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# Coagulation-Flocculation Treatment of Industrial Wastewater Using Tamarind Seed Powder

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**Abstract :** In this study, the effectiveness of tamarind seed powder as a coagulant for treating detergent wastewater using coagulation-flocculation process has been evaluated by varying pH, mixing time and coagulant dosage, which were the selected operating parameters for the treatment process. The coagulant was prepared by drying, crushing and grinding the tamarind seeds to form medium fine powder. A conventional jar test apparatus was used to carry out the coagulation-flocculation of the sample of wastewater using the tamarind seed powder. The optimum pH of the process was found to be 7.25 with turbidity and COD removal of 97.01% and24.86% respectively;the optimum mixing time was obtained to be 3 minutes of rapid mixing and 15 minutes of slow mixing with turbidity and COD removal of 97.78% and43.50% respectively while the optimum dosage was given to be 400 mg/L with turbidity and COD removal of 97.72% and 39.55% respectively. The kinetics of the coagulation-flocculation process was found to be obey the first order rate expression, the rate constant of which was estimated to be 0.044/min. The fitting of the rate equation to the kinetics data gave square of the correlation coefficient (R-squared) of 0.9983, which was an indication that the data was represented by the model very well. In conclusion, tamarind seed has been found to be effective in treating detergent industry wastewater. It is, therefore, recommended that local industries should consider using this material for wastewater treatment as an alternative to chemical coagulants because it is biological, cheap and readily available.

## 1.0 Introduction

Industrialization has led to pollution and consequently environmental degradation due to the release of pollutants to water bodies, land and/or air. One of these pollutant sources is industrial wastewater. Many industries consume fresh water and release wastewater as exhaust [1]. Wastewater is not just one of the main causes of irreversible damages to the environmental balances but also contributing to the depletion of fresh water reserves in this planet [2]. Wastewaters from industries differ very much in both flow and pollution strength. This makes it difficult to assign fixed values to their constituents. Generally, industrial wastewaterscontain suspended, colloidal and dissolved (mineral and organic) solids, may be either excessively acid or alkaline and may contain high or low concentrations of coloured matter. These wastes typically contain inert, organic or toxic materials and sometimes pathogenic bacteria. As a result of large quantities of water been used by industries, treatment and reuse of wastewaters, at least, to a level safe for disposal have become absolute necessity in order to avoid pollution of fresh water bodies [3].

Wastewaters from chemical industries are characterized by the presence of heavy metallic ions, chemical contaminant and turbidity. Exposure to lead (Pb), for example, is recognized as a major risk factor for several human diseases, and the structure of industrial ecological systems have made exposure to Pb unavoidable for most people alive today ([4],[5]). The removal of these toxic metals and contaminants from industrial wastewater is a matter of great interest in the field of water pollution, which is a serious cause of water degradation ([6],[7],[8])

A wide range of wastewater treatment techniques having some associated advantages and disadvantages are prevailing [2]. Most commonly wastewater treatments involve biological treatment such as nitrification, denitrification and phosphorus removal, physio-chemical treatment such as adsorption ([9], [10]), ion exchange [11], precipitation [12], reverse osmosis [13], coagulation, and electrocoagulation [14].

Coagulation-flocculation is a commonly used physico-chemical method in the treatment of metal bearing industrial wastewater because it removes colloidal particles, some soluble compounds and very fine solid suspensions initially present in the wastewater by destabilizing and formingflocs[15]. This process destabilizes the colloidal suspension of the particles with coagulants and then causes the particles to agglomerate with flocculants. After that, it accelerates separation and, thereby, clarifies the effluents [16]. Coagulation is normally accomplished through the use of chemicals known as coagulants. Coagulants used in wastewater treatment can be inorganic (such as aluminiumsulphate and polyaluminium chloride), synthetic organic polymers (for example polyacrylamide derivatives and polyethylenimine) or naturally occurring coagulants (such as chitosan and microbial coagulants). On the other hand, the process of forming large agglomerates of particles in suspension or of small agglomerates already formed as a result of coagulation through gentle stirring or agitation is called flocculation [17]. Coagulation-flocculation is a widely used method for wastewater treatment especially if the wastewater is discharged into surface water.

