POST TREATMENT OF WASTEWATER USING RECOVERED ALUM FROM WATER TREATMENT SLUDGE

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ABSTRACT

Water resources limitation exhibited the emergency to explore a novel approach to reuse secondary wastewater effluent as a sustainable alternative water source. In this study, the feasibility of using the recovered alum from water treatment sludge as a coagulant for post treatment of wastewater was investigated then, its efficiency was compared with fresh one. Jar test was used to determine the optimum conditions for alum recovery and the ideal alum dose for post treatment of wastewater. Afterwards, post treatment of wastewater was conducted using clari-flocculation model. Results revealed that the optimum operating conditions for alum recovery were 60 min. and 2.0 for mixing time and pH, respectively. In addition, the optimum doses of recovered and fresh alum for post treatment process were even (10 mg Al/L). The results obtained from the fabricated model showed that removal efficiencies of BOD_5, COD, TSS, PO_4 and NO_3 using the recovered alum were 51.9, 39.8, 55.7, 33.8 and 19.7%, respectively, versus 54.4, 43.7, 58.9, 61.2 and 14.2%, respectively, harvested by using fresh alum. Consequently, recovered alum revealed lower efficiencies in removal of BOD_5, COD, TSS and PO_4. Conversely, recovered alum surpassed fresh one in NO_3 removal efficiency. Hence, post treated wastewater by recovered alum has the ability for reuse in irrigation process according to Egyptian standards.

Keywords: Recovered alum, Water treatment sludge, Post treatment of wastewater, Hydraulic clari-flocculation, Swirl flow.

1 INTRODUCTION

Secondary wastewater effluent contains organic content, total suspended solids (TSS), nutrients and pathogen content. Its discharge into water bodies raises the growth of algae and results in eutrophication of lakes and streams. Hence, environmental regulations impose stringent standards for its disposal into environment. Therefore, post treatment of wastewater is required for additional decreasing of residual constituents in secondary sewage effluent. Generally, avariety of technologies employed for post treatment of wastewater such as chemical precipitation (Metcalf and Eddy,2003; El-Bestawy et al., 2005; Wu et al., 2005; El- Shorbagy and Chowdhury, 2013).

Chemical precipitation has been applied widely due to its advantages of low equipment cost, high efficiency and low operating costs and easy maintenance (Wang et al., 2005). Liu et al. (2013) used three inorganic coagulants for the advanced treatment of wastewater to enhance total phosphorus and organic removal and reported that poly- aluminum chloride was the most efficient coagulant for chemical oxygen demand (COD) removal followed by alum and ferric chloride while ferric chloride was the optimal coagulant for phosphorus removal. However, major cost of chemical precipitation depends on the chemicals and dosages to be used. Thus, there is an urgent need to find a low-cost coagulant for post treatment of wastewater (Nair and Ahammed, 2013). The recovered alum can be considered as efficient and low cost coagulant for wastewater treatment (Ishikawa et al., 2007).

Alum recovery becomes a promising technique to deal with large quantities of water treatment sludge (WTS) produced as by-product of clarification while removing colloidal impurities from the raw water (Nair and Ahammed, 2013). WTS is disposed into water bodies and that was reported to be toxic to aquatic life due to high residual aluminum which contains about 39% aluminum by weight (Boaventura et al., 2000; Evuti and Lawal, 2011). Alum recovery from WTS is a suitable way for reducing the disposal sludge volume by 40-50%, improving dewaterability of the sludge, and the safe disposal of the sludge (Abdo et al., 1993; Chen et al., 2011). Acidification method is a high efficiency and low cost method for alum recovery from WTS (Nair and Ahammed, 2014; Xu et al., 2009). Acidification process depends upon acidifying the sludge to a pH between 1.0 and 3.0 and alum recovery percent ranges from 60 to 80 % can be obtained using this method (Davis, 2010). Alum recovery provides reduction of sludge volume and mass and results in improving the settling and dewatering characteristics of residual solids after alum separation. As a result of this, the area required for drying beds will be reduced by a factor of approximately 2.7. Also, alum recovery makes the residual solids more suitable for landfilling without possible concerns due to metal accumulation (AWWA, 1991; Babatunde and Zhao, 2007). WTS can be used with ash to generate a brick with a high compressive strength after metals separation (Lin et al., 2006).

Several research efforts focused on coagulants recovery from WTS and its reuse in wastewater treatment. Reusing recovered coagulants in wastewater treatment can provide similar advantages as reuse in water treatment, but its reuse in wastewater treatment is less sensitive to the impurities present in recovered coagulant. Recovered coagulants have proven to be effective and economically viable in many wastewater treatment applications (Parsons and Daniels, 1999; Jimenez et al., 2007; Yang et al., 2014).

