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Chemically enhanced primary treatment of textile effluent using alum sludge and chitosan

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ABSTRACT

This study was conducted with the objective to develop a treatment system that can effectively reduce the elevated level of pollutants in textile effluent at primary stage of conventional wastewater treatment plant. Alum sludge, chitosan, and combination of alum sludge and chitosan coagulants were used as the replacement of conventional coagulants such as alum, etc. The performance of chemically enhanced primary treatment (CEPT) options was evaluated by measuring the supernatant residual total suspended solids (TSS), color, and chemical oxygen demand (COD) concentrations at various coagulants doses. In all CEPT options, TSS and color removal exceeded 95 and 85%, respectively. Use of alum sludge at the optimum dose of 400–500 ppm was not economical, due to high sludge production and higher cost associated with sludge disposal. Chitosan alone at optimum dose of 18 ppm resulted in enhanced COD removal as compared with other CEPT options. The use of chitosan in combination with alum sludge reduced the optimum dose of alum sludge and sludge production by 37.5 and 45.5%, respectively. Results also confirmed that CEPT options can also be used for decolorization of textile effluent.

Keywords: Alum sludge; CEPT; Chitosan; Cationic polymer; COD; Textile effluent

1. Introduction

Being eighth largest exporter of textile products, textile sector contributes 9.5% to Pakistan's GDP [1], but in recent years, industrial sector is forced to conform to environmental standards for the improvement of effluent quality [2]. Textile processes use ample amount of water and chemicals. Wastewater results from textile processes are of high strength having elevated levels of chemical oxygen demand (COD), solids, color, etc. Direct discharge of such wastewater into fresh water bodies can significantly reduce dissolved oxygen levels, and effect the flora and fauna [3]. Removal of dyes and heavy metals is prerequisite to have an effective biological treatment of textile wastewater. Different methods have been established for the removal of dyes and heavy metals

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from textile effluent, but these cannot be used individually [4]. Many physico-chemical primary treatment processes, such as Fenton oxidation [5], adsorption [6], and simple coagulation–flocculation [7,8], are reported with appreciable color, turbidity, and COD removal.

Mahmoud [7] reported 75, 64, and 69% of color, turbidity, and COD, respectively, at an optimum dose of 300 ppm of alum. Similarly, Moosvi and Madamwar [9] obtained 74% color removal and 75% COD reduction using ferric chloride and lime at optimum dose of 1,000 and 400 ppm, respectively. Chemically enhanced primary treatment (CEPT) showed promising results and should be preferred as it is simple and can easily be implemented on existing infrastructure, but the costs of chemicals and disposal of excessive toxic sludge put CEPT in jeopardy [10,11]. Therefore, efforts are required for the identification of natural coagulants with less sludge production. One possible solution is to use alum sludge (from conventional water treatment plant) as an effective way to reduce cost of coagulant [12]. Xu et al. [13] reported 96 and 53% of turbidity and COD removal from synthetic wastewater using alum sludge with 35.5% less sludge production, respectively. Many workers studied the coagulant recovery from conventional water treatment plants and its reuse, but the accumulation of toxic substances in recycled coagulant limits its application in water treatment plants [14]. However, it is also reported that reuse of alum sludge instead of alum recovery is a better approach to fully utilize the potential of alum as coagulant, which also reduced the operational cost of alum recovery [15]. In addition, the use of cationic and anionic polymers as a coagulant aid significantly enhances the effectiveness of coagulation–flocculation process as reported by Mahmoud [7] and Haydar and Aziz [16]. Various polymers, including chitosan, were tested by different researchers. Chitosan, a cationic biopolymer, was investigated as a coagulant for turbidity, natural organic matter, and color removal in natural water and wastewater at limited level [17]. Hassan et al. [18] reported 72.5% of COD removal and 94.4% of turbidity removal from textile wastewater at 30 mg/L of chitosan. To best of our knowledge, there is still no published literature on the combined use of alum sludge and chitosan for the treatment of textile effluent. Therefore, this study was carried out with the objective to investigate the effectiveness of alum sludge (from conventional water treatment plant) and chitosan for color, total suspended solids (TSS), and COD removal from textile effluent.