When surface water is used for drinking water production, turbidity removal is an essential part in the treatment process, and this is generally achieved by coagulation process with metal salts followed by aggregation of particles through flocculation and separation through sedimentation and filtration [18]. This treatment is very efficient in water treatment, and it has many factors that can influence its efficiency, such as the type and dosage of coagulant/flocculants, pH, mixing speed and retention time. The optimization of these factors greatly influences the process efficiency [19].

Considering the types of coagulants used for wastewater treatment, some of them are harmful to human body and are very costly [20]. To ease the problems associated with the chemical coagulants, several studies have pointed out the introduction of natural coagulants produced or extracted from microorganisms, animals, or plants [21].

Some researchers have demonstrated that the use of natural coagulants is a promising approach in industrial wastewater treatment. For instance, [22] used natural polymeric coagulant (chitosan) to treat chemical oxygen demand (COD) and colour in a soap and detergent industry wastewater. The results they obtained showed that chitosan was very effective in treating the wastewater. Also, they were able to achieve maximum COD and colour reductions of 83% and 90% respectively.[23] investigated the effectiveness of four different natural coagulants, namely*T.foenum-graecum*, *Moringa oleifera*, *Cicer arietinum* and *Dolichos lablab* to remove COD and turbidity from industrial dairy wastewater. At the optimum dosage and pH, the turbidity removal efficiencies of *M.oleifera*, *Dolichos lablab*, *T.foenum-graecum* and *Cicer arietinum* were obtained to be 61.60%, 71.74%, 58.20% and 78.33% while COD reduction efficiencies of these coagulants were estimated to be 65.0%, 75%, 62.5% and 83%, respectively. Based on the results obtained from the work, it was concluded that, among the coagulants considered in the work, *Cicer* arietinum was the most effective in treating dairy wastewater. [24]studiedthe coagulation efficiency of common bean extract in treatment of different distillery wastewaters and found that the best achieved efficiencies of organic matter removal were 68.8% for juice extraction wastewater at pH of 8.50 with coagulant dose of 5 ml/l, and 60% for molasses wastewater at the original pH of this stillage (5.40) with the same dose. They concluded that natural coagulants extracted from common bean could be used successfully for organic matter removal from extraction juice wastewater and molasses wastewater instead ofcentrifugation. Also, [25] used *Cicerarietinum*, *Moringa oleifera*, and Cactus to treat turbidity and COD in tannery wastewater by varying dosage of these coagulants and pH. They discovered that 0.1 g/500 ml *Cicer arietinum***,** 0.3 g/500 ml *Moringa oleifera* and0.2 g/500 ml Cactus and pH of 5.5, 4.5 and 5.5 respectively were theoptimum parameters for the wastewater treatment. Their results also indicated that all the three coagulants investigated were promising in treating the pollutants since the turbidity reduction efficiencies for all of them were observed to fall within the range of 78-82% while that of COD was in the range of 75-90%. However, *Cicer arietinum* was found to be the most effective in treating tannery wastewater with maximum turbidity and COD removal of 81.02 and 90%, respectively.[26] investigated the efficiency of using tapioca starch as coagulant in the treatment of semiconductor wastewater by varying the dosage of the coagulant and retention time, and they observed that variation of tapioca starch dosage highly influenced the COD and turbidity removal. The results obtained in their work further revealed that the optimum turbidity reduction was 99% at a settling time of 30 min with dosage of 0.1 g/L and that of COD was achieved to be 87% after 60 min of retention time and 0.1 g/L of dosage. They also discovered that high coagulant dosages between 0.8-1.0 g/L reduced the total suspended solids (TSS) concentration from 188 to 10.9 mg/L at retention time between 50 to 60 minutes. From the literature review carried out, to the best of our knowledge, no researcher has used tamarind seed to produce a coagulant that can treat wastewater from a detergent industry.