Ishikawa et al. (2007) demonstrated that recovered coagulant was found to be very effective in removing total phosphorus and COD from a municipal wastewater treatment plant with removal rate of 98.9% and 66.8%, respectively, and a slight total nitrogen removal about 29.9%. Nair and Ahammed (2013) assessed the reuse of poly-aluminum chloride-based water treatment sludge as a post treatment method of up flow anaerobic sludge blanket reactor treating urban wastewater. In addition, removal efficiencies obtained from post treatment of wastewater were 72% of COD, 74% of phosphate (PO_4), 84% of TSS, 78% of biological oxygen demand (BOD_5) and 89% of turbidity at optimum conditions of sludge dose 15 g/L, initial pH 9 and fresh coagulant 4.2 mg Al /L.

Nair and Ahammed (2014) applied the concept of coagulant recovery from WTS and reusing it as coagulant for post treatment of effluent wastewater after up flow anaerobic sludge blanket reactor. In addition, removal efficiencies obtained from post treatment of wastewater using recovered coagulant were 89% of PO_4, 71% of COD, 80% of turbidity, and 77% of TSS at dose 25 mg Al/L.

Swirl flow hydraulic clari-flocculators have been recently applied in the field of chemically enhanced primary treatment of sewage, where dividing into flocculation zone achieved by swirl flow, and gravity sedimentation zone in the same tank (Rashed et al., 2013). Ayoub et al. (2013) studied two various models of hydraulic clari-flocculators using swirl flow: up flow hydraulic clari-flocculator where the tangential inlet was situated at the bottom of the tank to generate a swirl flow in the conical tank in upward direction, and down flow hydraulic clari-flocculator were the tangential inlet was situated at the top of the tank to generate a swirl flow in the flocculation zone in downward direction. Results from previous study demonstrated that up flow flocculation reasonably improves uniformity of tapering of velocity gradient rather than down flow flocculation. In general, swirl flow hydraulic clari-flocculators provide excellent solids contact, enhance floc formation and remarkable solids capture.

This study was made to investigate the feasibility of using recovered alum from WTS in post treatment of secondary wastewater effluent and compare its effect on removal efficiency of pollutants with fresh alum.

2 MATERIALS AND METHODS

2.1 Collection and characteristics of wastewater

Secondary wastewater samples were collected from EL-Korashia wastewater treatment plant (WWTP) at the effluent of final clarifiers. This WWTP is located at EL-Korashia village, EL-Gharbia Governorate, Egypt. EL-Korashia WWTP was designed to treat about 10000 m^3/day of municipal wastewater where oxidation ditches were used for biological treatment as activated sludge system. Grab samples were collected over 3-months period**.** Table 1 represents the wastewater characteristics of EL-Korashia WWTP.

Table 1. Wastewater characteristics of EL-Korashia WWTP.

Parameter	Raw sewage *			Final effluent**		
	Max.	Min.	Average	Max.	Min.	Average
TSS, mg/L	241	208	224.10	42	25	30.80
COD, mg/L	817	617	691.70	67	54	61.70
BOD_5, mg/L	320	270	291.70	46	34	38.80
PO_4, mg/L	--	--	--	24.4	19.5	22.3
Nitrate – NO_3, mg/L	--	--	--	20.5	18.7	19.3

Notes:

-*samples of raw sewage were collected after grit removal, **Samples of the final effluent were collected after final clarifiers following the oxidation ditches.

- Results based on analysis of 10 samples.

2.2 Coagulants

In the present study, fresh alum [$Al_2(SO)_4.18H_2O$, CAS number 10043-01-3] and recovered alum from WTS were used as coagulants for post treatment of wastewater. Stock solution of fresh alum at 10 gm/L was produced by mixing 10 gm of fresh alum in one liter of distilled water. Aluminum (Al) concentration in the fresh alum solution was 410 mg AL/L measured using ICP-OES apparatus with pH value of 3.6.

Recovered alum was extracted from sedimentation sludge of El-Morashaha water treatment plant located at EL-Gharbia Governorate, Egypt. The average values of pH, total solids, and Al concentration of the collected sludge were 6.7, 17.76 gm/L, and 1318.37 mg/L, respectively. The organic content in the collected sludge was varied between 12% and 14% of total solids. Alum recovery process was carried out using a jar test apparatus. At first, sludge samples were acidified to a certain value of pH (in range 1.0-3.0) using sulfuric acid with concentration of 98%. After this, solutions were mixed at rotational speed of 150 rpm for a definite mixing time (30-90 minutes) and then, kept quiescent for 60 minutes for separation. Finally, the supernatant was drawn for analysis.