2. Materials and methods

2.1. Effluent sampling

Ten samples were collected from equalization tank, equipped with aerators for continuous mixing, of conventional wastewater treatment plant of Kohinoor Textile Mills (KTM), Rawalpindi, Pakistan and stored at 4˚C. Various parameters of concern were determined in accordance with procedures given in Standard Methods [19], and color was measured using spectrometer (HACH, DR6000) at the wavelength of 455 nm.

2.2. Coagulant preparation and jar test methodology

Alum sludge was obtained from Rawal water filtration plant located in Islamabad, Pakistan. Alum sludge was then dewatered and dried at 105˚C as reported by Chu [15]. Dry weight of TSS in mixed liquor was determined to make 2% stock solution. Since the addition of polymers can significantly improve the effectiveness of coagulation–flocculation process, Chitosan, 86.7 deactyl (CF05), was purchased from M/s G.T.C Bio Corporation through local vendor. Since chitosan is more soluble in acidic solution, which makes it more available for application. One percent stock solution was prepared by adding 1% hydrochloric acid (HCl) solution and mixed at 120 rpm for 40 min. Fresh solution was prepared before each set of experiments as chitosan may undergo some changes over the period of time [18].

Phillips and Bird (Model PB900) apparatus with six beakers was used for coagulation and flocculation process. For each test, one liter of textile effluent was mixed rapidly at 200 rpm for 2 min, which was followed by tapered flocculation at 40 rpm for 10 min and 20 rpm for 15 min. Settling time of 60 min was provided and all samples were drawn at the depth of 2 cm [20–24]. It was reported by Mahmoud [7] that the reduction of pH from alkaline (pH 11.5) to natural levels had significantly improved the effectiveness of a coagulant. Since the pH of KTM ranged from 7.3 to 7.7, all samples were adjusted to the pH of 7.5 in order to obtain uniform results. No coagulant dose was added in first jar, and hence served as a control jar. Jar tests were performed in the following series.

2.2.1. Series A

Series A experiments comprised preliminary investigations with the objective to determine the optimum pH and dose of alum sludge. Samples were taken at a fixed depth of 2 cm for the determination of residual color, TSS, and COD removal. Alum sludge dose varied from 0 to 600 ppm, in increments of 50 ppm, at adjusted pH of 7.5.

2.2.2. Series B

Series B experiments were performed to determine the suitability of chitosan as a coagulant and optimum pH. Divakaran and Pillai [20] reported that residual turbidity of less than five NTU can be achieved at very low chitosan dose, regardless of initial turbidity at pH range of 7.0–7.5. However, optimum range may vary depending on the structure and molecular mass of chitosan. Chitosan dose was varied from 0 to 20 ppm, in increments of 2 ppm, at adjusted pH of 7.5. Samples were again taken at a fixed depth of 2 cm for the determination of residual color, TSS, and COD removal.

2.2.3. Series C

Now, the alum sludge was used in combination with chitosan to investigate residual color, TSS, COD, and color removal. Alum sludge was varied from 0 to 300 ppm in increments of 50 ppm. About 5 ppm of chitosan dose was fixed and added after a lapse of 30 s during rapid mixing. The purpose of this lapse was to allow neutralization of negatively charged colloids with alum sludge so that chitosan could condition the floc formed.

3. Results and discussion

Table 1 depicts the characteristics of wastewater which shows high values for organic and solid contents. Almost all parameters exceeded National Environmental Quality Standards of Pakistan. BOD_5 and COD concentration varied from 559 to 679 ppm and 1,500–2,130 ppm, respectively; hence, classified the effluent as high strength [25]. The effluent can easily be treated biologically if BOD_5/COD ratio is greater than 0.5; if BOD_5/COD ratio is lesser than 0.3, it represents the presence of toxic components [26]. BOD_5/COD ratio in our case is 0.32 proving the fact that toxic components are present in KTM effluent. Therefore, primary treatment is mandatory.

Color was the most notable aspect of KTM effluent which depicted the presence of significant dye contents used during processing of textile products. TSS concentration varied from 635 to 1,590 ppm and formed by variety of suspended solids both organic and inorganic. Selected heavy metals were also tested, but most of them were meeting National Environmental Quality Standards of Pakistan except chromium.

