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Municipal wastewater treatment using different coagulants

Maruf Mortula[a], Tarig Ali[a], Ahmed Elaksher[b,*]

[a]*Department of Civil Engineering, American University of Sharjah, UAE, emails: mmortula@aus.edu (M. Mortula), atarig@aus.edu (T. Ali)*
[b]*College of Engineering, New Mexico State University, Las Cruces, New Mexico, USA, Tel. +1 575-646-2236; email: elaksher@nmsu.edu*

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ABSTRACT

Secondary wastewater treatment plants often release some organic material, phosphorus and turbidity. These residual pollutants are capable of causing problems even at a low level. Therefore, tertiary treatment of secondary effluent was used as the main objective of this study. Laboratory-based experiments were conducted to achieve the objectives. The jar test was used to represent the coagulation precipitation process. Lime, dried leaves, and polymer were used as the coagulants. Alum was used for comparison. The effect of the removal of phosphorus, BOD and turbidity was investigated as part of the advanced treatment. Secondary effluents from two different wastewater treatment plants were used in this study to assess the effect of pretreatment process on the performance of wastewater treatment. The results revealed coagulation precipitation process using different coagulants were capable of removing phosphorus up to 68%, and BOD up to 100%. The results were comparable with traditional coagulant, alum with 80% for phosphorus and 100% for BOD. The increase in pretreatment appeared to increase the ability of these coagulants in removing phosphorus from 34.5% to 48% and BOD from 73.3% to 82%.

Keywords: Coagulation; BOD removal; Phosphorous removal; Treated wastewater effluent; Jar test

1. Introduction

Municipal wastewater treatment often targets total suspended solids and biochemical oxygen demand through the primary and biological treatment process. However, residual organic material and phosphorus can cause problems for environment friendly reuse and/or disposal. Phosphorus plays an important role in promoting eutrophication [1,2]. The quantity of phosphorus discharged into water bodies needs to be controlled [3]. Many countries are getting strict on phosphorus disposal in surface water bodies. Berlin, Germany is adopting a total phosphorus limit of 50 μg/L in the treated wastewater [4]. For this reason, phosphorus removal is considered a priority for tertiary wastewater treatment. BOD removal from secondary effluent is also important not only to meet the regulatory requirements but also to limit the formation of disinfection by-products. For many industrial wastewaters, the trouble with BOD after biological treatment is even more common than residential wastewater.

There are many different processes used to remove phosphorus from wastewater. Biological phosphorus removal processes are often used in many treatment plants. However, they are not really effective at low phosphorus concentrations. For this reason, physical chemical processes are preferred for low phosphorus concentrations [5,6]. Chemical precipitation is one of the most viable options for phosphorus removal [7,8]. Chemical precipitation is a simpler process compared with adsorption and other physical

* Corresponding author.

processes which often require difficult configurations [9]. However, in addition to removal of phosphorus, precipitation process can also remove other pollutants as well. Ferric chloride and electrocoagulation have been used to remove 63%–97% phosphorus from spiked municipal wastewater [10,11]. In another study, ferrous sulfate, ferric sulfate, polyferric sulfate and acid mine drainage were used to remove phosphorus. Use of coagulation process for the removal of BOD is common. A previous study explored the potential for a tannin-based coagulant and observed 60% BOD removal [12]. Aluminum and iron salts were also capable of removing 88% removal of COD in a laboratory-based study [13]. However, there was no characterization done to evaluate the process. Another previous study conducted on the use of natural material from coconut tree and observed a significant BOD removal [14]. Tanfloc and polyaluminum chloride were used to remove BOD from wastewater [15]. The presence of cations was identified as one of the main reasons for the improved BOD removal.

