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The removal of phosphates from laundry wastewater using alum and ferrous sulphate as coagulants

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ABSTRACT: Phosphates are derived from a wide variety of sources including the atmosphere, agriculture, urban drainage domestic and industrial wastewater. Domestic and industrial wastewater such as from laundry and dry cleaning services release high concentration of phosphates through detergents used into the land and water environment. This work was aimed at studying the removal of phosphates from laundry wastewater using alum and ferrous sulphate as coagulants for treatment. Samples of wastewater were collected from two laundry companies in Lagos State, Nigeria. The physicochemical parameters measured were pH, total dissolved solids, total solids, total suspended solids, biochemical oxygen demand (BOD), chemical oxygen demand (COD), COD: BOD and phosphate removal. Using ferrous sulphate and aluminium sulphate as coagulants, the phosphates were precipitated from the waste water samples. The results obtained from locations A and B were pH (9.10 and 10.20), total solids (800.00 and 900.00 mg/l), total suspended solids (200 and 400 mg/l), total dissolved solids (600 and 500 mg/l), biochemical oxygen demand (276.70 and 134.00 mg/l), chemical oxygen demand (716.00 and 664.00 mg/l) and phosphate removal (26.0 and 30.0%) respectively. These results were compared with the Federal Environmental Protection Agency limits (FEPA, Nigeria) and found to be higher than the recommended standards. Thus, these results suggested adverse effects on the environment and impairment of the health of aquatic life where such waste water is being discharged. In conclusion, the use of alum in phosphates removal from laundry wastewater provided better results than ferrous sulphate.

KEYWORDS: Phosphate removal, detergent, laundry wastewater, coagulants, eutrophication.

1 INTRODUCTION

Industrialization is of special significance to a nation for socio-economic reasons such as improving the quality of life and general living standard of the population, provision of employment and infrastructural development [1]. However, industrialization is associated with pollution (water, land and air), environmental degradation, depletion of resources and threat to human health due to exposure to hazardous substances from industrial effluents and erosion [2]. Human beings have affected water quality over the years in many ways such as sewage disposal, toxic contamination through heavy metals and pesticides, run-off from agriculture and urbanization [2]. Municipal wastewater consists of wastewater from homes, commercial establishments and surface or ground water that enters the sewage system [3]. Phosphorus is introduced into the aquatic environment in different chemical forms and the most frequent soluble forms of phosphorus are orthophosphate (H_2PO_4 and HPO_4^{2-}), metaphosphate (or polyphosphate) and organically bound phosphate [4]. Phosphate is a common constituent of agricultural fertilizers, manure, organic wastes in sewage and industrial effluents. Phosphorus is an essential element for plant life but when in excess in water, it can speed up eutrophication (i.e. a reduction in dissolved oxygen in water bodies caused by an increase of mineral and organic nutrients) of rivers and lakes [5]. The increased load of phosphates in the environment as a result of human activities has been a matter of concern for more than four decades [18] but the primary issue has been to what extent additional phosphorus has contributed to the eutrophication of lakes, ponds and other bodies of water. Chemical treatments through the addition of alum or lime to precipitate out phosphates in wastewater have proved to be effective in removing about 95% of phosphates originally present in wastewater [7]. In Nigeria, there is an urgent need to provide simple method of phosphate reduction in domestic and industrial effluents in order to conform to acceptable standards before disposal into water bodies. Therefore, this work was carried out to study the removal of phosphates from laundry wastewater using alum and ferrous sulphate as coagulants.

2 SAMPLE COLLECTION

Two wastewater samples (containing detergents) from two laundry companies in Surulere and Ikotun, Lagos state, Nigeria were collected, analyzed and treated. The samples were collected in water-washed and labelled plastic containers. Physicochemical parameters such as pH, total dissolved solids (TDS), total solids (TS), total suspended solids (TSS), biochemical oxygen demand (BOD), chemical oxygen demand (COD) and phosphate removal were determined from the waste water samples and recorded. A portion of the sample meant for biochemical oxygen demand (BOD), chemical oxygen demand (COD) and phosphate removal were analyzed within 3 hours of collection while the remaining samples were refrigerated at 4°C. The pH was determined using a Mettler-Toledo pH meter. The electrode was rinsed with the samples, immersed and pH value displayed was recorded. Total solids, total suspended solids and total dissolved solids were determined using oven-drying and gravimetry methods. Biochemical oxygen demand (BOD) was determined by iodometric titration. Chemical oxygen demand (COD) was determined by chemical oxidation. Phosphate removal was determined by ascorbic acid-molybdate method after pre-treatment processes (turbidity removal, pH adjustment and phosphorus precipitation) were initially carried out.

