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Effect of Greywater Characteristics on its Chemical Coagulation

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Abstract— The effect of physico-chemical characteristics of greywater on its chemical coagulation was assessed employing real greywater with varying characteristics using both alum and polyaluminium chloride (PACl) as coagulants. Optimum PACl dosages required were significantly less compared to alum for similar initial turbidity levels. Also, PACl produced less turbid treated greywater. As the initial pH increased, the optimum coagulant dose also increased for both alum and PACl. At similar optimum dosages, PACl gave higher COD removal compared to alum. Total coliform removal showed no significant difference with removals of 98.3% and 98.9%, respectively for alum and PACl.

Keywords— *Greywater treatment; Chemical Coagulation; Alum; Polyaluminium chloride;Water reuse.*

I. Introduction

Freshwater is witnessed as the most essential natural resource in the world and must therefore be wisely managed (Liu et al., 2016). As the world's population grows, water demands raise and multiply without the possibility for an increase in supply. Thus treatment of greywater followed by its recycling and reuse can be considered as an effective step when it comes to the minimization of freshwater requirements.

Greywater is the water collected distinctly from sewage flow that originates from clothes washers, bathtubs, showers and sinks, but does not comprise wastewater from toilets (Odeh, 2003). The goal of greywater treatment is not at providing water of drinking water quality but at water for toilet flushing, sprinkling irrigation, laundry, car washing, floor washing, or fire extinguishing (Ghunmi et al., 2011). All types of greywaters show good biodegradability in terms of the COD: BOD5 ratios (Li et al., 2009). Recycling of greywater contains installing a system which treats greywater to meet quality standard for non-potable uses.

Greywater is moderately low in suspended solids and turbidity, signifying that a greater proportion of the contaminants are dissolved. The COD: BOD ratio is 4: 1 which is much greater than values reported for sewage. This is bounded with a deficiency of macro-nutrients such as nitrogen and phosphorus. The COD: N: P of greywater has been measured at 1030: 2.7: 1 and when compared with 100: 20: 1 for sewage wastewater, bathroom greywater is deficient in both nitrogen and phosphorus due to the exclusion of urine and faeces (Metcalf and Eddy, 1991; Bodnar et al., 2014; Abed and Scholz, 2016).

The emerging greywater treatment technologies is a result of investigations done in the field of greywater recycling. They range from low cost devices to complex treatment systems. The low cost devices revamp greywater to direct reuse while complex treatment systems combine treatment processes such as primary treatment, biological treatment, and disinfection. With higher levels of treatment, usually the cost and energy requirements of these systems differ. Thus, to diminish cost, treatment of greywater by natural system is gaining fame in both developed and developing countries (Li et al., 2009). Based on the limited literatures on the greywater treatment with chemical processes, such as coagulation, followed by a filtration and/or disinfection processes, were able to reduce the suspended solids, organics substances and surfactants in the low strength greywater to a desirable level to meet the non-potable urban resources (Lin et al., 2005).

Chemical coagulation is one of the most commonly used pretreatment options for greywater treatment. This pretreatment option intended at reducing suspended matter, biodegradable organics and nutrients in the feed. It was reported that some removal of microorganisms will be attained by this pretreatment too (Friedler et al., 2008). Colloidal impurities bearing negative electric charges repel them from each other, are more difficult to remove, due to their small size. This negative charge can be neutralized by coagulation and flocculation which intensifies the floc formation process. Eventually it increases the floc size and leads to rapid settling of the suspended and colloidal particles (Ghaitidak and Yadav, 2015). The optimum coagulant dosing is determined by conducting jar test. But an excessive coagulant dosing leads to increased treatment costs and health related issues, while an underdosing leads to a failure to meet the water quality targets and a less efficient operation of the wastewater treatment plant. Numerous studies have been reported in literature on the

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use of coagulants for greywater treatment (Chang et al., 2007; Pidou et al., 2008; Antonopoulou et al., 2013).

The present study focuses on the efficiency of chemical coagulation process for treating greywater using alum and polyaluminium chloride as coagulants.