Phosphorus and BOD are removed separately by using coagulation and precipitation process. However, studies focused on coupled removal of BOD and phosphorus is limited. A previous study identified the ability of riparian reeds to remove phosphorus and BOD from river water [16]. However, the study did not explore the context of water treatment. A rapid coagulation process using a mixture of glass and clay powder was able to achieve phosphorus removal up to 99% and BOD removal of up to 90% [17]. The study did not elaborate on the physical chemical processes involved during the water treatment. Another study conducted by Wu et al. [18], used ferric coagulation with ozonation and received good BOD removal and not much of phosphorus removal from petrochemical secondary wastewater. Biological process was used for the BOD removal. Coagulation with membrane bioreactor was also able to remove BOD and total phosphorus from car wash water [19]. However, biological process was the main reason for the efficiency of the water treatment.

The performance of coagulation precipitation process is often affected by different operating parameters. Even though the previous studies identified the effect of coagulant type, coagulant dose, and pH level on the phosphorus removal during coagulation precipitation [20–22], they were mostly limited within chemical coagulants, and not planned for coupled phosphorus and BOD removal using both natural material and chemicals. Therefore, there is a necessity to investigate the tertiary treatment option for removal of both phosphorus and BOD from secondary effluent. Chemical precipitation can also generate a large number of waste residuals, leading to a necessity for a suitable waste management option. Many wastewater treatment plants in the Middle East currently do not treat phosphorus from wastewater, as it is often deemed expensive to manage the subsequent waste. For this reason, selection of a locally available biodegradable material can be of advantage. Palm tree leaves are one such locally available material in the Middle East. However, there aren't any studies investigated on the potential of using dried tree leaves for removal of phosphorus and BOD in the Middle East. The use of palm tree leaves as adsorbents of heavy metal has been documented [23]. Biosorption process was identified for removal of heavy metals. For this reason, there is a possibility of these tree leaves to be capable of removing other pollutants.

The objective of this paper was to assess the effectiveness of different chemicals for coupled removal of BOD and phosphorus from secondary effluent. The research also aims to investigate the role of coagulant type and dosage on the chemical precipitation process. The objectives were achieved through laboratory-based experiments using jar tester. Secondary effluents from two different wastewater treatment plants were used in the study. Alum, lime, polymer and dried tree leaves were used to assess the effect of different types of materials. Different water quality parameters were monitored.

2. Materials and methods

2.1. Materials

2.1.1. Coagulants

In this study, four different types of coagulants such as lime (CaO), alum ($Al_2(SO_4)_3{\cdot}18H_2O$), polymer (polyaluminum chloride) and dried palm tree leaves were used. Lime and alum were commercial grade, procured from a commercial supplier. The polymer was collected from the Al Aweer wastewater treatment plant. Palm tree leaves were collected from locally available trees in American University of Sharjah Campus. The leaves were washed with deionized water, dried in the oven at 100°C for 24 h. After that, it was cooled down to room temperature and then crushed to particles with less than 1 mm size.

2.1.2. Wastewater

The secondary effluents were collected from two different wastewater treatment plants (WWTP1 and WWTP2) in United Arab Emirates. The wastewater samples in this study were collected after biological treatment processes. After being collected, they were stored in a freezer at 0°C, and experiments were conducted within a week. Water quality parameters for both the treatment plants were similar in nature. However, WWTP1 has different wastewater characteristics to WWTP2 (Table 1). However, nutrients were treated better in WWTP1 compared with WWTP2. However, phosphorus levels are still higher than many treatment plants in the west. Both the treatment plants are advanced

Table 1
Wastewater characteristics for two wastewater treatment plants in this study

Characteristics	WWTP1		WWTP2	
	Influent	Secondary effluent	Influent	Secondary effluent
BOD_5, mg/L	290	9.8	450	20
TSS, mg/L	325	12	282	10
NH_3–N, mg/L	38.5	2	40	14.61
PO_4, mg/L	20	0.9	9.75	7.2
pH	7.2	7.5	7.3	7.3

wastewater treatment plants (Fig. 1). Both of the plants are activated sludge–based wastewater treatment plants. The plants were within 30 km of each other. WWTP1 is bigger in size compared with WWTP2. WWTP1 has an additional biological filtration process used compared with WWTP2. However, none of the treatment plants was designed to remove nutrients. Due to the use of dual biological processes, WWTP1 had some phosphorus removal done.