Therefore, the aim of this study is to study the effectiveness of tamarind seed powder as coagulant for treating wastewater from a detergent industryby analysing the level of contamination of wastewater from the detergent industry, treating the wastewater using tamarind seed as coagulant, determining the optimum values of pH, mixing time and coagulant dose for reduction of turbidity and chemical oxygen demand (COD) to the minimum allowable values.

## 2.0 Methodology

The methods employed in investigating the effectiveness of tamarind seed powder as a natural coagulant in the treatment of the wastewater obtained from a detergent industry are as outlined thus.

### 2.1 Sample Collection/Characterisation

The sample of detergent wastewater used in this work was collected from a detergent company. After the sample was collected, it was analysed to determine some of its characteristics. Its turbidity was measured using turbidity meter, in which the sample was fed into a sample cell and put into the cell holder for measurement. The pH of the wastewater was measured with the aid of a digital pH meter. Its chemical oxygen demand (COD) was measured using the potassium permanganate consumption method. In this method, 100ml of the wastewater sample was put into a conical flask, 5ml of sulphuric acid was added, covered and boiled for 5 min. While boiling the mixture, 20ml of potassium permanganate ($KMnO_4$) solution was added from a pipette. The solution was allowed to simmer for 10min and, then, 20ml of oxalic acid was added and the entire mixture was heated until the colour completely disappeared. The temperature of the mixture was allowed to drop to about 80°C before titrating it against $KMnO_4$ solution until pink colour appeared and was persistent for at least 30 sec. A blank with 100ml of dilution water was analysed in parallel. The total consumption of $KMnO_4$ was calculated using the expression given in Equation (1).

$$Total\ KMnO_4\ Consumption = \frac{(A-B)\times F\times 316\ mg}{V} \quad (1)$$

where A is the $KMnO_4$ consumption by sample (ml), Bis the $KMnO_4$ consumption by blank (ml), Fis the titration factor of the $KMnO_4$ and V is the volume of sample used(ml).

### 2.2 Collection and Preparation of Tamarind Seed Powder

Tamarind seeds were collected from a tamarind tree available at staff quarters of Abubakar Tafawa Balewa University, Bauchi, Nigeria. The tamarind seeds were soaked for about 24 hr before they were washed to separate the seeds from the pulp and rewashed to remove adhering pulps. The seeds were dried under atmospheric temperature first and, then, insidean oven for about eight (8) hours at 50 °C. This was carried out thus so as to make the tamarind seeds easy to been crushed. The crushing of the seeds was carried out for size reduction using mortar and pestle. The crushed seeds were groundusing a blender to produce the tamarind seed powder that was sieved to form medium fine powder used as the coagulant.

### 2.3 Jar Test Experimental Procedure

The coagulation-flocculation test of this work was carried out using jar test experimental method, which is the most widely used experimental methods for coagulation-flocculation. The method was accomplished using the setup shown in Figure 1.The experiments were carried out in three parts, viz. coagulation at varying pH, coagulation at varying time and coagulation at varying dosage. Six jars that were filled to 500 ml marked were used for each part of the experiments. pH adjustment was achieved by addition of 2 M sulphuric acid and 2 M potassium hydroxide.

For the first part, coagulation was carried out at varying pH. In this case,the pH was varied within 2-8 at interval of 1.5 with the sixth jar coagulated at the initial pH of the sample (pH unadjusted) while the other variables were fixed. Constant mixing speed of 140 rpm was applied for 3 minutes in order to have rapid mixing and 40 rpm for 7 minutes was applied for slow mixing. A constant dosage of 400 mg/L of the coagulant was also used. The pH that gave the best turbidity removal efficiency andchemical oxygen demand (COD) removal was taken as the optimum one.