II. MATERIALS AND METHODOLOGY

A. Greywater samples

The greywater samples used in this study were collected from Mother Teresa Bhavan (Hostel-12) located at Sardar Vallabhbhai National Institute of Technology, Surat. The wastewater from bathrooms and hand basins were comprised in the collected greywater. Greywater was diverted from the greywater collection pipe into a 300L overhead collecting tank where the greywater was homogenously mixed. Sampling was done between 8:00 am and 4:00 pm from the outlet pipe provided at the bottom of the tank. Total number of greywater samples collected was 150 during the period December 2015 – April 2016.

B. Jar testing

The jar test procedure was used for the determination of optimum coagulant dosage. The test was performed using jar testing apparatus (DBK Instruments, India) with six identical 1 L circular jars. The containers were filled with 500 mL greywater samples. Different doses of coagulants were added in increments of 10 or 25 mg/L. The treatment conditions were 1 min flash mixing, 20 min slow mixing and 30 min settling. The turbidity values were measured for the supernatant and the optimum dosage was determined as the dosage beyond which there was little reduction in supernatant turbidity. A total of 150 jar tests was performed with both alum and PACl coagulants. pH, turbidity, electrical conductivity, alkalinity, COD, solids and total coliforms were analysed for raw and treated greywater samples.

C. Analytical methods

The quality parameters were determined by following the methods described in Standard Methods (2005): pH meter (Hanna 209) was used to measure pH and electrical conductivity meter (Systronics, India) was used to measure electrical conductivity. Total suspended solids were determined after filtering the samples through Whatman 40 filter paper and drying at 60°C for 24 h in a hot air oven. Turbidity was measured using a turbidimeter (Hach 2100P). COD was determined as per the closed reflux titrimetric method according to the Standard Methods (APHA 2005). Total coliforms was estimated using the most probable number (MPN) technique (APHA 2005), and the microbial counts were determined by the multipletube-fermentation technique using 5 tubes at each dilution. The results of these tests were expressed as MPN/100 mL.

III. RESULTS AND DISCUSSIONS

Table 1 presents the mean values of the characteristics of raw greywater used in 150 jar tests conducted. It may be noted that the tests were conducted with real greywater without any adjustment and it can be seen that the characteristics varied widely during the study period. For example, pH, turbidity and COD varied in the range of 6.54-9.30, 19-287 NTU and 66-354 mg/L, respectively. Figure 1 presents the effect of initial turbidity range on optimum coagulant dosage and turbidity of treated greywater using alum and PACl. When the initial turbidity was high, the coagulant dosage required was also high for both alum and PACl. Excess coagulant must be added to destabilize suspended colloids or to generate a good settling floc in case of low TOC raw water in which coagulation is controlled by turbidity, (Pernitsky and Edzwald, 2006). Comparing to alum, the turbidity of the treated greywater using PACl was observed less for the same initial turbidity range. For similar initial turbidity ranges, even though higher optimum dosages are obtained for alum, the final turbidity were significantly higher for alum compared to PACl. This may be due to the several limitations of alum such as requirement of fast mixing to proper functioning, inferior performance at lower temperatures and poor efficiency for attracting organic suspended solids. Non-optimum pH can also lead to excessive dosage requirements (Pernitsky and Edzwald, 2006). From these observations, PACl can be considered as more efficient coagulant than alum.

TABLE I
CHARACTERISTICS OF THE GREYWATER USED

Parameter	Range*	Mean ± SD*
pH	6.54-9.30	7.68±0.2 6
Turbidity (NTU)	19-287	83±50
Electrical conductivity (μS/cm)	420-1296	769±165
Temperature (˚C)	22.6-30.4	26.5±2.2
Akalinity (mg/L as CaCO3)	128-332	214±34
COD (mg/L)	66-354	134±71
Total solids (mg/L)	320-1050	575±144
Total dissolved solids (mg/L)	230-726	415±97
Total suspended solids (mg/L)	60-580	160±85
Total coliforms (MPN/100 mL)	$9.2x10^4$-$8.7x10^6$	$4.5x10^6$± $1.1x10^6$