2.2. Experimental approach

Laboratory scale jar test apparatus was used to represent the coagulation flocculation process. Standard jar test procedure was followed in conducting the experiments [24]. One liter of wastewater sample was added to each jar. Different doses (0, 20, 40, 60, and 80 mg/L) of the coagulants were added to the jars. A typical mixing rate of 300 rpm was used for 2 min for coagulation, 30 min of flocculation at 30 rpm, followed by 1 h without mixing for sedimentation [24,25]. After the process is completed, samples were collected through the individual ports from each jar. The collected samples were tested for different water quality parameters.

Assessment of the effectiveness of chemical precipitation was conducted by four sets of jar tests using lime, tree leaves, and polymer and compared them with a common coagulant, alum. The tests were conducted using wastewater from WWTP1. Assessment of the factors affecting the advanced treatment was conducted on wastewaters from both the wastewater treatment plants. Lime, polymer and tree leaves were used in these studies. The same coagulant dosage was used in these studies.

2.3. Analytical methods

Water quality analysis was conducted based on Standard Methods [26]. The samples collected after the jar tests were analyzed for pH, turbidity, phosphorus and biochemical oxygen demand (BOD). Phosphorus was measured based on the ascorbic acid method (standard method 4500-P-E) using Hach spectrophotometer. BOD tests were conducted based on the respirometric method (standard method 5210D) using Hach BOD Track system. Five-day BOD test was conducted as a standard indicator of organic pollution. Turbidity was measured based on nephelometry method (standard method 2130B) using Hach portable Turbidimeter (2100 P). pH of the samples was also measured using a standard pH meter.

3. Results and discussion

3.1. Treatment of municipal wastewaters

All the coagulants were able to remove phosphorus (Fig. 2). Alum was considered benchmark for assessment of the effectiveness of treatability as it is widely used and accepted as a coagulant [27]. With the dosage tested during the study, the phosphorus removal using lime (up to 68%) was comparable with alum (up to 80%). Other coagulants were not able to remove comparable phosphorus removal to alum. However, all the materials were able to remove more than 50% BOD removal. However, tree leaves were able to remove the largest amount of BOD (up to 100%). Turbidity levels dropped to 40 and 60 mg/L of coagulant dosage and then increased slightly (Fig. 3). However, the turbidity reduction in all the types of coagulants was comparable with alum. pH levels in water treated in tree leaves and polymer mostly remained unchanged. It was consistent with the effect of alum dosage on the pH level. However, pH level increased during lime treatment of the wastewater. The coagulants can be added in the aeration tanks, as common practice in many treatment plants around the world. Among the coagulants, polymer is viewed as more expensive than others. Also, dried tree leaves are waste materials and hence provide an added advantage on reduced waste going to landfill sites.

3.2. Assessment of factors affecting wastewater treatment

3.2.1. Effect of the different type of coagulants

Phosphorus levels decreased with the addition of all the three types of coagulants (Fig. 4). It indicated all the materials were capable of removing phosphorus. The polymer

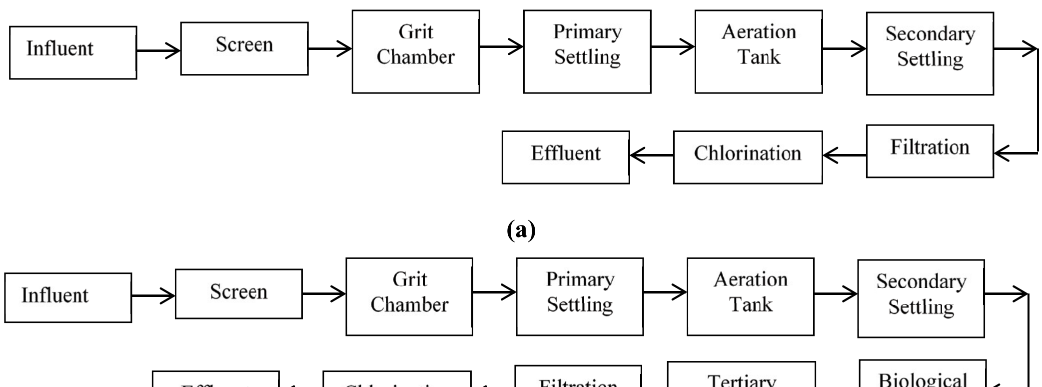

Fig. 1. Treatment process diagrams for two wastewater treatment plants in this study (a) WWTP1 and (b) WWTP2.

