Journal of Environmental Management 184 (2016) 494–503

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

A tannin-based agent for coagulation and flocculation of municipal wastewater: Chemical composition, performance assessment compared to Polyaluminum chloride, and application in a pilot plant

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ARTICLE INFO

Article history:
Received 7 May 2016
Received in revised form
9 October 2016
Accepted 16 October 2016
Available online 24 October 2016

Keywords:
Coagulation
Flocculation
Natural flocculant
Municipal wastewater

ABSTRACT

Chemical composition and flocculation efficiency were investigated for a commercially produced tannin – based coagulant and flocculant (Tanfloc). The results of Fourier Transform Infrared Spectroscopy (FTIR) and Energy Dispersive Spectroscopy (EDX) confirmed what claimed about the chemical composition of Tanfloc. For moderate polluted municipal wastewater investigated in both jar test and pilot plant, Tanfloc showed high turbidity removal efficiency of approximately 90%, while removal efficiencies of BOD_5 and COD were around 60%. According to floc size distribution, Tanfloc was able to show distinct performance compared to Polyaluminum chloride (PAC). While 90% of flocs produced by Tanfloc were smaller than 144 micron, they were smaller than 96 micron for PAC. Practically, zeta potential measurement showed the cationic nature of Tanfloc and suggested coincidence of charge neutralization and another flocculation mechanism (bridging or patch flocculation). Sludge Volumetric Index (SVI) measurements were in agreement with the numbers found in the literature, and they were less than 160 mL/g. Calcium cation as flocculation aid showed significant improvement of flocculation efficiency compared to other cations. Finally Tanfloc showed competing performance compared to PAC in terms of turbidity, BOD_5 and COD removal, floc size and sludge characteristics.

1. Introduction

Suspended solids are one of the major pollutants in municipal wastewater. Its concentration and size distribution vary according to two main factors, namely, the population and activities. While sand, silts and other discrete particles are easy to remove by sedimentation process; colloidal particles (about 0.01–1 micron) are very difficult to be removed, due to their extremely light weight in addition to its negative charge which is acquired naturally and cause the repulsion forces between the particles (Tchobanoglous et al., 2003). In order to remove these particles, repulsion electrical forces should be suppressed first. Coagulation is the process of destabilizing (reducing the charge) particles, while coagulant is the material used to accomplish coagulation. Flocculation is applied on the process of collision of particles to form bigger size particle which is easy to be removed by simple technique like sedimentation or filtration (Tchobanoglous et al., 2003; Tran et al., 2012). Moreover, flocculation can be achieved by providing velocity gradient that helps particles to attach to each other in order to be in bigger size (Tchobanoglous et al., 2003). Coagulation and flocculation could be accomplished by different mechanisms. Charge neutralization, bridging, electrostatic patch and enmeshment in sweep flocs are the most dominant mechanisms.

Charge neutralization is the process of adding cationic metals or polymer to neutralize the negative charge of the particles (Suopajärvi et al., 2013; Tchobanoglous et al., 2003).

Bridging is the action of combining particles by attached them to one polymer chain, the more molecular weight of polymer, the better bridging ability. (Bolto and Gregory, 2007; Tchobanoglous et al., 2003), Electrostatic patch takes place when there is a highly positively charged macromolecule attached to negatively charged particles. This will lead to form a spot of positive charge on the surface of negatively charged particles which acts as attracting point for other negatively charged particles leading to attachment point between these two particles (Renault et al., 2009; Bolto and

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http://dx.doi.org/10.1016/j.jenvman.2016.10.033
0301-4797/

Gregory, 2007).

Enmeshment in sweep is a mechanism related to metal coagulants like Al^{3+} and Fe^{3+}, if high concentration of metals is added to the water, a large quantity of metal hydroxide will appear. This amorphous hydroxide will settle down and sweep the particles in its way downward (Renault et al., 2009; Tchobanoglous et al., 2003).

Conventional coagulant like Al^{3+} and Fe^{3+} are known to act as an additional burden to the environment by producing non degradable sludge, furthermore, public health risk arouse from using of Al^{3+} (Aljuboori et al., 2015; Anastasios et al., 2004; Di Bella et al., 2014; Özacar and Şengil, 2003).

Many efforts were focused on providing environmental friendly alternatives for conventional coagulants and flocculants. Some of these efforts scoured limited success by producing good alternatives in lab scale with a little quantity. Others were able to produce affordable alternative in commercial quantity. Generally, the most common natural organic alternatives for the conventional coagulants and flocculants are divided into two main categories according to their source. First category is coagulants and flocculants that is produced by microorganisms such as bacteria and fungus (Aljuboori et al., 2013, 2015, 2014; Gong et al., 2008; Li et al., 2009; Lian et al., 2008; Shih et al., 2001; Xia et al., 2008), the other category is coagulants and flocculants that are extracted from natural resources such as trees (Abidin et al., 2013; Amagloh and Benang, 2009; Beltrán-Heredia et al., 2010, 2012; Freitas et al., 2015; Graham et al., 2008; Renault et al., 2009; Shak and Wu, 2014; Teh et al., 2014).

