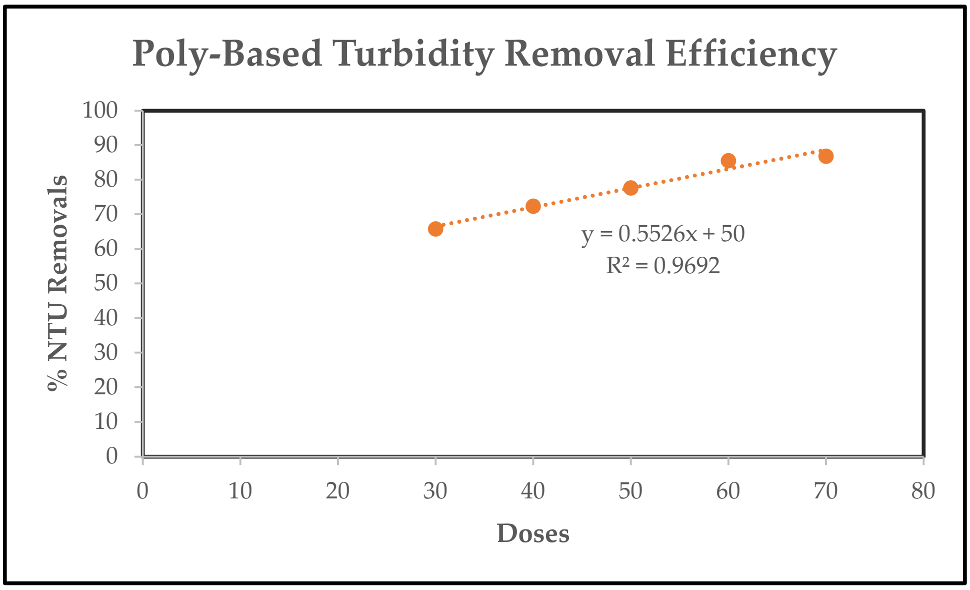

Figure 8. Poly-based coagulant Turbidity Removal Efficiency.

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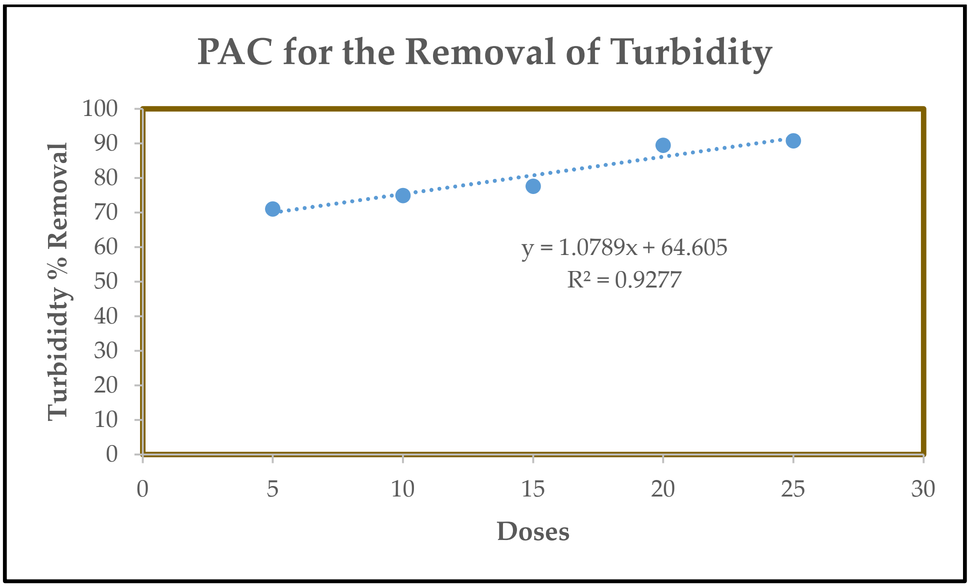

Figure 9. PAC coagulant Turbidity Removal Efficiency.