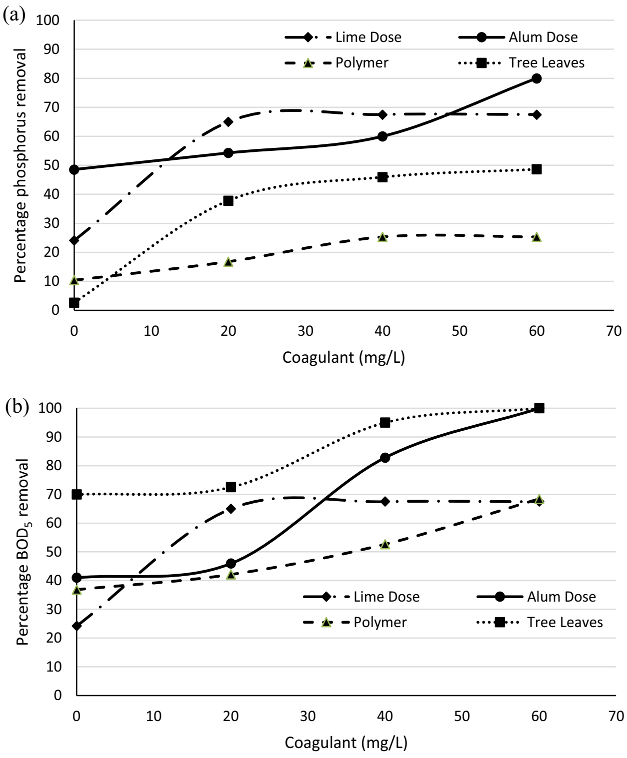

Fig. 2. Phosphorus and BOD removal from wastewater (a) Phosphorus removal from wastewater and (b) BOD removal from wastewater.

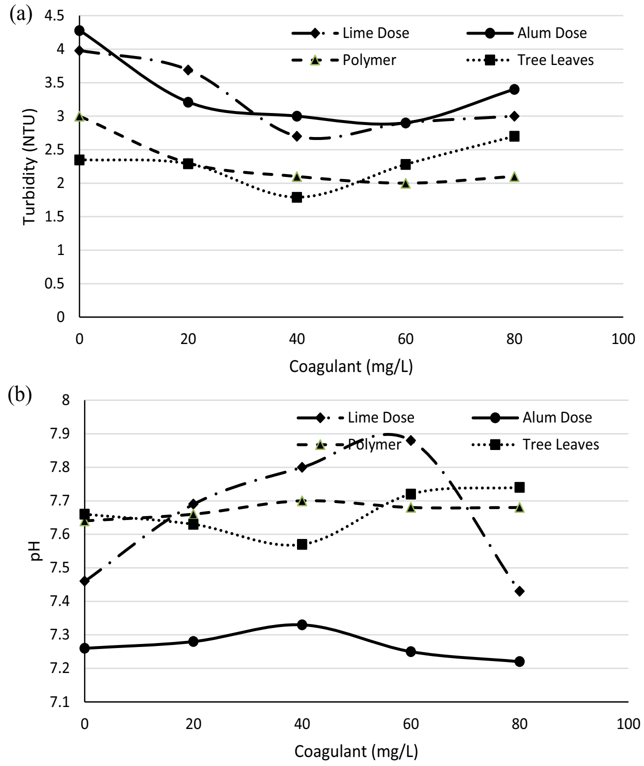

Fig. 3. Turbidity and pH during coagulation treatment (a) turbidity levels for all the different coagulants and (b) pH levels in all different coagulants.

showed the highest phosphorus removal capabilities, followed by lime and tree leaves. The same pattern existed for both the wastewaters. Polyaluminum chloride forms aluminium phosphate precipitate. Lime might have formed calcium phosphate precipitate to remove the phosphorus. Palm tree leaves have carboxyl group present. It could be an ion exchange process with phosphate replacing the carboxyl group.

