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Original Research

Chemically Enhanced Primary Treatment of Textile Industrial Effluents

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Abstract

Textile industries consume substantial volumes of water and chemicals for wet processing of textiles. Effluent discharge from textile industries to neighbouring water bodies and wastewater treatment systems is currently causing significant health concerns. Chemically enhanced primary treatment (CEPT) involves the use of chemical coagulants to enhance the coagulation or flocculation of wastewater particles. The chemicals of aluminum sulphate (alum), ferric chloride ($FeCl_3$) and cationic polymer were studied by jar test to select the most suitable coagulant for effective treatment of textile industrial effluents. The results showed that the optimum dosage for the removal of 75% of colour, 64% turbidity and 69% of chemical oxygen demand (COD) was 300 ppm of alum after pH adjustment at pH = 7.2. An experiment further revealed that the addition of 300 mg l^{-1} of alum and 1 mg l^{-1} of polymer could provide a reduction of colour, turbidity, COD and phosphorous higher than 95%, 75%, 76% and 90%, respectively. The experimental results confirmed that CEPT can be adopted as a decolorization of textile industrial effluents. Moreover, it can improve sludge setting and dehydration properties, and decrease the treatment cost.

Keywords: textile industrial, chemically enhanced primary treatment, decolorization, coagulation

Introduction

Industrial wastewater generally contains contaminants such as suspended solids, dissolved organic matters, heavy metals, and cyanides at levels considered hazardous to the environment and could pose a risk to public health. Wastewater from dye houses can have strong impacts on the aquatic environment. Due to its complex chemical structure, dye is one of the most difficult constituents in textile wastewater to treat. The treatment of dye house wastewater constitutes major economic and environmental issues [1]. Textile industries consume substantial volumes of water and chemicals for wet processing of textiles. These chemicals are used for desizing, scouring, bleaching, dyeing, printing and finishing. They range from inorganic compounds and elements to polymers and organic products. There are more than 8,000 chemical products associated with the dyeing process listed in the colour Index [2-4]. These dyes include several structural varieties of dyes, such as acidic, reactive, basic, disperse, azo, diazo, anthraquinone-based and metal-complex dyes. Interest in the pollution potential of textile dyes has been prompted primarily by concern over their possible toxicity and carcinogenicity [5].

Government legislation is becoming more stringent in developed countries regarding the removal of dyes from industrial effluents, which is in turn becoming an increasing problem for textile industries. Environmental protection agencies in Egypt are working to prevent the transfer of pollution problems from one part of the environment to another. This means that for most textile industries, developing on-site or in-plant facilities to treat their own effluents before discharge is fast approaching reality.

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Table 1. Characteristics of industrial wastewater from Misr El America for spinning and weaving Com.

No.	Sample	pH	TDS mg l^{-1}	Turbidity NTU	BOD mg l^{-1}	COD mg l^{-1}	BOD/COD
1	7/3/2006	11.8	1,130	46	500	2,456	0.20
2	4/4/2006	11.9	1,700	54	493	1,892	0.26
3	2/5/2006	11.5	1,017	42	475	1,700	0.28
4	18/6/2006	11.5	980	16	480	1,800	0.26
5	7/7/2006	12.3	2,406	660	500	3,700	0.13
6	10/8/2006	11.5	1,820	64	300	5,640	0.05

Recently, state and federal agencies in the United States have been requiring lower effluent colour limits (<200 units of American Dye Manufacturers Institute, ADMI) [6]. The presence of colour in wastewater is one of the main problems in the textile industry. Colours are easily visible to human eyes even at very low concentrations. Hence, colour from textile wastes carries significant aesthetic importance. Most of the dyes are stable and include no effect of light or oxidizing agents. They are also not easily degradable by conventional treatment methods. Removal of dyes from effluent is a major problem in most textile industries [7]. The physical and chemical techniques include electrochemical, membrane-filtration, ion-exchange, irradiation and ozonation used for industrial effluents. Some of these techniques have been shown to be effective, although they have shortcomings. Among these are: excess amount of sludge generation with obvious disposal problems; costly plant requirements or operating expenses; lack of effective colour reduction, particularly for sulfonated azo dyes; and sensitivity to variable wastewater input [8].