3 RESULTS AND DISCUSSION

3.1 PHYSICOCHEMICAL PARAMETERS OF THE WASTE WATER SAMPLES

The physicochemical parameters of the wastewater samples are presented on Table 1. The pH values obtained for samples A and B were 10.20 and 9.10 respectively. Both samples were alkaline. The pH value obtained for sample B was found to be within the stipulated Reference [8] allowable limit of 5.50-9.50 while the pH value of sample A was found to be above the allowable limit for wastewater before being discharged into surface water. pH values less than 7 is acidic and highly detrimental to aquatic macro-invertebrates and fishes. pH is among the physicochemical factors influencing the growth of bacteria in waste stabilization ponds [9]. Also, pH value is also an important factor for efficient removal of phosphorus using alum or other salts, as the solubility of their precipitates varies with pH. For alum, minimal solubility occurs in the pH range of 5.0 to 7.0 and for ferric in the range of 6.5 to 7.5 [10]. The optimum pH for phosphorus removal using alum ranges from 5.5 to 6.5, but in typical wastewater, it ranges from 6.0 to 9.0. Ferric chloride is more effective in removing phosphorus when the pH ranges from 4.5 to 5.0 with typical values of 7.0 to 9.0. The total suspended solids (TSS) values obtained for samples A and B were 200 mg/l and 400 mg/l respectively. The total suspended solids values obtained were very high and this revealed that there were suspended particles in the water samples analyzed which invariably decreased the transparency and showed that the samples were highly polluted. The total suspended solids values for both analyzed samples were higher than the Reference [8] allowable limit of 15 mg/l for wastewater. The results obtained were in line with the work of Reference [11]. High level of dissolved and suspended solids in the water system increases biological and chemical oxygen demand which depletes the dissolved oxygen levels in the aquatic systems [12;13]. Sample A had a biochemical oxygen demand (BOD) value of 276.70 mg/l and chemical oxygen demand (COD) value of 716.00 mg/l while sample B had a BOD value of 134.00 mg/l and COD value of 664.00 mg/l. The BOD and COD values obtained on analysis of the wastewater samples were found to be higher than the Reference [8] limit (BOD = 50.00 mg/l and COD = 250.00 mg/l) for wastewater before discharge into surface water. According to Reference [14], these levels of BOD and COD could constitute potential pollution problems to the water bodies since they contain organic compounds that will require a larger quantity of oxygen for degradation. The COD: BOD ratio for the samples under consideration were found to be less than 10.00 mg/l and indicated that the compounds in the analyzed samples were relatively degradable, a possible depletion of the dissolved oxygen in the receiving river and possess a potential effect on aquatic life. Thus, the BOD correlated positively with the COD for both samples (correlation coefficient, r = 0.7896). For correlation coefficient near zero, there is no linear correlation between the variables. Correlation measures the goodness of fit of the equation actually assumed to the data [15]

Table 1. Physicochemical parameters of the waste water samples

Samples	pH	TDS (mg/l)	TS (mg/l)	TSS (mg/l)	BOD (mg/l)	COD (mg/l)	COD/BOD	% P removal
A	10.20	600.00	800.00	200.00	276.70	716.00	2.60	26.0
B	9.10	500.00	900.00	400.00	134.00	664.00	5.00	30.0
FEPA limit	5.50-9.50	NS	NS	15.00	50.00	250.00		5.00

TDS- Total Dissolved Solids, TS-Total Solids, TSS-Total Suspended Solids, BOD- Biochemical Oxygen Demand, COD- Chemical Oxygen Demand, P- Phosphorus, NS-Not Stipulated

3.2 COAGULANTS AND PHOSPHORUS REMOVAL

The relationships between the amount of coagulant and the percentage phosphorus removed in both samples A and B are presented on Tables 2 and 3. When 0.0013 g of $Al_2(SO_4)_3.18H_2O$ (alum) was added to sample A, 26% phosphorus was removed and when the amount of coagulant added was increased to 0.0025 g, 30% phosphorus was removed. When 0.0038 g of coagulant was added, the percentage phosphorus removed was then reduced to 26%. However, when $FeSO_4.7H_2O$ (ferrous sulphate) was used as the coagulant of interest, the percentage phosphorus removed reduced progressively both for samples A and B. These amounts of phosphorus removed after the addition of coagulants as seen in Table 2 were lower than the Reference [8] limit of 5.00 mg/l for wastewater. According to the report of Reference [16], the decrease in phosphorus removal efficiency after optimum dosage was due to the restabilization of colloidal suspension and further increase in the amount of the coagulants resulted in ineffective and decrease in the efficiency of the coagulant. There is also the possibility of a second reaction after the precipitation of soluble phosphorus known as hydrolysis. In this reaction, aluminium forms aluminium hydroxide floc, which also assists in the precipitation of aluminium phosphate floc as well as other solids in the water. Also, alkalinity, temperature, pH and presence of other substances such as colloidal matter affected the efficiency of the coagulants [17].