BOD_5 decreased with the addition of all the coagulants (Fig. 5). It indicated that all the materials were capable of removing organic material. Tree leaves showed the highest organic removal capabilities, followed by polymer and lime. The results for polyaluminum chloride and lime were consistent with the previous literature [28,29]. Palm tree leaves have hydroxyl group present. BOD removal could be associated with organic material replacing the hydroxyl group.

All the coagulants were capable of removing turbidity (Fig. 6). Both lime and polymer are known to be used as coagulants for turbidity removal [25,30]. Palm tree leaves, however, have not been used previously. The results indicated that a highly charged surface from tree leaves was capable of removing turbidity. pH levels fluctuated (7.5–7.9) with the increasing coagulant concentrations all the three types of coagulants for both the type of wastewater (Fig. 7).

3.2.2. Effect of coagulant concentrations

The phosphorus removal increases with an increase in all the coagulant concentrations (Fig. 4). However, within the dosage of coagulants investigated, the percentage removals were mostly below 60%. For both the type of wastewater, all the coagulants removed more than 70% organic material at 80 mg/L (Fig. 5). The use of polymer decreased the turbidity levels until 40 mg/L for both the wastewater tested (Fig. 6). The result is consistent with the previous literature [31]. The optimal dosage for tree leaves was 35 mg/L for WWTP1 and 45 mg/L for WWTP2. However, within the dosage of experimentation, lime was not able to reach optimal dosage for WWTP1. For WWTP2, 45 mg/L was observed to be the optimal dose for lime. There were some decrease in pH level for lime coagulation for WWTP1 and polymer coagulation for WWTP2 (Fig. 7).

3.2.3. Effect of the pre-treatment processes

High level of pre-treatment (WWTP2) reduced the final phosphorus concentrations compared with WWTP1 (Fig. 4). It was expected since the initial concentration in WWTP1 was higher than WWTP2. Also, the percentage of phosphorus removal for WWTP2 was higher than that of WWTP1 for both lime and polymer. It could be due to the high degree of pre-treatment ensures a low level of competition for a surface charge. However, phosphorus removal on the WWTP1 using tree leaves was higher than that on the WWTP2. Tree leaves being organic material might not have been affected much by the surface charge.

For BOD_5 removal, pre-treatment in WWTP2 ensured higher percentage removal than WWTP1 using polymer