2.3 Post treatment of wastewater

In this study, wastewater coagulation, flocculation and sedimentation were performed with a jar test apparatus as a mechanical flocculation system using 1-L of wastewater samples in cylindrical beakers to determine the suitable coagulant dose for post treatment of wastewater. Coagulant doses were added to wastewater samples and then rapid mixing was initiated. The clarification procedure consisted of one minute of rapid mixing at 200 rpm, followed by slow mixing of 15 minutes at 30 rpm and then, 30 minutes of settling (Keeley et al., 2016). Afterward, the supernatant was drawn for analysis.

Then, clari-flocculator tank was designed for post treatment of wastewater. Prototype of clari-flocculator tank is a swirl flow hydraulic clari-flocculator designed to treat 5000 m^3/d of secondary wastewater effluent. The flocculation process takes about 33% of total retention time, whereas the sedimentation process takes about 67% of total retention time. A distorted model was designed and fabricated to simulate the previously mentioned prototype depending upon Froude number (Young et al., 2007; Rashed et al., 2013; Ayoub, 2016). The fabricated model is shown in figure (1). Table (2) represents dimensions and operational conditions of the experimental model and prototype of hydraulic clari-flocculator. Ayoub, (2016) demonstrated that optimum sludge hopper diameter ranges between 0.20-0.40 of hydraulic clari-flocculator diameter. In addition, figure (2) shows schematic diagram of post treatment of wastewater in EL-Korashia WWTP.

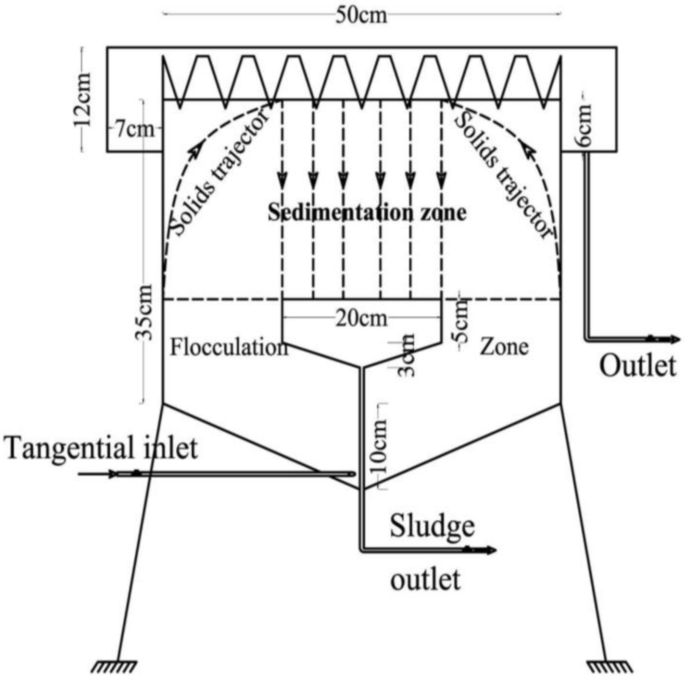

Figure 1. Experimental model of hydraulic clari-flocculator.

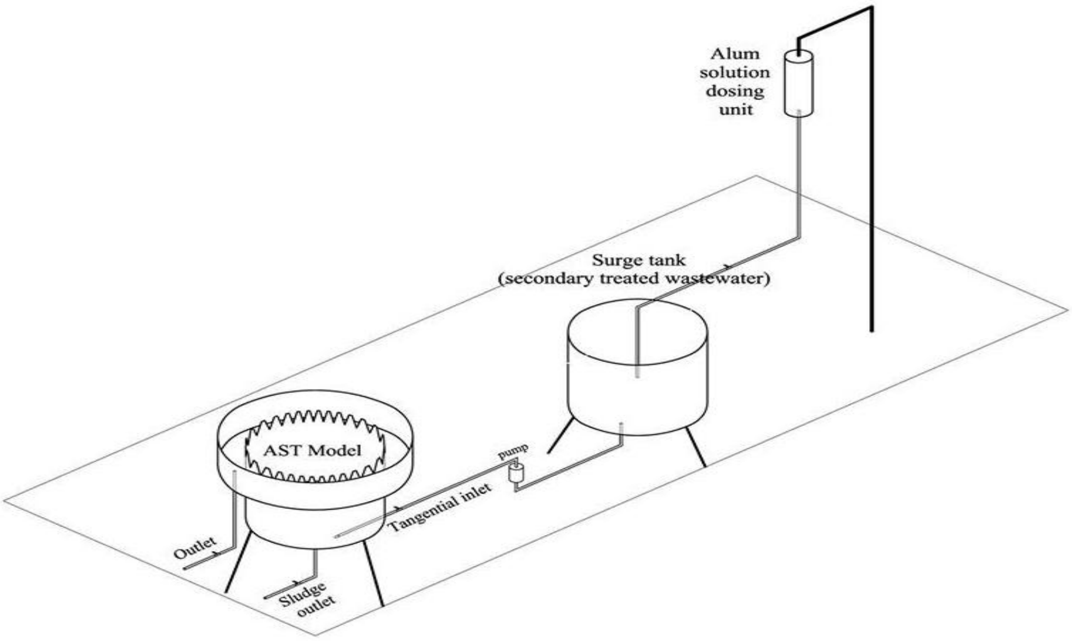

Figure 2. Schematic diagram of post treatment of wastewater in EL-Korashia WWTP.