3.1. Series A

Results obtained from series A—graphically represented in Figs. 1–3—showed appreciable removal efficiencies for TSS, color, and COD. The optimum dose of alum sludge for TSS, color, and COD was 400, 450, and 500 ppm, respectively, as percent removal slightly reduced with the increase of alum sludge dose. Maximum TSS, color, and COD removal of 96.5, 85.5, and 58%, respectively, were achieved at respective optimum dose of alum sludge. These results are in agreement with the findings of Xu et al. [13]. Residual TSS,

Table 1
Characteristics of homogenized KTM effluent

Parameter[a]	N[b]	Minimum	Maximum	Average	NEQs[c]
Temperature (°C)	10	38	45	42	40
pH	10	7.3	8.3	7.7	6–9
Color (PCU)	10	875	3,450	1,280	–
Total solids	10	5,500	8,000	6,250	–
TSS	10	635	1,590	891	150
BOD_5	10	559.2	679	585	80
COD	10	1,500	2,130	1,780	150
Chlorides	10	340	789	666	1,000
Chromium, Cr	10	1.37	2.17	1.89	1.0
Copper, Cu	10	0.03	0.07	0.045	1.0
Lead, Pb	10	0.11	0.79	0.38	0.5
Nickel, Ni	10	0.25	0.34	0.27	1.0
Total alkalinity as $CaCO_3$	10	470	590	525	–

Notes: [a]All units are in ppm except pH.
[b]No. of samples.
[c]National Environmental Quality Standards of Pakistan.

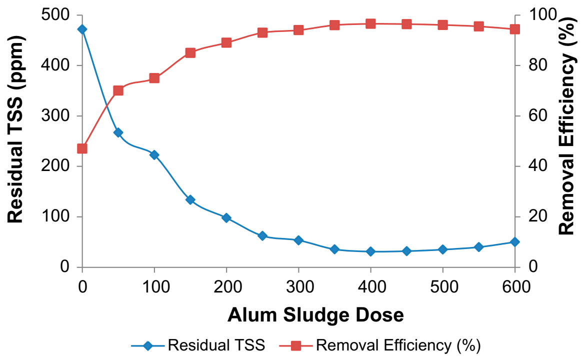

Fig. 1. Effect of alum sludge dose on TSS removal.

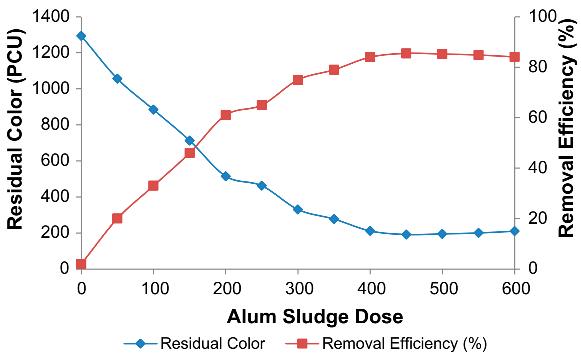

Fig. 2. Effect of alum sludge dose on color removal.

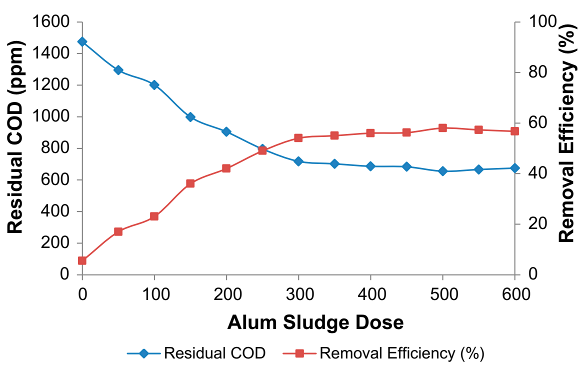

Fig. 3. Effect of alum sludge dose on COD removal.

color, and COD concentration were 31.15 ppm, 191.4 PCU, and 655.2 ppm. Effluent standards (NEQs) of Pakistan were met for TSS i.e. 150 ppm using alum sludge, but secondary treatment is required for COD removal to meet effluent standards.

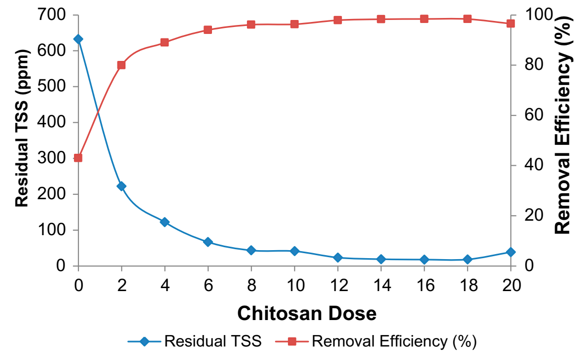

Fig. 4. Effect of chitosan dose on TSS removal.