Most contaminants in industrial effluents are poorly soluble in water, resist biological degradation, and may exert significant toxicity toward the mixed microbial communities within biological treatment systems [9]. The same characteristics which render these target compounds resistant to biological treatment make them amenable to removal through chemically enhanced primary treatment (CEPT). Chemically enhanced primary treatment is the process by which chemicals, typically metal salts and polymers in the form of organic polyelectrolytes, are added to primary sedimentation basins. The chemicals cause the suspended particles to clump together via the processes of coagulation and flocculation. The particle aggregates, or flocs, settle faster, thereby enhancing treatment efficiency, measured as removal of solids, organic matter and nutrients from the wastewater. CEPT is a relatively simple technology providing a low-cost and effective treatment, which is easily implemented over existing infrastructure. Additionally, CEPT provides the opportunity for either reducing the size of subsequent treatment units, or increasing the capacity of existing conventional treatment plants, such as activated sludge basins [10, 11]. Recently, several investigations on sewage sludge from CEPT have been made to show the efficiency of the sludge-adsorbent for the treatment of phenol [12], reactive dyes [13], crystal violet, indigo carmine [14] and textile wastewater [15].

The objective of this study is to investigate the combined effect of alum, ferric chloride and a cationic polymer on removal colour, turbidity, and organic substances (BOD and COD) and heavy metals of textile industrial effluents generated in Misr El Ameria for spinning and weaving.

Material and Methods

Experiment Procedures

Stock solutions (1,000 ppm) of ferric chloride and alum ($Al_2(SO_4)_3$ n H_2O) were prepared by dissolving the appropriate weight of pure chemicals in the least amount of water, and then transferred into a 1 L measuring flask and completed to the mark with distilled water. The cationic polymer used was a commercially available high molecular weight polyacrylamide flocculant (PAM). The detailed molecular structure of the product was not revealed, but the general properties include molecular weights ($7 \cdot 10^7$), pH (6-7), bulk density (0.5 g cm^{-3}) and physical form (white granular powder). The stock polymer solution was prepared by adding 0.5 g of the cationic polymer (Zetag 63, supplied by allied Colloids) to 3 ml methanol in order to thoroughly dissolve the product. 97 ml distilled water was then added and the mixture was vigorously shaken for 10 minutes and further stirred with a magnetic stirrer overnight. This procedure resulted in a 500 ppm stock polymer solution.

Jar tests were carried out to test the effectiveness of the various coagulants used. The conventional jar test involved setting up a series of samples of wastewater on special multiple paddle stirrers, and dosing the samples with a range of various coagulants in different concentrations. This was performed by mixing one liter of wastewater samples. After the addition of chemicals (ferric chloride and alum) the wastewater was rapidly stirred at 160 rpm for one minute and then slowly stirred at 20 rpm for 10 minutes. The wastewater was then allowed to settle for 60 minutes and the supernatant was taken for the measurement of a turbidity and chemical oxygen demand (COD).

In the case when the polymer was used, the wastewater was first stirred at 160 rpm for one minute after the addition of these chemicals. Then, the polymer was added and the wastewater was further stirred for one minutes and 160 rpm and slowly stirred at 20 rpm for 10 minutes. The wastewater was then allowed to settle for 60 minute and the supernatant was taken for the measurement of the pH, EC, turbidity, color, biochemical oxygen demand (BOD), chemical oxygen demand (COD), phosphorus and heavy metals.

The pH was determined by pH meter and EC was measured by a conductivity meter. Turbidity for water samples was measured using a Hach 2100 series turbidimeter. Standard Hach 20 ml vials were filled with the sample and measured using the NTU scale. Colour was assayed at wavelength 455 nm on a spectrophotometer. BOD_5 and COD concentrations were measured according to standard methods [16]. Phosphorus was estimated by the vanadomolybdophosphoric acid colorimetric method [16]. Water samples were filtered if necessary and heavy metals measured by flame atomic absorption.

Results and Discussion

Characteristics of Industrial Wastewater

Table 1 presents the characteristics of industrial wastewater from Misr El Ameria. Total dissolved soils (TDS) ranged from 980 to 2,406 mg l^{-1} with 1,693 average, whereas the water used is usually within 340 mg l^{-1}. Increasing the mineral content of the industrial wastewater resulting from raw materials used in dyeing and other processes affects its reuse potential, especially for irrigation. The wastewater was highly alkaline (pH 11.5-12.3). This may be due to the use of sodium hydroxide and silica in dyeing.