For the second part, the pH of the samples was adjusted to the optimum pH as determined from the experiment carried out at varying pHs.pH and coagulant dosage were kept constant at 7.25 and 400 mg/L respectively and the mixing time was varied. The rapid mixing speed of 140 rpm for 3 minutes were used for all the jars and slow mixing of 40 rpm was used at time intervals of 0, 5, 10, 15, 20 and 25 minutesin order to determine the optimum mixing time that would give the best turbidity removal efficiency and COD removal.

For the third part of the experiments, constant pH of 7.25 and mixing time of 140 rpm for 3 minutes and 40 rpm for 15 minutes were used while the coagulant dosage was varied from 100 to 3800 mg/L. The dosage that gave best turbidity removal efficiency and COD removal was taken as the optimum one in this case also.


**Figure 1:Jar test experimental setup**

## 3.0 Results and Discussion

### 3.1 Wastewater Characteristics

The results obtained from the analysis of the wastewater collected from the detergent industry were as given in Table 1.

**Table 1: Characteristics of wastewater obtained from the detergent industry**

| S/N | Parameter | Value |
|---|---|---|
| 1. | Turbidity (NTU) | 1670 |
| 2. | Initial pH | 12.68 |
| 3. | COD (mg/L) | 1118.64 |

As can be seen from the results given in Table 1, the values of the characteristics of the wastewater were found to be higherthan the acceptable limit of the water that could be discharged into a river directly without treating. For instance, the pH of the water was found to be far from neutral, as can be noticed from the table. So, the need for the treatment of the wastewater was very obvious.

### 3.2Coagulation-Flocculation byVarying pH

The results obtained for coagulation-flocculationcarried out at various pH values with constant mixing time and dosage aregiven in Figures 2 and 3. The constant values used for mixing speed were 140 rpm for 3 minutes and 40 rpm for 7 minutes while that of the dosage was 400mg/L. From Figures 2 and 3that are showing the effect of pH on turbidity and COD removal when the coagulant dosage and the mixing speed were kept constant, it was observed that turbidity removal and COD removal were changing as the pH of the wastewater was also changing. The pH that gave the highest turbidity removal was found to be 7.25. The results obtained in this case was found to be in line with the literature because [27]found an optimum pH of 8 for turbidity removal when wastewater from a textile industry was treated using tamarind seed powder as coagulantat constant dosage of 150 mg/L and mixing time of 100 rpm for 1 – 2 min rapid mixing and 30 – 40 rpm for 20 min for slow mixing.

