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Post treatment of UASB effluent by using inorganic coagulants: Role of zeta potential and characterization of solid residue

Nitin Kumar Singh[a,*], Siddhartha Pandey[a], Shriom Singh[a], Seema Singh[b], Absar Ahmad Kazmi[a]

[a] Department of Civil Engineering, Indian Institute of Technology, Roorkee, 247667 Uttarakhand, India
[b] Department of Chemical Engineering, Indian Institute of Technology, Roorkee, 247667 Uttarakhand, India

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ABSTRACT

In the present study, potential of four coagulants (ferric chloride, FC; ferrous sulfate, FS; poly aluminum chloride, PAC; and aluminum sulfate, AlS) was investigated in terms of removal of traditional water pollution indexes such as COD and TSS for the treatment of upflow anaerobic sludge blanket (UASB) reactor effluents. In particular, the effect of various process parameters such as coagulant dosage (m) and pH on treatment efficiency was examined along with characterization of coagulant sludge residue to evaluate its usability in future applications. The results achieved were also verified using zeta potential (ζ) measurement and particle size distribution (PSD) of coagulants in reaction mixture. Among the all investigated coagulants, maximum removal efficiency was found to be 85.5%, 80.2% and 97.4% for COD, TSS and turbidity respectively, at $m = 150$ mg/L and pH 8.5 with FC coagulant. Confirmation experiments also demonstrated that ζ measurement and PSD is a powerful and useful tool in optimization of coagulation process for the treatment of UASB reactor effluent. Scanning electron microscopy (SEM), energy dispersive X-ray spectroscopy (EDX), surface area, pore size distribution analysis and thermo-gravimetric analysis (TGA/DTA) were used for characterize the solid residue obtained after coagulation experiments. These investigation results revealed that solid residues, produced by different coagulants, have good calorific value, mesoporous in nature and possess higher surface area.

1. Introduction

In last two decades, reuse of treated municipal wastewater has gained vast attention due to increase in water demand as well as water scarcity [34]. Among the various wastewater treatment technologies, upflow anaerobic sludge blanket (UASB) is a promising technique in developing countries, particularly in Colombia, Brazil and India due to its unique features such as less sludge production, negligible energy requirement, low operating cost and energy production capability [13,41,30]. Still, effluent from UASB cannot meet the discharge standards in some countries [32]. To cope up with this issue, integration of UASB systems was successfully adopted using various post treatment strategies such as downflow hanging sponge (DHS), aerated lagoons, biological aerated filters, pond systems, constructed wetland and trickling filters so that whole system could meet the stringent discharge standards of these countries. But most of them are energy as well as investment intensive. A detailed collection of these post treatment strategies has been summarized in literature [15]. However, the removal of chemical oxygen demand (COD) and biological oxygen demand (BOD) was found to be less effective than required due to stringent discharge standards of concerned areas [14,23].

Recently, coagulation–flocculation (CF) treatment technology came into existence as an alternate of conventional post treatment technologies for the treatment of effluent from anaerobic reactors due to advantages like low cost, high efficiency and operational simplicity [51,38–40]. This treatment method cannot be used as pre-treatment as it will require immense amount of chemicals thus ultimately affects the economic viability. In addition, this method is mainly applied for the residual COD which is generally caused by inert and/or non-biodegradable materials.

To date different inorganic coagulants such as ferric chloride ($FeCl_3$), ferrous sulphate ($FeSO_4$), poly aluminum chloride (PAC) and aluminum sulphate ($AlSO_4$) have been used successfully worldwide in the wastewater treatment applications [26,52,27,6]. In CF process, the metal and hydroxyl ions, generated by the dissolution of metal inorganic coagulants in water, play significant

* Corresponding author.
E-mail address: nitin261187@gmail.com (N.K. Singh).

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role in removal of wastewater impurities. During this treatment metal ions interacts with hydroxyl ions to form insoluble metal hydroxide which adsorb the impurities by the flocculation and sedimentation process [22,33,57,21]. Furthermore, ζ-potential plays a crucial role during CF treatment and may help to understand the mechanism of pollutant removals in UASB-CF systems [54,11,8]. The value of ζ potential decreases with stability of colloidal solutions (by charge neutralization mechanism and precipitation of UASB effluent impurities on the surface of metal hydroxide flocs) followed by sedimentation and precipitation [53,44–46]. The charge neutralization mechanism, adsorption of impurities on the surface of coagulants and sedimentation followed by precipitation can be understood by measuring the ζ potential of the colloidal solution during the CF treatment.

