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SHORT REPORTS

Evaluation of plant-based natural coagulants for municipal wastewater treatment

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Abstract

In this study, four plant-based natural coagulants (banana peel powder, banana stem juice, papaya seed powder and neem leaf powder) were evaluated for the removal of turbidity, chemical oxygen demand (COD) and total suspended solids (TSS) from municipal wastewater. The experiments were conducted at room temperature without adjusting the initial pH. The maximum turbidity removal was observed with banana peel powder (59.6%) at 0.4 g/L of dosage. Papaya seed powder and banana stem juice were the most effective for TSS removal (66.66%) and COD removal (66.67%), respectively. Significant linear relationships between turbidity and TSS ($R^2 = 0.67–0.88$) and turbidity removals and COD removals ($R^2 = 0.68–0.8$) were observed. Interestingly, all the natural coagulants tested in the study did not change the pH of the wastewater, which is an added advantage. FTIR analysis of banana peels revealed that functional groups such as carboxylic acid, hydroxyl and aliphatic amines might be responsible for promoting the coagulation–flocculation by neutralizing the charge on impurities in water. Overall, the results suggest the potential of low-cost natural coagulants in municipal wastewater treatment.

Keywords Coagulation · Natural coagulants · Turbidity · Banana peel powder · Sewage treatment

Introduction

Coagulation is a physical–chemical process to remove turbidity of drinking water and wastewater. Conventionally, chemical-based coagulants such as alum ($AlCl_3$), ferric chloride ($FeCl_3$), polyaluminium chloride and synthetic polymers (polyacrylamide) are used to remove the turbidity of water (Šćiban et al. 2009; Alwi et al. 2013; Choy et al. 2014). Though chemical coagulants are effective in wastewater clarification, their use is not sustainable. Generation of excessive non-biodegradable sludge is the major issue of using chemical coagulants for wastewater treatment (Carvalho et al. 2016).

An alternative greener and sustainable approach is use of natural coagulants for turbidity removal. Natural coagulants from plant-based materials or renewable sources are attracting a lot of attention due to their various advantages over chemical counterpart. They are biodegradable (Asrafuzzaman et al. 2011), non-toxic, non-corrosive (Swati and Govindan 2005) and cheaper than chemical coagulants. Since they produce lesser sludge with high nutritional value (Choy et al. 2014), the sludge handling and treatment cost is minimal. Despite these advantages, natural coagulants are not commercialized so far (except few such as *Moringa oleifera* seeds) (Choy et al. 2014). Challenges in harvesting and processing of natural coagulants from plants might be the major factors limiting their commercialization.

Waste or non-useful materials such as orange peel, banana pith and neem leaf powder have also been utilized as natural coagulants (Anju and Mophin-Kani 2016; Kakoi et al. 2016). However, most of these natural coagulants have been tested on synthetic wastewater. The main objective of this study is to evaluate the coagulation potentials of banana peel powder, banana stem juice, papaya seed powder and neem leaf powder for the treatment of municipal wastewater.

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Materials and methods

Materials

Fresh banana (*Musa acuminate*) peels and papaya (*Carica papaya*) seeds were collected from the Hostel Kitchen of Doon University, Dehradun, India. Banana (*Musa acuminate*) stem and neem (*Azadirachta indica*) leaves were either collected from field or purchased from local market. The raw municipal wastewater used in the study was collected after the preliminary treatment (fine screening) from sewage treatment plant (STP), located near Doon University, Dehradun. The wastewater was characterized in terms of pH (7.73 ± 0.05), COD (chemical oxygen demand; 118.66 ± 22 mg/L), turbidity (71.66 ± 5.5 NTU) and TSS (total suspended solids; 113.33 ± 4.16 mg/L).

Preparations of natural coagulants

The banana peels were cut into small pieces and washed thoroughly with tap water to remove any external dirt. The washed pieces of banana peels were air-dried under sunlight for 2 weeks and oven-dried for 24 h at 105 °C. The dried banana peels were grinded to fine powder using mortar pestle. The banana stem juice was prepared as per the methodology reported by Alwi et al. (2013). In brief, small pieces of the stem pith (~ 100 g) were grinded with 10 ml of distilled water in mortar pestle. The grinded pith was then filtered to collect the banana stem juice, which was kept in a refrigerator at 4 °C till use. The papaya (*Carica papaya*) seeds were first dried at ambient temperature (20–28 °C) for a period of 5 days and then crushed into fine powder using mortar pestle and used as coagulant. The leaves of neem were washed with tap water and then dried under sunlight for 3 days before grinding to fine powder. The powder obtained after grinding the banana peels, papaya seeds and neem leaf was sieved with a mesh of size 0.5 mm and used as coagulant.

