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Performance optimization of coagulant/flocculant in the treatment of wastewater from a beverage industry

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Abstract

This study investigated the effect of coagulation/flocculation treatment process on wastewater of Fumman Beverage Industry, Ibadan, Nigeria. The study also compared different dosages of coagulant, polyelectrolyte (non-ionic polyacrylamide) and different pH values of the coagulation processes. The effect of different dosages of polyelectrolyte in combination with coagulant was also studied. The results reveal that low pH values (3–8), enhance removal efficiency of the contaminants. Percentage removal of 78, 74 and 75 of COD, TSS and TP, respectively, were achieved by the addition of 500 mg/L $Fe_2(SO_4)_3 \cdot 3H_2O$ and 93, 94 and 96% removal of COD, TSS and TP, respectively, were achieved with the addition of 25 mg/L polyelectrolyte to the coagulation process. The volume of sludge produced, when coagulant was used solely, was higher compared to the use of polyelectrolyte combined with $Fe_2(SO_4)_3 \cdot 3H_2O$. This may be as a result of non-ionic nature of the polyelectrolyte; hence, it does not chemically react with solids of the wastewater. Coagulation/flocculation may be useful as a pre-treatment process for beverage industrial wastewater prior to biological treatment.

Keywords: Coagulation; Polyelectrolyte; Beverage wastewater; pH control; Sludge

1. Introduction

There are little or no stringent laws guiding environmental pollution in Nigeria, hence, many industries discharge untreated or inadequately treated wastewater into water ways.

The global demand for abatement of environmental pollution calls for methods of treatment, which is dynamic in approach and complete in practice such that the various waste products of our modern technology can be adequately treated for safe discharge into the environment.

In beverage industrial wastewater, coagulation/flocculation process may be used as a pre-treatment prior to biological treatment in order to enhance biodegradability of the wastewater during the biological treatment.

Some of the raw materials (e.g. agricultural products, sugar and phosphates) that are used for production of the beverages may enhance the organic load of the wastewater. An essential feature of wastewater flocculation is the elimination of suspended solids (SS) and as much of the organic material as possible [1].

Coagulation/flocculation is an essential process in water and in industrial wastewater treatment [2–4]. Several studies have been reported on the examination of this process for the treatment of industrial wastewater, especially with respect to performance optimization of coagulants, determination of experimental conditions, assessment of pH and investigation of flocculant addition [4,5]. Coagulation/flocculation process has been found to be cost effective, easy to operate and energy saving treatment alternatives [6]. Coagulant dosages vary in a wide range aiming at maximum removal efficiency of pollutants using minimum doses at optimum pH [7,8].

$Fe_2(SO_4)_3 \cdot 3H_2O$ is a widely used coagulant. It has been used for the treatment of wastewater of industry that is concerned with the production of potato chips [3] and food processing industry [9].

Although several studies have been conducted, in the developed countries, into the treatment of water and wastewater through granular activated carbons [10,11], adsorbent [12,13],

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Fenton's reagent [14], wet oxidation [15], coagulation–electro-oxidation [16] and advanced oxidation with biological oxidation [17], developing countries still lack basic technology of water and wastewater treatment.

The objectives of this study were to simulate a coagulation/flocculation process efficiency for beverage industrial wastewater treatment plant with respect to removal of COD, TSS and TP, also, to investigate optimum coagulant dosages, pH values and effect of combination of coagulant and polyelectrolyte on the removal of COD, TSS and TP from beverage industrial wastewater.

2. Materials and methods

Samples of the wastewater were collected three times weekly for 9 months between 9.00 and 3.00 p.m. of each sampling day from pipe conveying all the wastewater out of Fumman Agricultural Products factory that produces juice drink from all sorts of agricultural products (e.g. orange, grape and guava). Each time a sample was collected, the rate of flow was determined with the aid of a flow-meter. Samples were collected every hour between 9.00 and 3.00 p.m. to make six samples at the end of each day of sampling; a composite sample was generated by adding together volumes of samples proportional to their rates of flow. The estimated annual outputs of the factory at the time of sampling were 7.73 × 108 kg (773,000 t). The average volumes of wastewaters generated daily from the factory were 320×10^4 L. The composition of the beverage wastewater is given in Table 1.

