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A tannin–based agent for coagulation and flocculation of municipal wastewater as a pretreatment for biofilm process

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ABSTRACT

The effects of a commercially produced Tannin-based coagulant and flocculant (Tanfloc) in a biofilm process pilot plant treating municipal wastewater were investigated. The investigated flow rates were 10, 14 and 18 L/min for the entire pilot plant, with two additional flows of 22 and 24 L/min were used for flocculation and sedimentation processes only. There was no clear deterioration in flocculation efficiency; even at 24 L/min, where the flocculation time was only 7.5 min. In terms of the clarification process, the enhancement was remarkably good; especially at high flows. Without Tanfloc, the removal efficiencies in the clarifier were less than 20%, 40%, 22% and 8% for turbidity, total suspended solids, biochemical oxygen demand and total phosphate, respectively. Meanwhile, when Tanfloc was used, they achieved 75%, 61%, 60% and 16% for the same respective pollutants. A significant rise in dissolved oxygen level in the aeration tank was observed when Tanfloc was applied (promising saving of energy during aeration). For instance, a dissolved oxygen level of 3 mg/L measured in experiments without Tanfloc, witnessed a climb to 6 mg/L when Tanfloc was used. In addition, volatile suspended solids concentration in the aeration tank decreased when Tanfloc was used (promising less production of sludge). Other measurements of total suspended solids (mg/L), chemical oxygen demand (mg/L) and biochemical oxygen demand (mg/L) in the experiments without Tanfloc were in the range (12–36), (60–104) and (24–50), respectively. Remarkably Tanfloc was able to reduce these measurements to low levels of (9–26), (28–68) and (7–24). In conclusion, the results suggest Tanfloc as promising agent to enhance the performance of clarification in a biological treatment unit. In light of this enhancement, Tanfloc could be used to upgrade existing treatment plants or design compact treatment units.

1. Introduction

Conventional sewage treatment plants construction and operation are highly expensive and require spacious area. In order to limit this problem, several attempts were conducted to develop and modify the conventional treatment units or provide other alternative methods with less requirement of construction, operation or land cost.

Reducing of organic load on the biological unit in the treatment plant is one of the attempts that may contribute to reduce the requirement of volume and oxygen for this unit. By reducing the organic load, faster treatment process is expected and consequently, exploitation of the same tank for the treatment of higher flow is anticipated. Moreover, since aeration of wastewater is the main consumer of energy in treatment plant (Dotro et al., 2011; Zhou et al., 2013), it will be a great benefit to reduce the oxygen requirement. United States Environmental Protection Agency (2010) stated that Oxygen requirement is a reflection of diurnal pattern of organic load, based on that, less requirement of oxygen coincides with having less organic load.

Practically, enhancement of sedimentation process is one of the alternatives to reduce the organic load on the biological unit (Tchobanoglous et al., 2003). Enhancement of sedimentation

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process could be achieved by preceding coagulation and flocculation into the process. An argument about the feasibility of this strategy is anticipated, however feasibility depends on the characteristics of the targeted wastewater (portion of suspended organic matters to total organics), availability of land, power cost, flocculant cost, primary sludge production expected increment due to capturing of more solids and anticipated decrement as a consequence of compaction when more solids are captured (Beltrán-Heredia and Sánchez-Martín, 2009), secondary sludge production (expected decrement due to slower biofilm growth rate as a consequence of lower influent organic load (Andreoli et al., 2007) and anticipated increment due to less compaction effect when the separated biofilm solids are less).

Flocculation has been used in combination with other treatment processes to treat a variety of wastewater. It has been used in full scale treatment plants with filtration as a post treatment process for municipal wastewater (Wang et al., 2017). Moreover, it has been used in pilot plants as a pretreatment (Sánchez-Martín et al., 2010) with sedimentation and slow sand filtration, and as a post treatment (Bongiovani et al., 2015) with filtration to remove the trace of organic matters. Finally, it has been used in batch-wise experiments in combination with oxidation and filtration (Hashem et al., 2016) and in coupling with membrane filtration and Fenton reactions (Gonçalves et al., 2017) and with photo-Fenton oxidation and sequential batch reactor (Rodrigues et al., 2017).