Figures 7 and **8** shows the efficacy of solid removal in terms of turbidity and the corlor test. This level of relevance was predicted based on the fact that chemical coagulation has the ability to coagulate sparse flocs and then agglomerate them into one heavy settleable floc that essentially settles off due to gravity, [13]. A significant correlation factor of 0.9675 was obtained, indicating solid efficiency. **Figure 8** shows a coagulant that is significantly more effective because it is Poly based. At modest doses, this coagulant was able to reach low particalate COD tests. This evidence demonstrates that Poly is more resilient and efficient in the treatment of suspended soils, resulting in the ejection of inroganics in the form of particle COD. It was possible to get a significance level of 0.9692. A mixed coagulant is preferable because it delivers an early high removal capacity at extremely low dosages, in addition to being an affordable convenience from an engineering standpoint. As seen in **Figure 9**, this is the case. The avarage removel effectiveness on solids and turbidity was demonstrated. Chemical coagulation, as indicated in most literature, is an important step in water and wastewater treatment because it can break the bindings of inerts and ingorganics that cannot be handled by upstream techniques that solely rely on substrate biodegradation [7, 13].

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3.1.2. COD Removal Profile

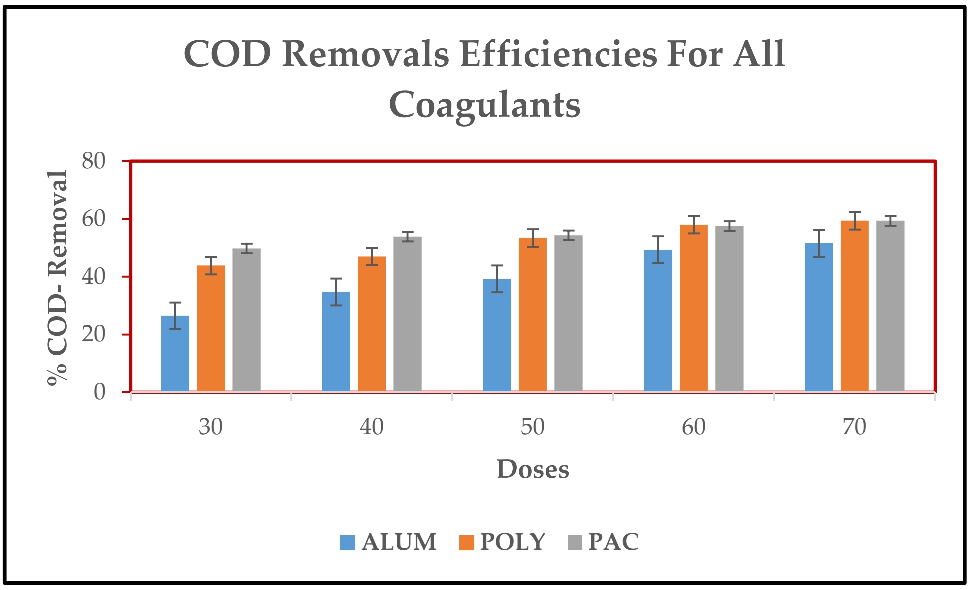

Figure 10. COD removal assays for all coagulants bases.

Figure 10 presents COD removal profile at different dosage rate for both chemicals. It can be observed from the graph, that poly is more effective than alum although they both yield to anticipated results, for both coagulants previous studies has shown that they can yield to a COD removal of 55 - 65%. On this trail, alum was found to remove 51.59% and poly removing 59.36%. Overall, on COD removal both coagulants were not far apart in terms of performance.