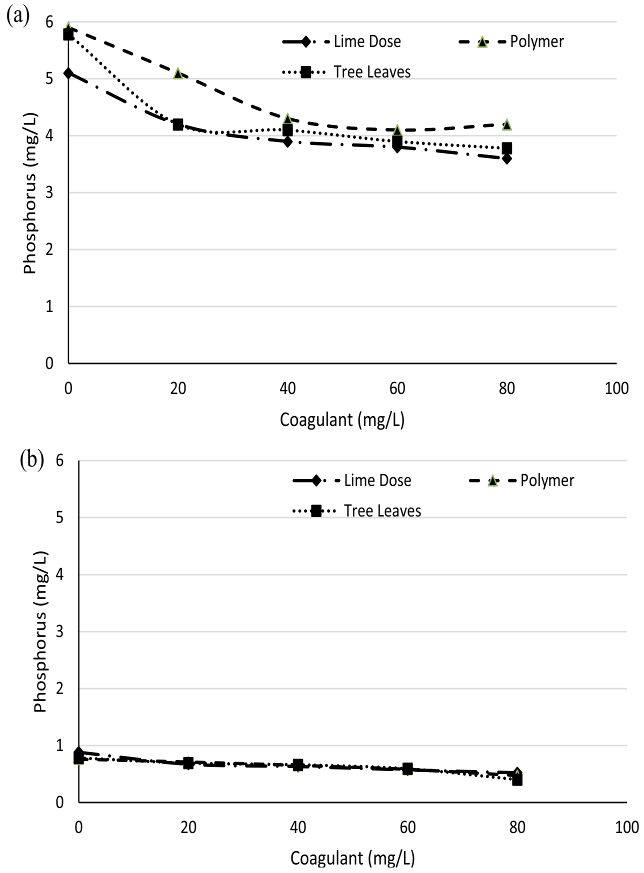

Fig. 4. Effluent phosphorus concentrations at different coagulant dosage (a) WWTP1 and (b) WWTP2.

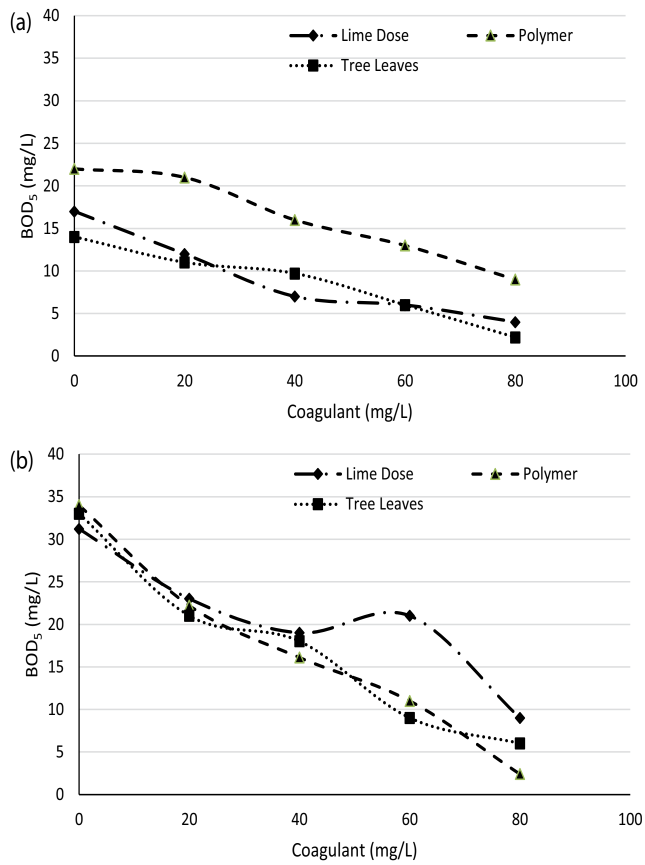

Fig. 5. Effluent BOD concentrations at different coagulant dosage (a) WWTP1 and (b) WWTP2.

and tree leaves (Fig. 5). It could be due to the WWTP2 had lower competition for the organic removal compared with the WWTP1. On the contrary, for lime, WWTP1 had higher organic removal than WWTP2. Initial BOD_5 concentrations were, however, higher in WWTP2 than WWTP1. Therefore, the lime was still able to remove a higher amount of organic material in WWTP2 compared with the WWTP1.

Regarding the turbidity levels, WWTP2 had a lower level of minimum turbidity compared with the WWTP1 (Fig. 6). Both the wastewaters have similar optimal dosage of coagulants, except lime treatment for WWTP1. pH levels for WWTP1 were slightly higher than WWTP2.

4. Conclusions and recommendations

The experimental results showed that all of the different materials used in this study were capable of reducing the phosphorus, organic material and turbidity from the secondary effluent. However, phosphorus removals were below 60% for tree leaves and polymer. The ability of different coagulants for wastewater treatment was comparable with alum with 80% for phosphorus and 100% for BOD. pH levels ranged within 7.5–7.9. Polymer had the highest phosphorus removal (up to 93%) characteristics among the different types of coagulants. Tree leaves had the highest organic removal (up to 100%) characteristics among the coagulants investigated in this study. An increase in the coagulant concentrations increased the phosphorus removal. For almost all the materials had 35–45 mg/L of dosage appeared to serve as the optimal level in reducing turbidity. High level of pre-treatment can ensure improvement of the treatment capabilities with an average increase of 34.5%–48% for phosphorus removal and 73.3%–82% for BOD removal across the different materials used in this study.