Concentrations of BOD and COD ranged from 475 and 1,700 to 500 and 5,640 mg l^{-1}, respectively, which would classify the wastewater as high strength [17]. The calculated 0.05-0.28 as range of BOD to COD ratio indicates that it might have toxic components. With a BOD-to-COD ratio of 0.5 or greater, the wastewater is considered to be easily treatable by biological means [17, 18]. If the ratio is below about 0.3, either wastewater may have some toxic components or acclimated microorganisms may be required in its stabilization.

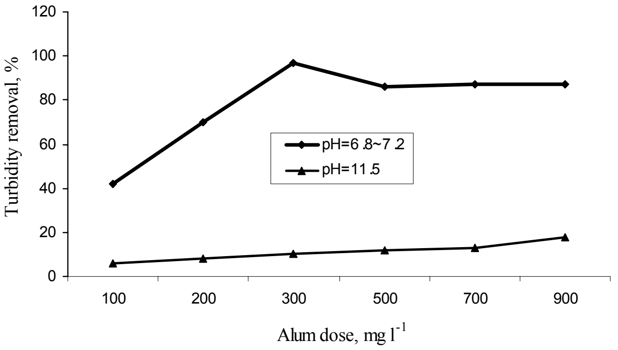

Fig. 1. Effect of pH adjustment with alum concentration on turbidity removal.

Average wastewater turbidity ranged from 16 to 660 NTU. Turbidity may be caused by dyes and pigments, binder, solvents and others inorganic substances and also caused by a wide variety of suspended materials (as colloidal, sub colloidal).

Effect of pH Adjustment before Primary Coagulation

The effect of pH adjustment before primary coagulation with alum addition as coagulants is illustrated in (Fig. 1). In general, reducing the pH from alkaline (pH=11.5) to natural levels had a strong positive effect on turbidity removal. Turbidity removal ranged from 0-20% at pH (11.5) to 60-98% at pH (6.8-7.2). Raising alum dosages had a slight effect on turbidity removal at pH=11.5, it could be due to consumption of hydroxyl ions of alum hydrolysis in decrease of water alkalinity [9]. This would slightly affect organic and inorganic substances that produce turbidity. Coagulation with alum involves three steps [19],

(i) destabilization begins after the operational solubility limit of aluminum hydroxide has been exceeded;

(ii) aluminum hydroxide species are then deposited onto the colloidal surfaces;

(iii) under typical conditions, aluminum hydroxide is positively charged, while the original colloidal particles are negatively charged.

The position process thus can lead to charge neutralization or charge reversal at certain doses. The results showed that pH must be adjusted before coagulation.

Coagulant Performance Comparison

Efficacy of contaminant removal is compared (Table 2) for alum and ferric chloride ($FeCl_3$). Using a 200, 300, 400 and 500 mg l^{-1}dosage each, efficiency was:
Alum > $FeCl_3$ for turbidity removal,
Alum = $FeCl_3$ for COD removal.

COD removal efficiency was promoted by adding increased coagulants. But optimal COD was found at 300 mg l^{-1} of alum = $FeCl_3$. Turbidity removal decreased with increased $FeCl_3$ addition, The decreases in turbidity removal when adding $FeCl_3$ may be due to producing a wider variety of solid precipitates, some of which are not soluble, but also generates a yellow coloring in the reclaimed water. Similar effects have been previously noted in sewage treatment plant studies [20]. The results showed that for nearly all alum dosages, alum dosage higher than 300 mg l^{-1} caused no significant change in turbidity and COD removal efficiency. Thus, 300 mg l^{-1} of alum was chosen for the next phase of experiments. Alum was more effective in color and COD removal than ferrous sulfate and ferric chloride [21].

Table 2. Effect of coagulant types on COD and turbidity removal (average sample, n=8).