*Based on the analysis of 150 samples

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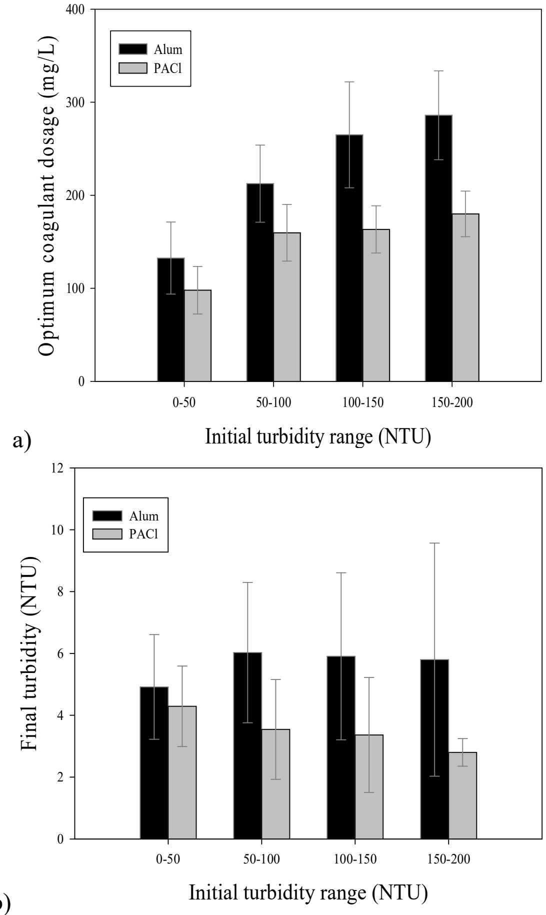


Figure 1 Influence of initial turbidity on optimum coagulant dosage and final turbidity of alum and PACl.

Figure 2 presents the effect of optimum alum and PACl dosages on turbidity removal of greywater sample. Percentage turbidity removal was higher at higher optimum coagulant doses. The removal of turbidity improved from 85 to 92% for alum and from 86 to 99% for PACl as the optimum coagulant dosage was increased, indicating that higher optimum dosages resulting in better turbidity removal. The mean raw turbidity level of 83±50 NTU was reduced to 6±2 NTU (removal 92%) with alum treatment and to 4±2 NTU (removal 94%) with PACl treatment. Pidou et al. (2009) while investigating coagulation of shower greywater with alum, reported turbidity removal from 46.6 to 4.28 NTU (removal 91%) at an initial pH of 4.5 and alum dose of 24 mg Al/L. In the present study, a similar turbidity removal was obtained. PACl exhibited high removal efficiency compared to alum. Pernitsky and Edzwald (2006) reported that PACls were found to be more effective as coagulants for both high and low turbidity water. This may be due to the high charge they possess and less dependence on temperature than alum. Unlike alum, where Al hydrolysis products are formed in situ, the Al species already exist for PACl and are available for coagulation (Edzwald, 1993).

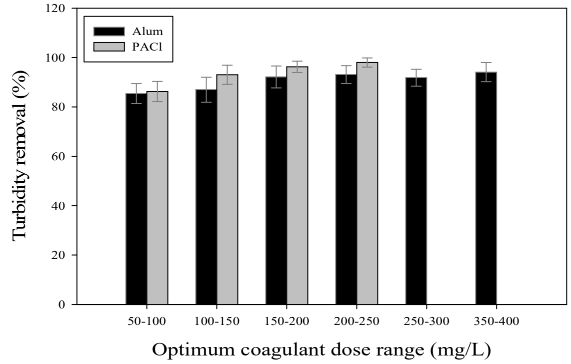
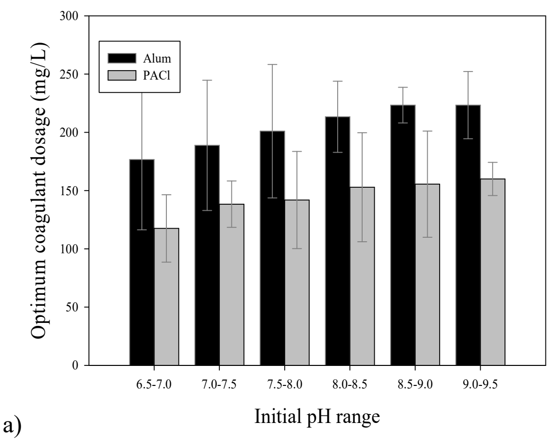