In continuation of our related studies [2,16,17,15,51,36], present study was aimed for the post treatment of UASB reactor effluents using different inorganic coagulants (ferric chloride, FC; ferrous sulphate, FS; poly aluminum chloride, PAC; and aluminum sulphate, AlS). Particularly, the effect of coagulant dose (m) and initial solution pH (pH_o) has been studied on removal efficiency major pollution indexes such as COD, TSS and turbidity. The measurement of ζ potential and particle size distribution (PSD) has also been used as a confirmation and mechanism revealing experiment in this study. Presently various methods are available for the recovery of coagulants from sludge residues such as acidification, alkalization, ion exchange and membrane separation [29,42]. However, a combination of these may also be used for better results [12]. A detailed summary of these methods is well documented in Ref. [9]. Moreover, further investigations are required to assess the affordability of aforementioned methods. It was determined that under present technology affordability coagulant recovery offers no cost benefit in comparison to conventional practice. However process improvements, such as incorporating acid recovery, identifying alternative waste disposal routes and improving membrane performance, can significantly increase economic viability.

To gain insight about the processes involved in coagulation and flocculation, a detailed and comprehensive study is required e.g. particle size distribution and their interactions for a better understanding about removal of pollutants from the wastewater. In addition, selective information about the recyclability/reusability of solid residue and recovery of coagulants is required for practical applications. Having these considerations in mind present study was done by paying attention on role of zeta potential and potential applicability of sludge residue generated after treatment.

2. Experimental programs

2.1. Chemicals and materials

A UASB technology based sewage treatment plant located in Saharanpur, Uttar Pradesh (India) and having capacity of 38 million liters per day (MLD), was selected for regular monitoring over a period of six month. The wastewater samples were collected from the outlet of the UASB reactor and transported to the environmental engineering laboratory at IIT, Roorkee within 1 h to refrigerate at 4 °C for subsequent experiments. The main physicochemical characteristics of UASB reactor effluent are presented in Table 1. Characterization results revealed that UASB effluent still has a sufficient amount of solids and organics which can deteriorate quality of water bodies if discharged as it is. Four commercial inorganic coagulants selected in present study were ferric chloride, FC; ferrous sulphate, FS; poly aluminum chloride, PAC; and aluminum sulphate, AlS. All coagulants were obtained from Ranbaxy Chemicals Ltd. All other necessary chemicals (silver sulphate, NaOH, H_2SO_4 and mercuric sulphate etc.) were also of analytical grade and procured from Himedia Laboratories, Mumbai, India. Double distilled water was used to prepare the feedstock solutions of all coagulants. The pH values of samples were adjusted using 0.1 N NaOH or 0.1 N H_2SO_4 whenever required.

Table 1
Characteristic of samples before and after CF treatment.

Before treatment		After treatment			
Parameters	Values	Removal (%)			
		FC	FS	PAC	AlS
COD (mgL^{-1})	520	85.5	80.3	79.5	72
pH	8.2	9.7	9.9	10.4	10.8
Turbidity (NTU)	180	99	97	90.5	89.2
Total solids (mgL^{-1})	150	97.4	90.3	82.6	74.5
BOD (mgL^{-1})	210	80.2	79.2	68.4	62.4

2.2. Batch experiments methodology

In present study, several sets of CF experiments including effect of coagulant dose and solution pH on the removal of COD were performed to determine optimum conditions according to standard Jar test. The standard jar test was performed in 1-L flasks under the following conditions [20]: stirring speed during coagulation: 200 rpm; coagulation time: 5 min; stirring speed during flocculation: 20 rpm; flocculation time: 115 min settling time: 20 min. A wide range of dosage (100–500 mg/L) of coagulants was used in this study. Prior to adding coagulants, pH of samples were adjusted (from 3.5 to 10.5) to the desired level by addition of appropriate amounts of diluted H_2SO_4 and/or NaOH solution. All the treated samples were analyzed in duplicate to ensure reproducibility of the experimental results. After the designated treatment time, the supernatant samples were taken beneath the liquid surface and filtered using whatman filter paper for the measurement of turbidity, BOD, COD, and TSS. Removal efficiencies of parameters were obtained using the following equation:

$$\text{Removal}\ \% = \frac{(C_o - C_f)}{C_o}100$$

where C_o and C_f are the initial and final parameter concentrations of untreated and treated samples respectively.

The process performance was also evaluated and confirmed by measurement of ζ potential and particle size distribution (PSD) for each coagulant type which helps in optimization of coagulant dose and solution pH during the treatment. Zeta measurement of UASB effluent and supernatant of treated UASB effluent was done using a Malvern zeta sizer as per the manufacturer's instructions. In present work no dilution was made for the zeta measurement of treated and untreated UASB effluent. Although minimum of 0.75 mL volume is required for measurement but we took 3/4th of the cuvette volume as the zeta potential measurement is independent of sample volume.

2.3. Analytical and instrumental analysis

The chemical oxygen demand (COD) of treated and untreated samples was determined by using a digester unit (DRB 200, HACH, USA) and double beam UV–visible spectrophotometer (HACH, DR 5000, USA) according to standard methods for examination of water and wastewater [4]. The pH was recorded by a digital pH meter (Cyberscan 510) while turbidity of the raw sample and supernatant was measured by a portable turbidimeter (Aqualytic, Germany).