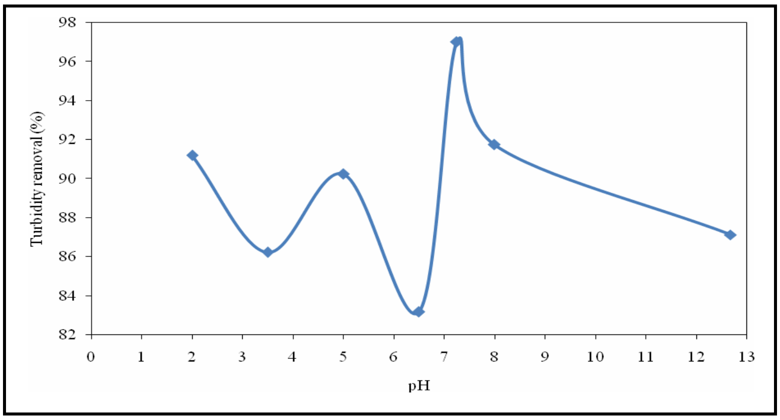


**Figure 2: Turbidity removal by varying pH with constant coagulant dosage and mixing time**

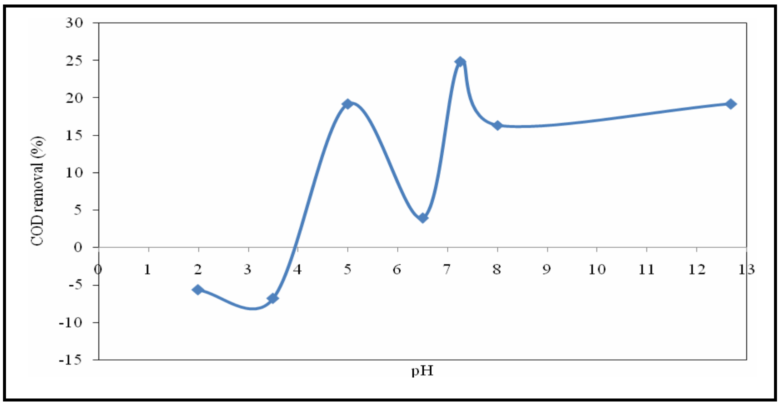


**Figure 3: COD removal by varying pH with constant coagulant dosage and mixing time**

### 3.3 Coagulation-Flocculation byVarying Time

The turbidity removal of the coagulant was also observed by varying mixing time,and the results obtained were as shown in Figure 4. In this case, the pH and the coagulant dosage were kept constant at 7.25 and 400 mg/L, respectively. From the figure, the turbidity removal was observed to increase as the mixing time was increasingup to 15 minutes after which it dropped, though it rose again later. The highest turbidity removal of approximately 98% was observed to occur when the mixing time were 15 and 25 min.

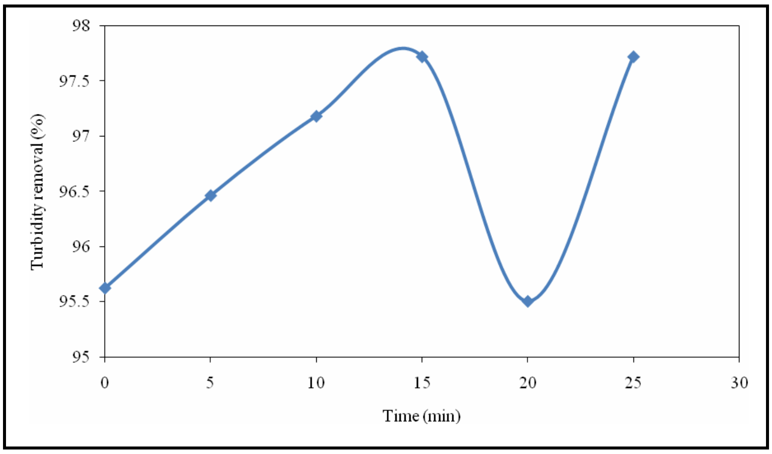


**Figure 4: Turbidity removal by varying mixing time with constant pH and dosage**

Figure 5 shows the COD removal that was observed when the mixing time was varied. Based on the figure, the COD removal was observed to be increasing and decreasing as the mixing time was increasing, but the best COD removal was observed when the mixing time was 15 minutes.

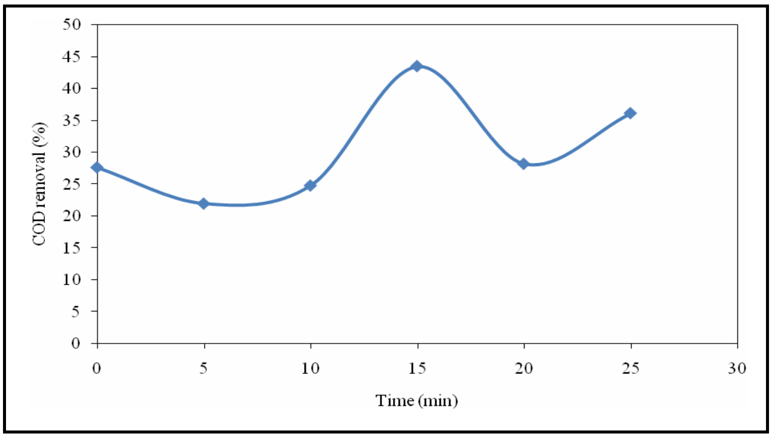


**Figure 5: COD removal by varying time with constant pH and coagulant dosage**

### 3.4 Coagulation-Flocculation byVarying Coagulant Dosage

Shown in Figures 6 and 7 are the results obtained when the dosage of the tamarind coagulant used in this work was varied while keeping pH constant at 7.25 and fixing the mixing time at 140 rpm for 3 minutes and 40 rpm for 15 minutes.