Coagulation tests to study the municipal wastewater treatment by natural coagulants

A laboratory jar testing apparatus (Microteknik, India) with six-paddle rotor for 500–1000 mL beakers was used for coagulation tests. All the experiments were performed using 500 mL of wastewater in beakers as reported by Alwi et al. (2013) and using desired dosage of natural coagulants. The dosages of coagulants tested in the study are described in Table 1. The wastewater in the beakers (with and without coagulant) was stirred at high speed of ~ 120 rpm for 1 min. The speed of the mixer was then reduced to ~ 30 rpm and the contents of the beakers were mixed for 20 min. The purpose of high-speed mixing was to evenly distribute the coagulant, while the slow speed mixing was used to keep floc particles uniformly suspended in the water (Alwi et al. 2013). The content of the beaker was then kept for 1 h to allow the settling of floc particles. The supernatant was then collected without disturbing the settled floc particles and analyzed for turbidity, TSS, COD and pH. The experiments were conducted at room temperature and the pH of the wastewater was neither adjusted before the experiment nor controlled during the experiment. All the experiments were performed in duplicates.

Table 1 Dosages of natural coagulants tested for wastewater treatment

Jar number	Coagulant dose			
	Banana peel powder (g/L)	Banana stem juice (ml/L)	Neem powder (g/L)	Papaya seed powder (g/L)
1	0	0	0	0
2	0.4	10	1.0	0.8
3	0.8	20	1.2	1.2
4	1.2	30	1.6	1.6
5	1.6	40	1.8	2.0
6	2.0	50	2.0	3.0

Analytical methods

The turbidity and pH of the wastewater, before and after jar test, were measured using the nephelometer and pH meter, respectively. The COD and TSS of the water samples were analyzed as per the standard methods of water and wastewater treatment (American Public Health Association (APHA) et al. 2005). Closed reflux method was used for COD analysis. Fourier-transform infrared spectrum (FTIR) of the banana peel powder was obtained as KBr pallet with Thermo Nikolet Nexus FT-IR spectrometer.

Results and discussion

Municipal wastewater treatment by natural coagulants

Figure 1 shows the wastewater treatment efficiencies of natural coagulants. The maximum coagulation activities (turbidity removal efficiencies) of banana peel powder (0.4 g/L dosage), neem leaf powder (1.0 g/L dosage), papaya seed powder (0.8 g/L dosage) and banana stem juice (10 mL/L dosage) were found to be 59.6, 43.96, 41.89 and 18.78%, respectively (Fig. 1). It is clearly evident from Fig. 1 that the dosage of coagulant significantly affects the coagulation