3.2. Series B

Chitosan, natural material, showed appreciable removal efficiencies for TSS, color, and COD at very low doses. The results are presented in Figs. 4–6. Chitosan showed far better TSS and COD removal when comparing with alum sludge. Color removal with alum sludge and chitosan was approximately identical.

The optimum dose of chitosan was determined to be 18 ppm. Maximum TSS, color, and COD removal of 98.36, 86.8, and 70.9%, respectively, were achieved. Mohd et al. [18] reported 72.5% of COD removal and 94.4% of turbidity removal from textile wastewater at 30 mg/L of chitosan. Chitosan was even better for TSS and color removal at very low dose as no significant increase in TSS and color removal was recorded with an increase in chitosan dose from 8 to 20 ppm. Residual TSS, color, and COD concentration were 18.2 ppm, 139 PCU, and 515 ppm were obtained.

3.3. Series C

The objective of series C was to check the combined effect of both alum sludge and chitosan. For this

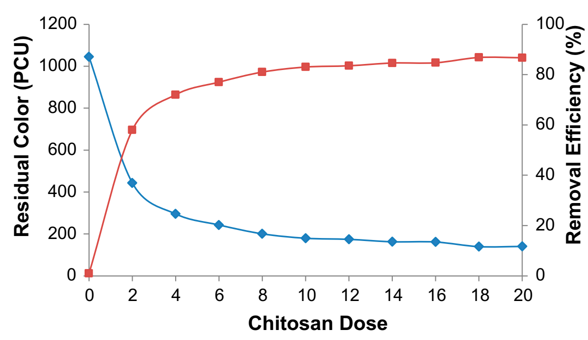

Fig. 5. Effect of chitosan dose on color removal.

purpose, jar tests were again conducted. The dose of alum sludge varied from 0 to 300 ppm and chitosan dose was fixed at 5 ppm. Results obtained from this combination are given in Figs. 7–9. The combined effect of alum and sludge and chitosan-reduced alum sludge dose to 250 ppm as compared with the optimum dose of 400 ppm obtained from series A. Maximum TSS, color, and COD removal of 98.9, 88.3, and 65.7%, respectively, were achieved as illustrated in Figs. 7–9. Significant improvement in TSS, color, and COD removal was obtained when compared with series A. The improvement in removal efficiencies may be due to the enhanced destabilization caused by chitosan in the presence of alum sludge coagulant.

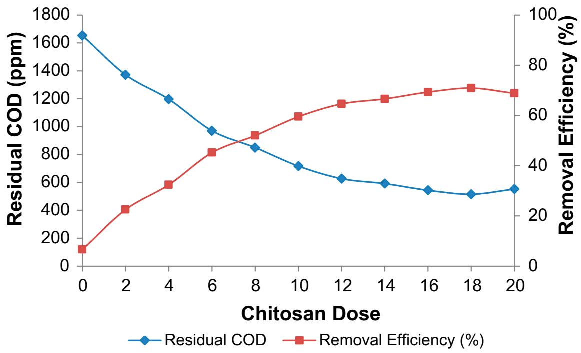

Fig. 6. Effect of chitosan dose on COD removal.

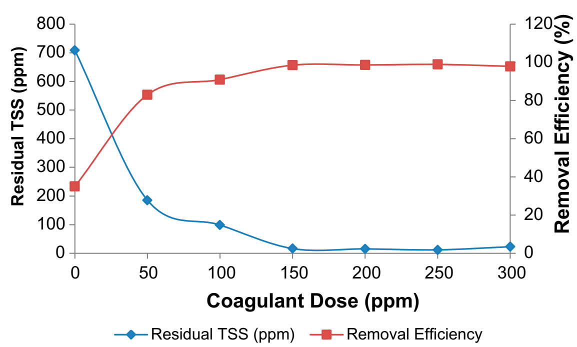

Fig. 7. Effect of alum sludge and chitosan on TSS removal.