2.1. Sample analyses

Each time a sample was collected, the temperature, pH and dissolved oxygen (D.O.) were determined, at the spot of sampling with a good grade celsius thermometer (Zeal, England), portable pH meter and portable D.O. meter (Model 9071 D. O_2 meter, Phillips, England), respectively.

2.2. Experimental

(1) The 100, 250, 500, 750, 800 or 1000 mg $Fe_2(SO_4)_3{\cdot}3H_2O$ was added to 1 L wastewater sample. After rapid mixing for 2 min at 200 rpm and slow mixing for 30 min, the liquid was clarified for 1 h, then, the supernatant was withdrawn from a point located about 2 cm below the top of the liquid level of the beaker to determine the COD, SS and TP by using standard methods [18], so that the effect of coagulant dose could be studied. The raw and treated samples have been repeatedly analyzed in order to validate/evaluate the produced results and the analytical errors were less than ±5%. All chemicals used for the analytical determinations were of analytical grade.

(2) The pH value of 1 L wastewater sample was adjusted to a pH 3–8, respectively, by using 1.0 M H_2SO_4 or 1.0 M NaOH, before addition of 500 mg/L $Fe_2(SO_4)_3{\cdot}3H_2O$ to the sample. After stirring and clarifying, as in (1) above, the supernatant was withdrawn as in (1) above to determine the COD, SS and TP, so that the effect of pH on coagulation could be studied.

(3) The pH value of 1 L wastewater sample was adjusted to 3–8, respectively, by using 1.0 M H_2SO_4 or 1.0 M NaOH and 500 mg/L $Fe_2(SO_4)_3{\cdot}3H_2O$ was added. After rapid mixing for 2 min at 200 rpm. The 5, 25, 45, 65, 85 or 100 mg/L polyelectrolyte were added and the liquid was mixed slowly for 30 min at 60 rpm, the supernatant was withdrawn as in (1 and 2) above to determine the optimum polyelectrolyte that enhances coagulation. The pH was again measured after the optimal polyelectrolyte dose had been determined. After withdrawal of supernatant, the volume of wet sludge produced was determined from the sludge level on the bottom of the jar-test beakers.

Table 1
Characteristics of beverage industry wastewater

Parameter	No. of samples	Mean	Minimum	Maximum
pH	80	7.24	7.02	7.66
TSS (mg/L)	40	1620	367	2940
Conductivity ($\mu S\ cm^{-1}$)	40	2995	1460	3740
Alkalinity ((mg $CaCO_3$)/L)	40	371	270	465
COD (mg/L)	40	1750	620	3470
BOD_5 (mg/L)	40	894	728	1745
Total phosphorus ((mg P)/L)	40	89.5	62.4	100.2
Orthophosphate ((mg P)/L)	40	41.2	25.5	70.6
Nitrate-nitrogen ((mg N)/L)	40	28.4	8.3	62.5

BOD_5: Biochemical oxygen demand at 5 days.

3. Results and discussion

3.1. Effects of coagulant dose on coagulation

The effect of different doses of $Fe_2(SO_4)_3{\cdot}3H_2O$ on the removal of COD, SS and TP by coagulation is shown in Fig. 1. The removal of COD, SS and TP increased with increasing concentration of $Fe_2(SO_4)_3{\cdot}3H_2O$. It is clear that the removal of COD and SS increased slowly, when the concentration of $Fe_2(SO_4)_3{\cdot}3H_2O$ exceeded 500 mg/L. However, SS removal capacity increases in a diminishing fashion with increasing dose of $Fe_2(SO_4)_3{\cdot}3H_2O$ above 750 mg/L, this may be as a result