Coagulants	Concentration	Turbidity	COD
	mg l^{-1}	Average removal, %	
Fe Cl$_3$	200	56.5	62.3
	300	32.6	63.9
	400	-41.3	60.1
	500	-89.1	57.7
Alum	200	60.9	63.8
	300	63.9	69.2
	400	62.6	70.1
	500	61.6	46.2

Effect of Polymer Dosage on Removal Efficiency

When the alum was added as a coagulant (no polymer was added), dosage as 300 mg l^{-1} of alum achieved 63 and 69% of the turbidity and COD removal, respectively. When the polymer was added as a secondary coagulant (i.e. after alum), dosages as low as 1 and 2 mg l^{-1} of polymer had achieved 95, 75, and 76% of the colour, turbidity and COD removal, respectively. Increasing the dosage of polymer did not improve and even decreased removal efficiency. The latter might be due to the so-called overdosing phenomenon. Similar effects have been previously noted in water treatment studies [22]. Above the optimum dosage, it was noted that the parts of polymer separated in solution and a reduction in floc size which led to increase in the COD. Turbidity removal is increasing with the increase in coagulant dose till it reached an optimum value, after which turbidity removal started to decrease. This can be attributed to restabilization of colloidal particulates that may occur due to the reversal of charges when coagulants are used at dosages higher than the optimum value [23]. One of the most likely actins of this polymer was that it bridged the alum floc by the formation of insoluble polyacrylate, which led to enhanced destabilization [24].

Characteristics of Treated Effluent

The characteristics of industrial wastewater samples before and after treatment, including pH-adjusted wastewater (6.8-7.2) using alum, and PAM at optimum concentrations (alum: PAM – 300:1 mg l^{-1}) were compared to reused drainage waters from 9 sites in the Nile Delta and water criteria for irrigation (Table 3). In general, the treated water of CEPT had lower levels of heavy metals and salinity than reused drainage waters in the Nile Delta. With regard to salinity, heavy metals except Cd of treated water fell within the acceptable range for irrigation [25]. The results reveal that 300 mg l^{-1} of alum with 1 mg l^{-1} of polymer could remove about 95% of colour, 75% of turbidity, 76% of COD and 90% of PO$_4^{-3}$. In fact, heavy metals were reduced during CEPT, presumably due to adsorption/precipitation

Table 3. Characteristics of treated effluent.

Parameters	Units	Crude sewage, n=10	CEPT average (n=10)	Removal %	DRI[a]	Water criteria of irrigation[b]
pH		11.91	7.08		7.10-8.10	6.5-8.4
TDS	mg l^{-1}	1,700	980		268.8-729.6	2,000
color	PCU	1,220	52	96		<200
Turbidity	NTU	64.0	3.2	75		
COD	mg l^{-1}	1,092	262	76	94-748	60[c]
BOD	mg l^{-1}	443	110	75		40[c]
PO$_4$	mg l^{-1}	9.94	1.02	90		
Fe	mg l^{-1}		0.08		0.10-0.71	5.00
Zn	mg l^{-1}		0.01		0.70-0.9	2.00
Mn	mg l^{-1}		0.09		0.02-0.33	0.20
Cu	mg l^{-1}		0.03		0.07-0.14	0.20
Cd	mg l^{-1}		0.03		0.05	0.01
Pb	mg l^{-1}		0.14		0.19	5.00
Ni	mg l^{-1}		0.13			0.20

[a] Range of values for six Nile Delta sites, Drainage Research Institute Reuse Report, 1995.
[b] Egypt (48/1982).
[c] US. EPA 1993.

reactions. CEPT reduced dissolved inorganic phosphate levels through the precipitation of insoluble aluminum phosphate. Polyphosphates and other organic phosphorus compounds may also be removed by being entrapped, or adsorbed in the floc particles [26]. BOD and COD concentrations in CEPT had higher than the Egyptian guideline for irrigation. But most dissolved organic matter (DOM) in CEPT is presumed to be mainly in the form of low molecular weight organic molecules, as they are not favorably removed by the CEPT compared to the more complex molecules. These simple organic molecules are easily biodegradable; therefore BOD of the treated water is expected to decrease after discharge to the receiving waters.

Conclusion

The above results confirm that CEPT could be used as a simple and low-cost technology for treating industrial textile effluents. Although decolorization is a challenging process to both the textile industry and wastewater-treatment facilities, the literature suggests a great potential for microbial decolorizing systems for achieving total colour removal. CEPT was capable of removing more than 95% of colour and heavy metals. Thus, CEPT can be adopted for decolorization of textile industrial effluents.

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