Figure 2 Effect of optimum coagulant dosage on turbidity removal

Figure 3 shows the effect of initial pH on optimum coagulant dosage and pH reduction. It is evident that as the initial pH increases optimum dosage also increases. The optimum alum dosage was observed as 175 ± 60, 190 ± 55, 200 ± 57, 210 ± 30, 220 ± 15 and 225 ± 28 mg/L and for PACl, the average optimum dosage was observed as 117 ± 28, 138 ± 19, 141 ± 41, 152 ± 46, 155 ± 45 and 160 ± 14 mg/L for greywater from pH 6.5 to 9.5 with an interval of 0.5 value respectively. It is seen that as the initial pH increased, the pH reduction also increased. The reason for this could be that the addition of high coagulant dosage at higher initial pH leads to more pH reduction. Nearly alike reduction rate was observed for alum and PACl in lower pH ranges whereas in the upper pH ranges, alum dosed samples exhibited larger drop in pH value than PACl dosed sample. In alum coagulation treatment processes for greywater treatment, initial pH is very important because aluminum species solubility is pH dependent. PACl operates within a range of pH 4.5 – 9.5 and is much less sensitive to pH.



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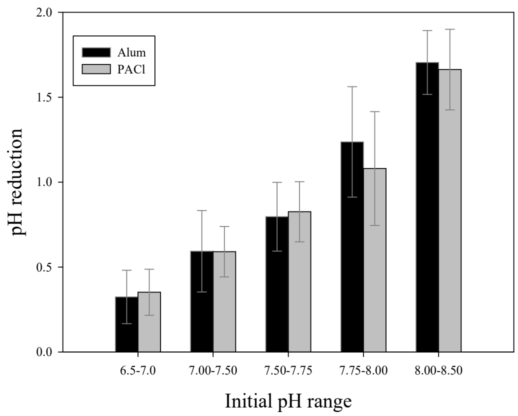

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Figure 3 Effect of initial pH on optimum coagulant dosage and pH reduction for alum and PACl

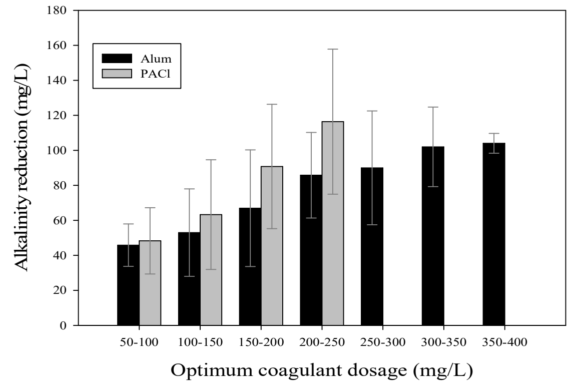


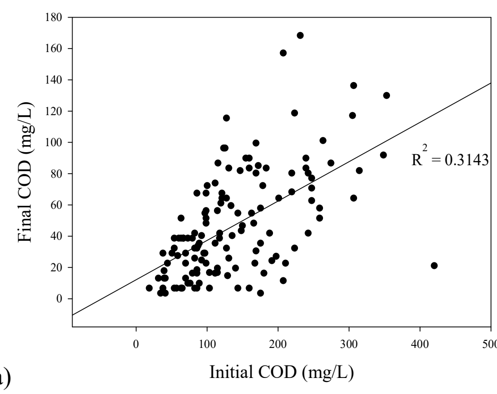
Figure 4 Effect of optimum dosage on alkalinity reduction of alum and PACl

Electrical conductivity (EC) is an alternate measure for total dissolved solids, which provides a measure of the dissolved salt content. In the current study, EC of greywater was in the range 420-1296μS/cm. It is found that the conductivity of the treated greywater is closely correlated with the initial conductivity of greywater. Coagulation ensued in an increase in conductivity of greywater which might be due to the addition of dissolved ions in the form of alum and PACl dosages. As the alum and PACl dosage was increased, the conductivity increment rate also increased due to more addition of ions. In alum, conductivity increment was high as the dosage was high compared to PACl.

The initial alkalinity of the greywater was between 100 and 330 mg/L and the final alkalinity was in the range 64-188 mg/L and 64-190 mg/L for alum and PACl respectively. Alkalinity is a measure of the acid-neutralizing capacity of water and serves as a buffer against changes in pH. If the initial alkalinity of the raw water source is too low to buffer the decreasing pH due to coagulant additions, additional alkalinity will have to be added (Crittenden et al. 2012). In this study, the levels of alkalinity in each water source were sufficient to buffer the water and prevent the pH from decreasing below 6 with the largest alum doses.