The material investigated in this study was tannin based coagulant and flocculent, generally, tannin are polyphenolic compounds, with high solubility in water and molecular weight ranging from 500 to few thousand of Daltons. Major tannin source is trees such as Acasia mearrnsii de wild, Schinopsis balancae, and Castania sativa. Chemically, tannin is not one type, in addition, its complexity and the fact that it is extracted from different sources make the determination of its exact chemical structure is a difficult task.

Cationization of tannin is the process of granting cationic character to the tannin molecules. Based on that, the modified compound that will be produced possesses the same characteristics of the pure tannin in addition to other added characteristics. This new characteristics has its important application in coagulation process by accomplishment of charge neutralization.

From theoretical point of view, a common procedure under the name of Mannich reaction is known in the literature for cationization of tannin. Generally, this procedure comprises modification of tannin by the addition of (NH_4Cl) or other compound of Nitrogen (e.g. mono or diethanolamine) with formaldehyde in a certain proportion (to prevent tannin gelification which causes disability of dissolving Tannin in water), the resulting tannin polymer has a higher molecular weight because of formaldehyde and Mannich base crosslinking, and also has the ampholytic character due to the addition of anionic phenols and cationic amines to the polymer (Beltrán-Heredia et al., 2010, 2011).

TANAC company developed a commercially tannin base coagulant and flocculant under the name of Tanfloc. Acacia mearnsii de wild tree is the source of tannin used in this Tanfloc. This tannin was polymerized by the addition of formaldehyde, quaternary Nitrogen (NH_4Cl) and Hydrochloric acid, a mixture of these three chemicals is stirred and heated, then Tannin extract is added, this process takes several hours until a viscous mixture contains 40% solids is produced. Evaporation process where it is considered as the last step to produce Tanfloc in its powder form. (Beltrán-Heredia and Sánchez-Martín, 2009; Sánchez-Martín et al., 2009, 2010). The average molecular weight of Tanfloc is 1.7 KDa (Heredia and Martín, 2009).

The probable chemical structure of tannin extracted from Acacia mearnsii is shown in Fig. 1.

The aim of this work is to investigate the chemical characteristics of Tanfloc and its performance as coagulant and flocculent to reduce pollutants concentration in municipal wastewater in order to investigate the potential of using it as pretreatment for the conventional sewage treatment plants.

2. Materials and methods

2.1. Materials

2.1.1. Chemicals

Tanfloc was purchased in powder form, all the other chemicals PAC ($Al_2Cl\ (OH)_5$), $FeCl_3$, $CaCl_2 \cdot 2\ H_2O$, KI, $Al_2Cl(OH)_5$ were in analytical grade and supplied by R&M company. NaCl was in commercial grade.

Tanfloc and PAC were used in the experiments in solution form. Distilled water was used to prepare a solution of 1 g Tanfloc/L daily (pH became 3.1 after mixing). Moreover, PAC solution also was prepared daily by mixing 1 g PAC with 1 L distilled water (pH became 4.3 after mixing), both of these two solution were mixed for 10 min at 125 rpm by magnetic stirrer.

2.1.2. Raw water

A real municipal wastewater which produced from the hostel of faculty of Engineering/Universiti Putra Malaysia (which accommodates for 336 students) was used in both jar test and pilot plant. The main characteristics of this wastewater are listed in Table 1.

2.1.3. Pilot plant

Transparent PVC was used to build the pilot plant, according to the layout shown in Fig. 2. A submersible pump controlled by floating switch was used to pump the municipal wastewater from the sump of an existing treatment plant which is preceded by a screen unit. The wastewater was pumped to the storage tank where another submersible pump was used to deliver the wastewater to the pilot plant units at a rate of 7 L/minute (the design flow) maintained by controlling valve and flow meter.

Rapid mixing has the dimension of length, width and depth of 0.5, 0.4, and 0.56 m respectively, it is supplied with a mixer (Montroli type ML7124, with power of 0.37 kW) driving a disk – type radial flow impeller with diameter of 20 cm, at 180 rpm. It is provided with pH meter and dosing pump to introduce Tanfloc, the dosing pump (Seko brand) has a maximum flow of 2 L/hr (for viscous liquid) and 9 L/hr for water, the flow could be adjusted.

Slow mixing tank has the dimension of length, width and depth of 0.85, 0.5, and 0.52 m respectively, it is supplied with a mixer (Montroli ML 632.4, with power of 0.18 kW) driving a tow layer

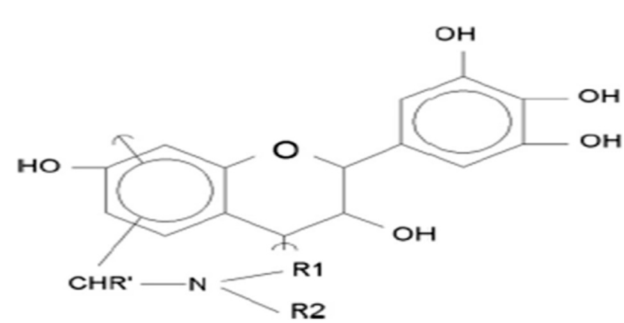

Fig. 1. Probable chemical structure of Tanfloc (Sánchez-Martín et al., 2010).