While coagulation is neutralization of negatively charged colloidals, flocculation is the accumulating of these neutralized colloids together to form bigger particles which can be easily settled (Tran et al., 2012). Coagulants and flocculants are those materials which possess the ability to achieve coagulation and flocculation. Conventional coagulants and flocculants are aluminum and ferrous salts. Several environmental (Nair and Ahammed, 2015) and public health (de Paula et al., 2014; Kakoi et al., 2017) problems aroused due to extended use of these conventional chemicals. Because of that, great efforts were paid to provide organic environment friendly alternatives to be substituted for the conventional inorganic chemicals. For example, Chitosan (Renault et al., 2009), Moringa oleifera seeds (Amagloh and Benang, 2009), Tannin (Beltrán-Heredia et al., 2010), Jatropha curcas seeds (Abidin et al., 2013) in addition to biopolymers exerted by certain species of microorganisms (Aljuboori et al., 2014) were exploited as environmental friendly coagulants. While some alternatives are produced in commercial quantity, others are still in the limits of lab scale production.

Tanfloc is a natural organic coagulant and flocculant, mainly consists of tannin which is extracted from *Acacia mearnsii De Wild* tree, this tannin is cationized by a certain chemical procedure under the name of Mannish reaction. In this reaction, a mixture of formaldehyde, quaternary Nitrogen (NH_4Cl) and hydrochloric acid (HCl) is stirred and heated, and then tannin extract is added, this process takes several hours until a viscous mixture contains 40% solids is produced, evaporation process is the last step to produce Tanfloc in its powder form. . The modified tannin possesses additional characteristics (cationic charge and higher molecular weight which is around 1.7 KD) that improve its ability to coagulate and flocculate colloids (Sánchez-Martín et al., 2009). Unlike conventional inorganic coagulants, Tanfloc is a biodegradable material. The value of biochemical oxygen demand (BOD_5)/chemical oxygen demand (COD) ratio for the aqueous solution of Tanfloc is 0.62 which indicates high biodegradability (Hameed et al., 2016).

Tanfloc has been used as a pretreatment agent in pilot plants comprise only physical/chemical treatment units such as sedimentation/slow sand filtration (Sánchez-Martín et al., 2010) and multi-layer filter/chlorination (Bongiovani et al., 2015). The aim of this study is to evaluate the effect of Tanfloc as a pretreatment agent on the performance of a pilot plant comprises biological treatment unit.

2. Materials and methods

2.1. Materials

2.1.1. Tanfloc

Tanfloc was purchased in powder form and used in the experiments as an aqueous solution with pre-determined concentrations depending on wastewater flows in the experiments.

2.1.2. Raw municipal wastewater

The municipal wastewater which is used in the experiment was produced from the hostel of Faculty of Engineering at Universiti Putra Malaysia. This hostel accommodates for 336 students with one central canteen. The main characteristics of the municipal wastewater are listed in Table 1.

2.1.3. Biofilm carrier

Cosmoballs (trademark of Pakar Management Technology/ Malaysia) were used as biofilm carrier, they are hollow spherical polyethylene media with eight holes, each hole is 1 cm diameter, specific gravity of 0.9, average diameter of 8 cm, specific surface area of 160 m^3/m^2 and 2000 pieces occupy 1 m^3. The cosmoballs were packed in mesh bags used for fishing (100 pieces/bag) to maintain packed bed condition and immersed in the aeration tank with a filling ratio of 50%. This filling ratio is recommended by the manufacturer and it falls in the range that used by the researchers (Gu et al., 2014; Pal et al., 2012).

2.1.4. Pilot plant

The pilot plant was installed in the hostel mentioned earlier. It is made of transparent PVC and consists of the following units as illustrated in Fig. 1.

2.1.4.1. Raw water tank. Raw water tank (1250 L) is the first unit in the pilot plant. It receives wastewater from the sump of the real treatment plant in the hostel which is preceded by a screen unit. A submersible pump in this tank is used to convey the wastewater to the successive units of the pilot plant. A gate valve and flow meter were used to control the flow of this pump.

2.1.4.2. Dosing pump. Two dosing pumps (Seko) were able to eject a total amount of 10 L Tanfloc solution per hour. They were taking the solution from the buckets and dosing it to the coagulation tank.

2.1.4.3. Coagulation tank. This tank has the dimension of length,

Table 1
Raw wastewater characteristics.

Parameter	Unit	Value
Turbidity	NTU	38–79
Total suspended solids (TSS)	mg/L	52–120
Total dissolved solids (TDS)	mg/L	205
BOD_5	mg/L	50–146
COD	mg/L	134–352
Conductivity	μ s/cm	413
Nitrate (NO_3)	mg/L as N	0.4–0.9
Nitrite (NO_2)	mg/L as N	0
Ammonia Nitrogen (NH_3- N)	mg/L as N	15–29
Total Phosphate (PO_4)	mg/L as p	3.5–7.9
Temperature	C	27–29
pH		6.6–7.9