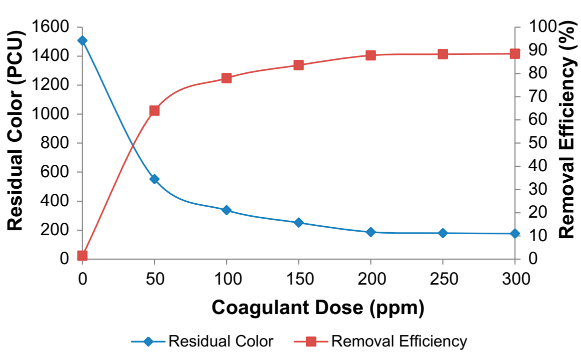

Fig. 8. Effect of alum sludge and chitosan on color removal.

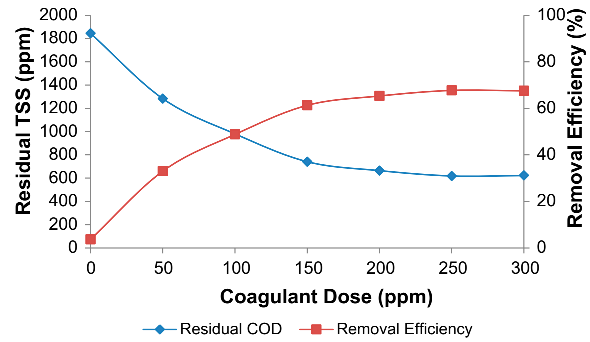

Fig. 9. Effect of alum sludge and chitosan on COD removal.

3.4. Sludge production

Major drawback of CEPT is the handling and treatment cost of sludge, which is responsible for the increase in operational cost of wastewater treatment plan. It was reported that sludge dewatering adds 30–50% to the operational cost in wastewater treatment plant [27]. Enhanced sludge production in CEPT is due to supplementary removal of suspended and colloidal impurities. Volume of sludge in series A–C jar tests at optimum coagulant dose was measured using graduations on jars. Fig. 10 illustrates the sludge production in mL/L for three CEPT options i.e. (i)

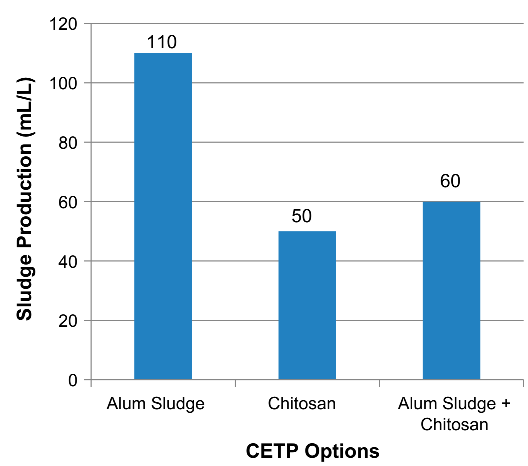

Fig. 10. CEPT options and sludge production.

when alum sludge is used as only coagulant; (ii) when chitosan is used as sole coagulant; and (iii) when alum sludge was used in combination with chitosan.

As evident from Fig. 10, increased sludge production was observed for alum sludge coagulant, and hence handling cost would be high as well. Significant reduction of 54.5 and 45.5% in sludge volume was achieved for option (ii) and (iii) respectively when compared with option (i). Sludge in all options was mainly composed of inorganic and organic solids, aluminum hydroxide gel, polymers, and fractions of heavy metals [28]. Due to toxicity in the sludge, it needed to be disposed of carefully.

4. Conclusion

This investigation has confirmed that CEPT options with alum sludge and chitosan coagulants are efficient methods for treating textile effluent at primary stage of conventional wastewater treatment as significant TSS, color, and COD removals were achieved and will lead to decrease in the waste disposal costs for textile industries. In all CEPT options, TSS and color removal exceeded 95 and 85%, respectively. The use of alum sludge as sole coagulant is not feasible due to the high volume of sludge production and higher cost associated with sludge disposal. Chitosan at the optimum dose of 18 ppm resulted in enhanced COD removal as compared to other CEPT options. However, cost of chitosan (US$40/kg) coagulant can be further reduced when used with alum sludge. About 5 ppm dose of chitosan reduced the optimum dose of alum sludge and sludge production by 37.5 and 45.5%, respectively. Color removal is a challenging task for textile industries; all CEPT options in this study exhibited more than 85% color removal. Therefore, CEPT can also be adopted for color removal.

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