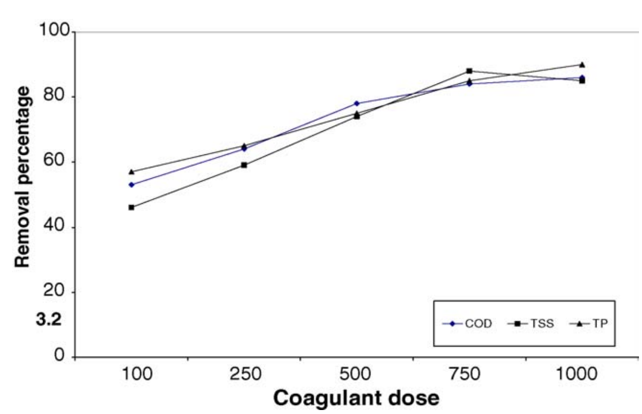

Fig. 1. The effect of coagulant doses on the removal of COD, TSS and TP from the wastewaater.

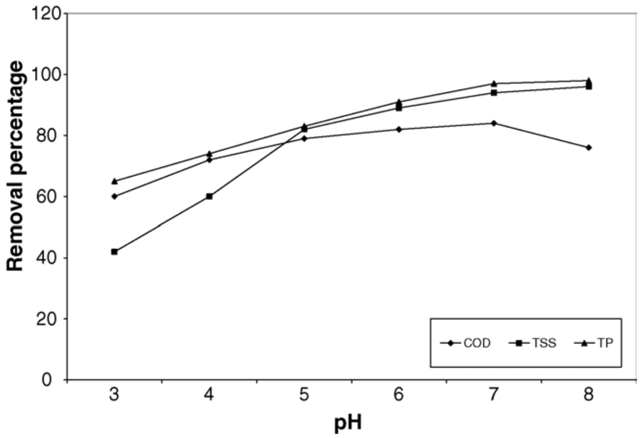

Fig. 2. The effect of pH values on the removal of COD, TSS and TP from wastewater.

of re-suspension of solids at this concentration [3], again, the high concentrations (>750 mg/L) of the coagulant confer positive charges on the particle surface (a positive zeta potential), thus, re-dispersing the particles [19].

3.2. *Effects of pH on coagulation*

The effect of pH values on the removal of COD, SS and TP by coagulation is shown in Fig. 2. It can be seen that the optimum range of pH is between 3 and 8, increasing pH markedly deteriorates the quality of the wastewater. In the pH range 3–8, the contaminants decreased as pH increases. If the pH is too low, less than three hydrogen ions compete with ($Fe_2(SO_4)_3{\cdot}3H_2O$ for COD, SS and TP, resulting in poor removals of the contaminants. On the other hand, higher pH values (greater than 8), may produce negatively charged organic contaminants on which adsorption will be electro-statically hindered [1]. In the present work, it is recommended that pH value of 7 is the best, when using $Fe_2(SO4)_3{\cdot}3H_2O$ in coagulation process.

3.3. *Effect of polyelectrolyte dose on the removal efficiency*

The removal efficiencies of COD, TSS and TP using different doses of polyelectrolyte are shown in Fig. 3. The dose of polyelectrolyte was varied from 0 to 100 mg/L. The removal of COD, TSS and TP increased with increasing dose of polyelectrolyte.

3.4. *Effect of polyelectrolyte on $Fe_2(SO_4)_3{\cdot}3H_2O$*

The experiments were carried out with a fixed dose of coagulant (500 mg/L), whereas the dose of polyelectrolyte was varied from 0 to 100 mg/L to determine the optimal dose of the polyelectrolyte that will enhance coagulation with respect to the removal of COD, TSS and TP in the wastewater. Table 2 shows the removal efficiency of COD, TSS and TP using 500 mg/L $Fe_2(SO_4)_3{\cdot}3H_2O$ and different doses of polyelectrolyte (non-ionic polyacrylamide). The optimum dose of the polyelectrolyte that was combined with coagulant, which caused substantial removal of the contaminants, was found to be 25 mg/L.