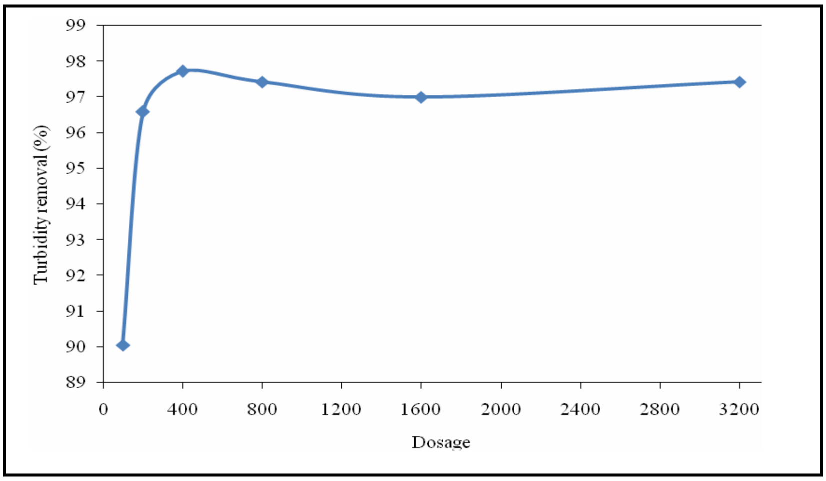


**Figure 6: Turbidity removal byvarying coagulant dosage with constant pH and time**

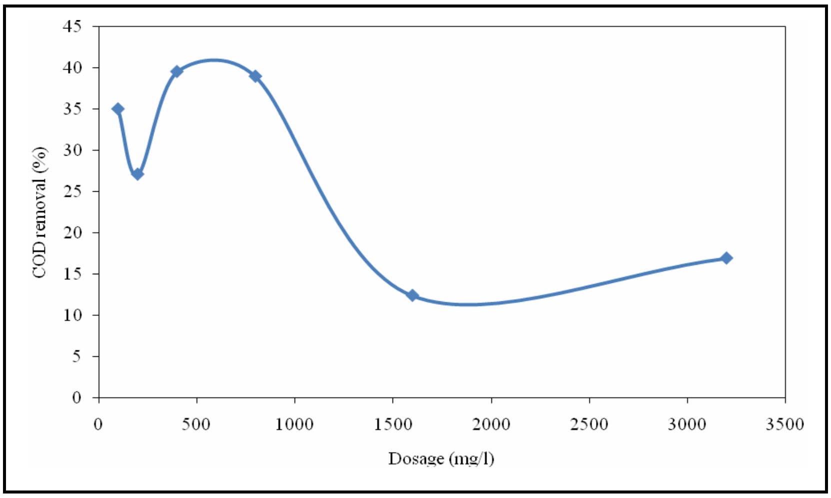


**Figure 7: COD removal by varying coagulant dosage with constant pH and time**

From the information acquired from Figure 6, it was discovered that the turbidity removal was increasing as the coagulant dosage was increased from 100 to 400mg/L and, then, decreased as the dosage was increased from 400 mg/L to 1600 mg/L. It was also observed that the turbidity removal later increased up till when the dosage was 3200 mg/L. From the experiment carried out, the highest turbidity removal was given when the dosage of the coagulant was 400 mg/L.

According to Figure 7 showing the variation of COD removal as the coagulant dosage was varied, it was observed that the highest COD removal occurred when the dosage was 400 mg/L, but the general trend of the curve given in Figure 7 was observed to have both local and global minimum and maximum.