3.1.3. Inert - COD Profile

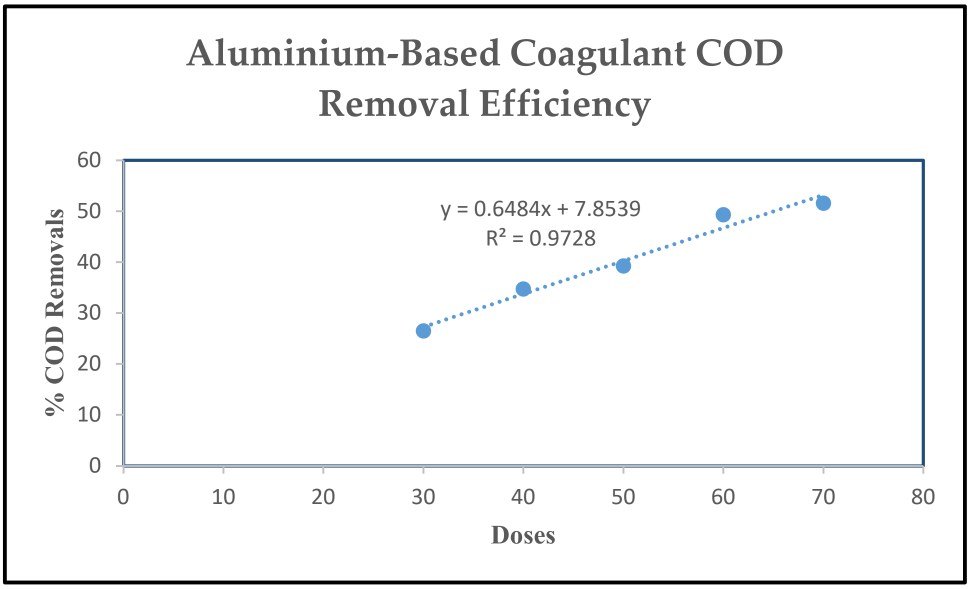

Figure 11. COD profile for ALUM based dose.

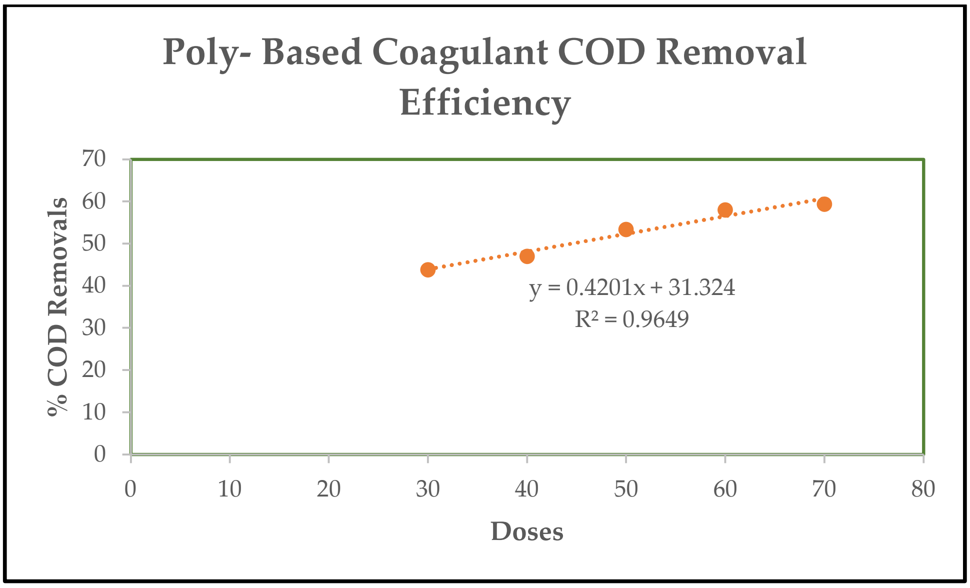

Figure 12. COD removal for Poly-based Dose.