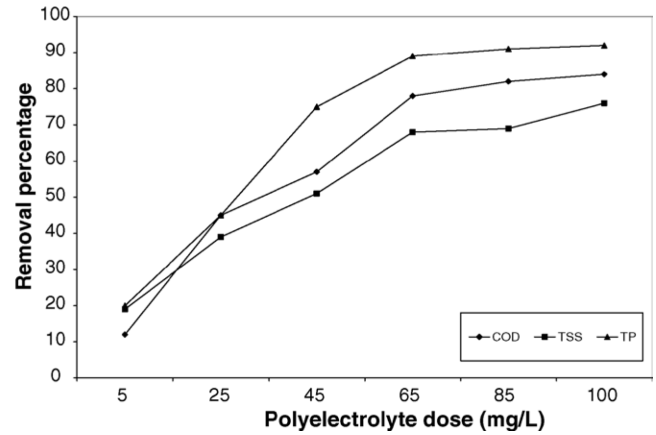

Fig. 3. The effect of polyelectrolyte dose on the removal of COD, TSS and TP from wastewater.

Table 2
The effect of combination of polyelectrolyte and $Fe_2(SO_4)_3{\cdot}3H_2O$ on the removal of COD, TSS and TP from the wastewater

	%	Dose of polyelectrolyte (mg/L)					
		5	25	45	65	85	100
$Fe_2SO_4{\cdot}3H_2O$ (500 mg/L)	COD	90	93	93	92	89	84
	TSS	85	94	92	92	90	88
	TP	92	96	95	95	94	93

Prior to the addition of the polyelectrolyte, experiments were carried out with the pre-determined pH (pH 7) that enhances contaminant removal. pH was measured again after determination of optimal polyelectrolyte dose and the pH was found not to be below 6.90 ± 1%. This shows that addition of the polyelectrolyte has little or no influence on the pH. The polyelectrolyte was reported [19] not to affect pH of the wastewater system and generally do not require pH adjustment for effective use [18].

3.5. *Sludge formation*

The amount and the characteristics of the sludge produced during the coagulation/flocculation process are highly depended on the specific coagulant used and on the operating conditions [4]. In this study, the sludge volume was estimated from the wet sludge volumes remained on the bottom of the jar-test beakers.

The combined use of coagulant and polyelectrolyte resulted in production of relatively low sludge volume with reduction of over 50% of the amount produced, when only coagulant was used for treatment.

4. Conclusions

(1) Coagulation process using 500 mg/L $Fe_2(SO_4)_3{\cdot}3H_2O$ efficiently reduced COD, TSS and TP by 78, 74 and 75%, respectively. Increasing the coagulant concentration above 500 mg/L increased the removal efficiency of the contaminants, however, COD and TSS removal increased slowly, when the coagulant dosage was above 500 mg/L.

(2) TSS removal efficiency decreases on addition of $Fe_2(SO_4)_3{\cdot}3H_2O$ above 750 mg/L, this was as a result of re-suspension of solids at this concentration. Also, the high concentration (>750 mg/L) of $Fe_2(SO_4)_3{\cdot}3H_2O$ can confer positive charges on the particles surface (a positive zeta potential), thus, re-dispersing the particles.
(3) Coagulation was enhanced at pH range 3–8, below which hydrogen ions compete with $Fe_2(SO_4)_3{\cdot}3H_2O$ for COD, TSS and TP, resulting in poor removals of the contaminants and above which there can be production of negatively charged organic contaminants on which adsorption is electrostatically hindered.
(4) Results of the present work indicated that the addition of 25 mg/L polyelectrolyte to the coagulation process enhances the reduction of COD, TSS and TP by 93, 94 and 96%, respectively.
(5) The combined use of coagulant and polyelectrolyte resulted in production low sludge volume with reduction of over 50% of the amount produced, when only coagulant was used for treatment.

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