3.3 EFFECTS OF PH AND AMOUNT OF COAGULANT

The variations in the pH after coagulation and the amount of coagulant are also presented on Tables 2 and 3. A decrease in the amount of coagulant resulted in a corresponding decrease in pH after adjustment. On further decrease of the amount of coagulant ($Al_2(SO_4)_3.18H_2O$) added, the pH further reduced but pH remained almost constant when $FeSO_4.7H_2O$ was used as coagulant. At pH greater than 8, the ions of the coagulant become soluble and hence, the amount of phosphorus removed decrease [18]. Upon increasing the amount of coagulants, the pH was more important than its initial pH before addition of coagulants. The effect of pH on the amount of residual phosphorus can be explained by the change of orthophosphate compound with pH [19]. Phosphate removal as aluminium or iron phosphate depends on water. After alum or $FeSO_4.7H_2O$ was added into the water sample, the pH of the solution decreased due to the fact that part of the alum was precipitated as the hydroxide forms and hydrogen ions were formed. However, below a pH range of 5.5, the aluminium ions are soluble and do not participate in the hydration reaction necessary to make alum effective as a coagulant. Also, the formation of insoluble aluminium phosphate is not possible as it is soluble below pH of 6 and above pH of 8 [10]. On the other hand, when the pH level of the water is above 8 after the addition of alum, aluminium ions again become soluble and the efficiency of the coagulation is decreased [18].

Table 2. Percentage phosphorus removal and pH variation during phosphorus precipitation with alum

Sample	pH	pH adj	P1 (mg/l)	Coag (g)	pH coag	P2 (mg/l)	P removal (g)	% P removal
A	10.20	7.30	8.71	0.0013	8.10	6.47	2.23	26.0
	10.20	7.10	9.84	0.0025	7.90	6.93	2.91	30.0
	10.20	7.50	9.85	0.0038	7.80	7.32	2.52	26.0
B	9.10	7.10	0.90	0.0013	7.80	0.69	0.21	23.0
	9.10	7.20	1.00	0.0025	7.80	0.70	0.30	30.0
	9.10	7.10	1.00	0.0038	7.70	0.75	0.26	25.0

P1- initial phosphorus concentration before coagulation P2- residual phosphorus concentration after coagulation pH ad,j-pH after adjustment pH coag.-pH after coagulation Coag.-amount of coagulant added

Table 3. Percentage phosphorus removal and pH variation during phosphorus precipitation with ferrous sulphate heptahydrate

Sample	pH	pH adj.	P1 (mg/l)	Coag. (g)	pH coag.	P2 (mg/l)	P removal (g)	% P removal
A	10.20	7.50	10.06	0.0013	8.30	7.03	3.03	30.0
	10.20	7.80	10.14	0.0025	8.20	7.64	2.50	25.0
	10.20	7.90	10.15	0.0038	8.20	7.99	2.16	21.0
B	9.10	7.20	0.92	0.0013	7.80	0.70	0.23	25.0
	9.10	7.10	1.03	0.0025	7.80	0.78	0.25	24.0
	9.10	7.10	1.03	0.0038	7.70	0.84	0.19	19.0

P1- initial phosphorus concentration before coagulation P2- residual phosphorus concentration after coagulation pH adj.-pH after adjustment pH coag.-pH after coagulation Coag.-amount of coagulant added

3.4 COMPARISON OF THE EFFECTS OF THE TWO COAGULANTS

A comparison of the effects of the two coagulants (Tables 2 and 3) show that $Al_2(SO_4)_3.18H_2O$ elicited better phosphate removal in both samples than $FeSO_4.7H_2O$ indicating that the former is a better coagulant for the phosphorus removal in wastewater. This is due to the low metal (aluminium) to phosphorus ratio required for the formation of a precipitant. Also, the benefit of using $Al_2(SO_4)_3.18H_2O$ in wastewater treatment include the wide pH range where aluminium phosphate remains insoluble between pH of 2 and 9. Unless the precipitant is exposed to extremes of either acidic or basic conditions [17].

4 CONCLUSION

The phosphorus removal by $Al_2(SO_4)_3.18H_2O$ and $FeSO_4.7H_2O$ were found to be highly pH dependent with an optimum pH of 7.90 to 8.20. At this pH, $Al_2(SO_4)_3.18H_2O$ dosage of 2.91 mg/l removed 30.0% of the total phosphorus while $FeSO_4.7H_2O$ dosage of 2.50 mg/l removed 25.0% of the total phosphorus in sample A. A better phosphorus removal was achieved when the sample pH was adjusted to 7. However, phosphorus removal according to the results obtained in this study was not affected by changing and varying mixing period because phosphorus removal is relatively fast. The dosages of $Al_2(SO_4)_3.18H_2O$ and $FeSO_4.7H_2O$ and pH played important roles in phosphorus removal and the removal efficiency increased with increasing pH. The results obtained showed that the use of $Al_2(SO_4)_3.18H_2O$ (alum) as a coagulant demonstrated better results in phosphorus removal than $FeSO_4.7H_2O$.

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