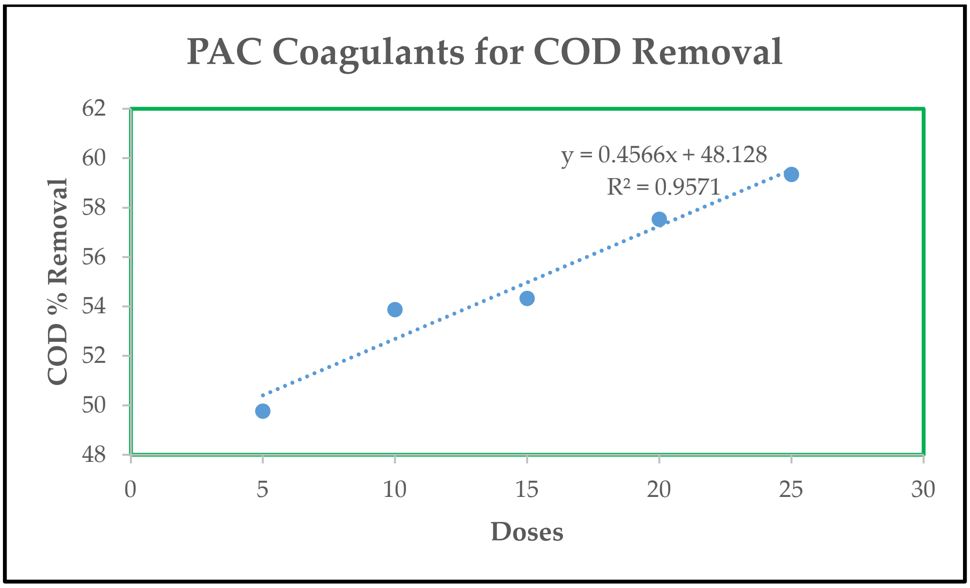

Figure 13. COD removal for PAC based dose, Varied Poly and constant ALUM bases.

Figure 13 presents the poly concentration that were varied at smaller quantities from 5, 10, 15, 20 and 25 ppm while the alum concentration was kept constant at 50 ppm. The turbidity was reduced quiet significantly on the wastewater, reducing to 7.2, which is 90.50% of the influent turbidity. These results shows the effect of polyamine concentration on turbidity removal. Addition of poly flocculent improved colour removal even when the alum dosage was 50 ppm (50% of alum-alone treatment). This part of the data showed a positive removal of significance of 0.9571 in terms of poly based coagulant against alum which as presented in **Figure 11,** gave a corellation factor of 0.9728. When using poly alone as a flucculant a strong removal efficiency was also achieved posing to be better than alum alone flocculant, as presented in **Figure 13**. A significance of 0.9649 was ascertained. From a scientific point of view, poly-based coagulant had a greater effect in terms of chemically treating the inorganic contents found in this complex brewery substrate. This insight can be confidently applied to all of the areas addressed above, [7, 13].

4. Conclusions and Recommendations

4.1. Conclusions

Previous studies indicate that the brewery effluent is high in organic matter, which is highly biodegradable. This is the type of wastewater that can be effectively treated by biological treatment system. This current study has shown that chemical coagulation on brewery wastewater using a Lab scale Flocculator, have impressive removal of COD, phosphorus, turbidity and TSS when aluminium based coagulant and poly are coagulants. The results indicated that the removal of COD, colour and turbidity could be successfully enhanced by adding a small amount of poly and 50% of alum-alone treatment. The beneficial effect of using an alum/poly system was evident. However, an overdose of alum can produce higher residual aluminium ion concentrations in the water. Recent studies have shown that a high aluminium ion concentration can cause fatal disease. Overall results of this article have indicated that chemical coagulation on brewery wastewater is pragmatic, effective and worth conducting.

4.2. Recommendations

- To achieve zero liquid effluent discharge and water reuse it is recommended to conduct a thorough study on post treatment.
- It is critical that the chemical industry shifts to green energy paradigms and wastewater treatment alternatives, viewing effluent as a commodity resource rather than a waste stream for bioenergy production, such as bioelectricity production in an MFC unit.

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Conflicts of Interest "The authors declare no conflict of interest."

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