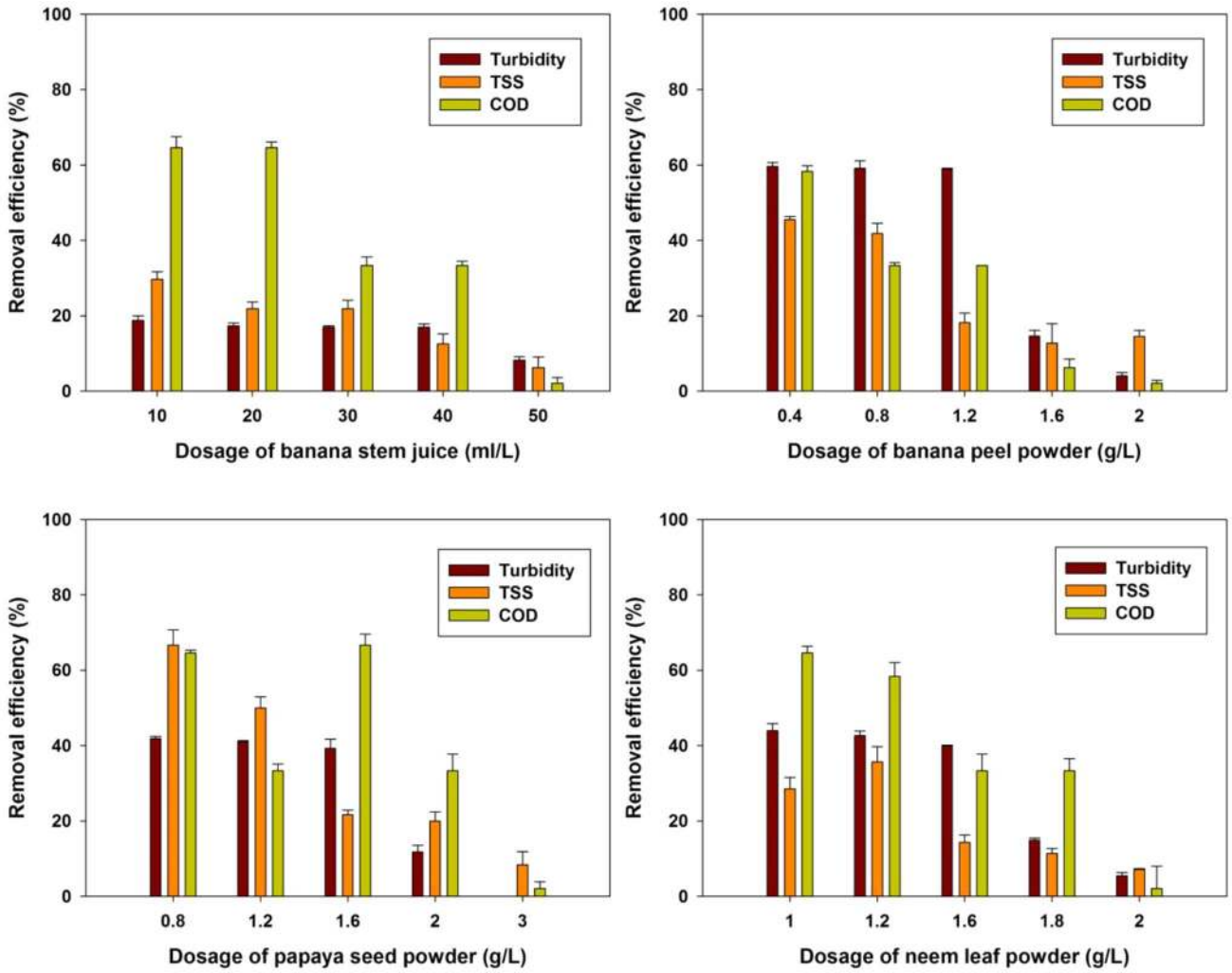

Fig. 1 Wastewater treatment by natural coagulants. **a** Banana stem juice. **b** Banana peel powder. **c** Papaya seed powder. **d** Neem leaf powder

activity (turbidity removal). It is observed that high dosage of coagulant had negative impact on the coagulation activity. In case of banana peel powder, the coagulation activity decreased from ~ 59 to 14.6% when the dosage increased from 1.2 to 1.4 g/L. Similar results were obtained with papaya seed powder and neem leaf powder (Fig. 1).

The TSS and COD removal efficiencies also decreased at higher dosage of natural coagulants. It is obvious as there is a relationship between turbidity and TSS of wastewater, which can be represented by Eq. 1 (Tchobanoglous et al. 2003):

$$\mathrm{TSS} \approx (\mathrm{TSS_f}) \times (T) \quad (1)$$

where, TSS is total suspended solids (mg/L); T is turbidity (NTU) and $\mathrm{TSS_f}$ is conversion factor (mg/L TSS/NTU).

In our study, significant linear relationship between turbidity and TSS (R^2 = 0.67–0.88) was observed. Similarly, turbidity removals and COD removals were found to have significant linear relationship (R^2 = 0.68–0.8). Mucha and Kułakowski (2016) also reported a high correlation of TSS and COD with turbidity of wastewater. The order of maximum TSS removal efficiencies by natural coagulants were papaya seed powder (66.67%) > banana peel powder (45.45%) > neem leaf powder (35.75%) > and banana stem juice (29.69%). Among the tested natural coagulants, the banana peel powder had slightly less COD-removal efficiency (58%) than banana stem juice (64%), papaya seed (66.67%) and neem leaf powder (64%).

Effect of natural coagulants on pH

The initial pH of the wastewater before the jar test was 7.73. It was observed that after the jar test, the pH was not significantly changed, irrespective of coagulant type used (banana peel powder, neem leaf powder, papaya seed powder and banana stem juice) and it varied between 7.1 and 8.0. This

property of the coagulant has significant value in the wastewater treatment either as primary treatment or tertiary treatment. In both cases, adjustment of pH would not be required after the coagulation process.

Potential coagulants presents in banana peel powder and possible mechanism of coagulation

Banana peel powder was found to be a better coagulant than others in terms of coagulant activity (turbidity removal). Banana peel is composed of polymeric substances such as fiber (11.04%) and protein (10.14%) (Memon et al. 2008). The FTIR analysis of banana peels revealed various peaks of different functional groups such as carboxylic acid (C=O), hydroxyl (-OH) and aliphatic amines (N–H) indicating the presence of both positively and negatively charged species in the polymeric substances (Fig. S1). These functional groups of banana peel powder might be responsible for promoting the coagulation–flocculation by neutralizing both positively and negatively charged impurities in water. Memon et al. (2008) and Thirumavalavan et al. (2011) also reported the role of these functional groups in the removal of impurities from water.

Conclusion

The present study evaluated the feasibility of using natural coagulants from four waste or low-cost materials viz. banana stem juice, banana peel powder, papaya seed powder and neem leaf powder to clarify the wastewater. In terms of coagulation activity, the banana peel powder was found to be the most effective while banana stem juice had poor coagulation activity. The initial results indicate that banana peel powder as natural coagulant has tremendous potential for wastewater treatment.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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