The study identified the ability of the coagulation flocculation process for removal of multiple pollutants from treated wastewater. The study was focused on two wastewater treatment plants. However, further studies involving other treatment plants around the world would be useful in investigating the role of different pre-treatment processes on the effectiveness of pollutant removal. Advanced treatment studies involving removal of precursors of disinfection byproducts would also be very useful.

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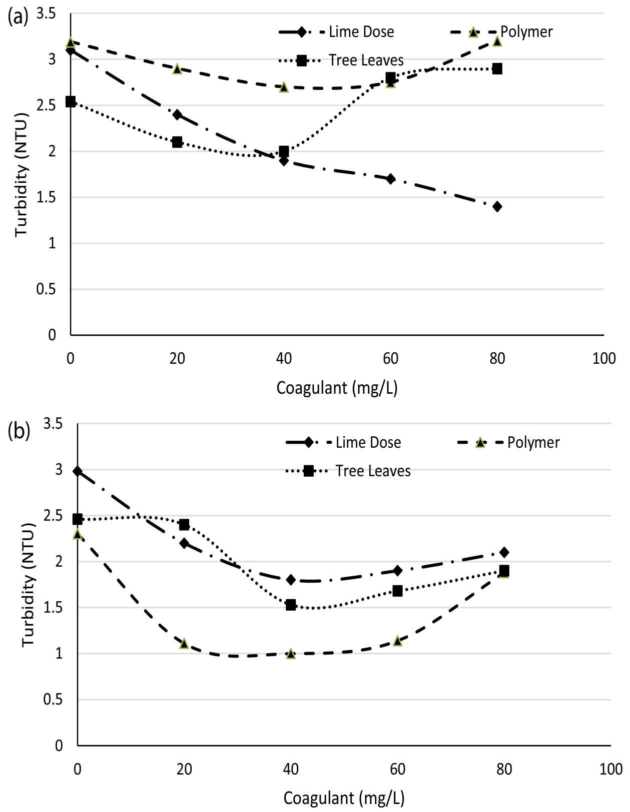

Fig. 6. Effluent turbidity at different coagulant concentrations (a) WWTP1 and (b) WWTP2.

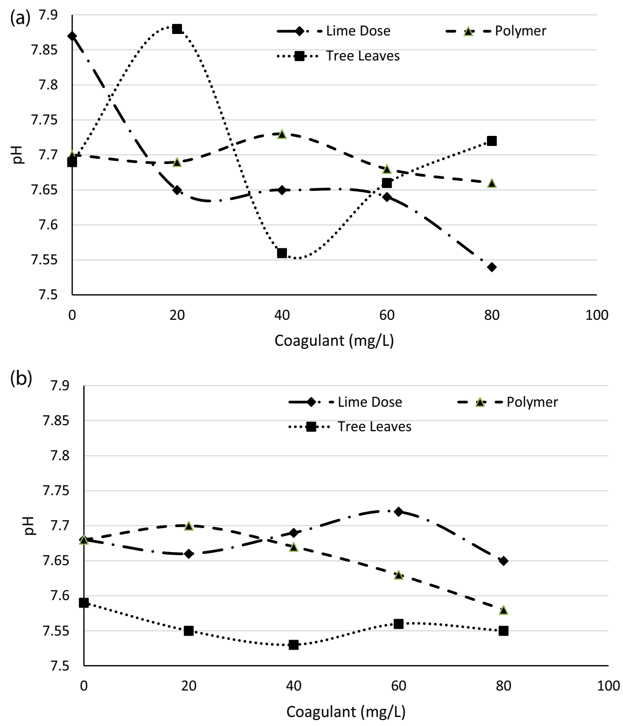

Fig. 7. Effluent pH level at different coagulant dosage (a) WWTP1 and (b) WWTP2.

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