### 3.5 Kinetics of coagulation-flocculation process

The curve obtained from the kinetics study of the coagulation-flocculationprocess carried out on the detergent industry wastewater using tamarind seed powder as the coagulant was as shown in Figure 8.

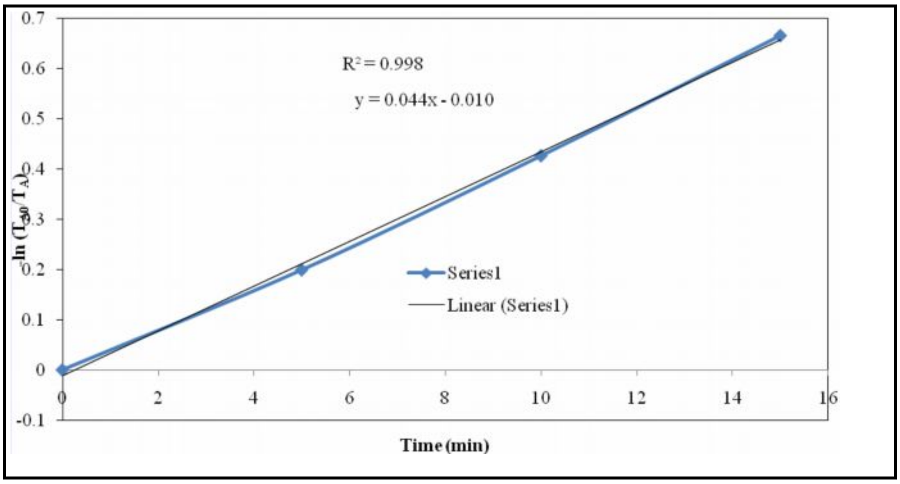


**Figure 8: First order plot of** $\ln T_A / T_{A0}$ **against** $t$

From the figure, it was observed that a first order plot of turbidity against time, that is, $ln\left(T_A / T_{A0}\right)$ versus $t$, was a straight line graph, which affirmed the linearization that had been carried out on the data used to obtain the plot. Also noticed from the plot was that the process rate constant, $k$, was estimated to be 0.044/min. As such, the rate expression of the first order process was given to be:

$$-r_A = 0.044\,T_A \left( NTU / min \right)$$

The analysis carried out on the plot given in Figure 8 revealed that the fit (model) had a high R-squared value of 0.9983, which was found to be very close to unity, inferring that the reaction data was able to be well fitted into the first order kinetic model selected.

## 4.0 Conclusion

The observations made from this research work showed that tamarind seed was effective in the coagulation-flocculation treatment of the wastewater obtained from the detergent industry considered because significant reduction in its turbidity and chemical oxygen demand were achieved. Also, the factors investigated such as pH, mixing time and coagulant dosage were found to have effectson the process (coagulation-flocculation) and, hence, the wastewater treatment.The optimum pH was obtained in this work to be 7.25. At constant pH and dosage, the turbidity and COD removal efficiency were found to increase as mixing time was increasing. The optimum mixing time was found to be 3 min of rapid mixing and 15 min of slow mixing for coagulation-flocculation at optimum pH of 7.25. Also, at constant pH and time, the increase in coagulant dosage was observed to cause increasein the turbidity and COD removal efficiency. The optimum dosage was obtained to be 400 mg/L for coagulation at optimum pH of 7.25 and mixing speed of 3 minutes of rapid mixing and 15 minutes of slow mixing. Therefore, the optimum pH, mixing time and coagulant dosage for the treatment of the detergent wastewater have been obtained to be 7.25, 140 rpm for 3 min and 40 rpm for 15 min and 400 mg/L, respectively. Furthermore, the kinetics study of the coagulation process revealed that it could be governed by a first order rate equation, which was found to fit the data very well because the calculated square of the correlation coefficient (R-squared) was 0.9983.

### Nomenclature

| | |
|---|---|
| COD | Chemical oxygen demand |
| $T_A$ | Turbidity at time t |
| $T_{A0}$ | Initial turbidity |
| TSS | Total suspended solid |

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