Figure 4 demonstrates the effect of optimum coagulant dosage on alkalinity reduction with alum and PACl. The coagulant addition not only decreased pH as they are acidic but also diminished alkalinity, as expected. It is coherent that with increase in coagulant dosage, alkalinity reduction increased for both alum and PACl. It is said that chemical coagulants consume alkalinity. It has been reported that alkalinity can affect the hydrolysis processes of many coagulants and have deep domination on coagulation efficiency (Ye et al., 2007).

Figure 5 shows the relationship between initial and final COD for alum and PACl coagulation treatment. As can be seen, a week relationship existed between initial and final COD. Figure 6 presents the effect of optimum coagulant dose on COD removed. It is seen that at similar dosages, PACl gave higher COD removal compared to alum. For alum, at lower dosages (50-100 mg/L), the average COD removal efficiency was 66% and at higher dosages (300-350 mg/L), the removal efficiency enhanced to 82%. For PACl also, the average COD removal increased from 70 to 84% when the dosage was rised from 50 to 200-250 mg/L. This is similar to removal efficiency reported in the literature. Pidou et al. (2008) observed an optimum COD removal efficiency of 64% at an optimum aluminium dose of 24 mg/L with alum. In this study, the average COD removal was not significantly different for alum and PACl at their optimum dosages, with alum and PACl showing COD removals of 73.2 and 74.2%, respectively.



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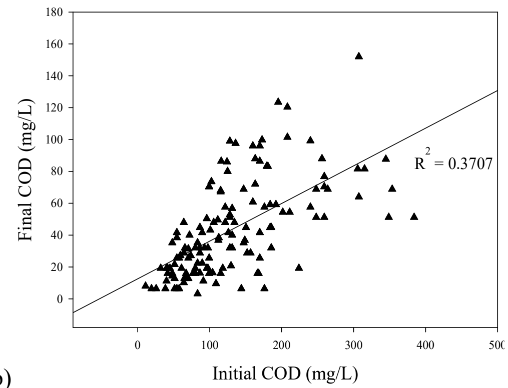

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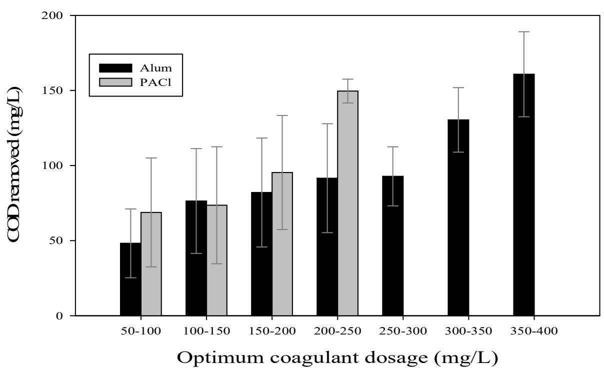
Figure 5 Relationship between initial and final COD at optimum coagulant doses for a) Alum and b) PACl



F
igure 6 Effect of optimum dosage on COD reduction of alum and PACl

Total coliform removal was also monitored and showed no significant difference with alum and PACl with removals of 98.3% and 98.9%, respectively for alum and PACl.

IV. CONCLUSIONS

Suitability of coagulation for treatment of real greywater was assessed with both alum and PACl as coagulants. In general, as the initial turbidity increased the optimum coagulant dose needed also increased for both alum and PACl. However, for similar initial turbidity levels, optimum PACl dosages required were significantly low compared to alum. Also, PACl produced lower turbidity in treated greywater. Percentage turbidity removal was higher at higher optimum coagulant doses. The removal of turbidity improved from 85 to 92% for alum and from 86 to 99% for PACl as the optimum coagulant dosage was increased. Coagulant addition significantly reduced the final pH. The pH reduction, however, was significantly higher for alum compared to PACl due to higher optimum dose requirement for alum. At similar dosages, PACl gave higher COD removal compared to alum. Total coliform removal showed no significant difference with removals of 98.3% and 98.9%, respectively, for alum and PACl. and tables must be centered in the column. Large figures and tables may span across both columns. Any table or figure that takes up more than 1 column width must be positioned either at the top or at the bottom of the page.

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