Table 2. Characteristics of hydraulic clari-flocculator prototype and model

Parameter	**Prototype**	**Experimental Model**
Discharge (Q), m^3/d	5000	1.5377
Diameter (Φ), m	12.7	0.5
Side water depth (d), m	3.3	0.35
Volume, m^3	418	0.07
Retention time (t), hr	2	1.07

2.4 Laboratory tests

Wastewater and sludge samples were collected in plastic bottles, transported immediately to Sanitary Engineering Laboratory, Faculty of Engineering, Tanta University and preserved in a refrigerator at 4°C during the sampling periods. Experimental work was conducted in Sanitary Engineering Laboratory, Faculty of Engineering, Tanta University, Egypt as well as laboratory of EL-Korashia WWTP, EL-Korashia village, EL-Gharbia Governorate, Egypt. Parameters and equipment utilized in the laboratory tests are represented in table (3). All tests were performed using the procedures outlined in Standard Methods for the Examination of Water and Wastewater, 20th edition, prepared and published by APHA, AWWA and WEF, 1998.

Table 3. Parameters and equipment utilized in the laboratory tests

Parameter	**Equipment and product information**
pH, Temperature	pH / ° C Model CONSORT P400
Jar test apparatus	VELP® Scientifica, Italy- Jar volume of 1 liter- flat blade impeller
Aluminum (Al), mg/L	Inductively Coupled plasma (ICP-OES); model OPTIMA™ 7000 DV, USA
TSS, mg/L	Using paper filter-Drying oven (BINDER®) company- Analytical balance (OHAUS®), Germany
COD, mg/L	COD reactor (DINKO), and spectrophotometer(biochrom) Model Libra S1
BOD_5, mg/L	BOD incubation (Fisher Scientific), USA
Phosphate, Nitrate, mg/L	YSI Photometer, Model 9300, China

3 RESULTS AND DISCUSSION

3.1 Alum recovery process

Aluminum(Al) concentration in recovered alum was measured at a series of mixing times ranged from 15 minutes to 90 minutes to determine a suitable mixing time for alum recovery as shown in figure (3). Samples were acidified to pH of 1.50 and mixed with rotational speed of 150 rpm. It can be observed that Al concentration in recovered alum increases with the increase of mixing time. However, it is noticed that a slight increase in Al concentration from 366.5 mg/L to 371.8 mg/L if mixing time increases from 60 minutes to 90 minutes. Hence, the optimum mixing time for alum recovery is 60 minutes. These results are compatible with that obtained from Ayoub and Abdelfattah (2016).

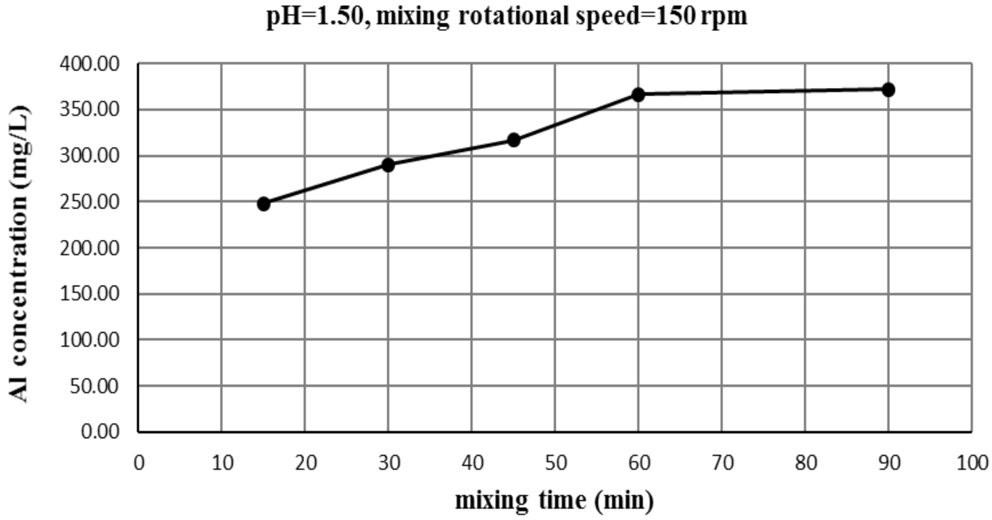

Figure 3. Effect of mixing time on Al concentration in recovered alum

Aluminum(Al) concentration in recovered alum, volume of added acid and reduction of sludge volume were measured at a series of pH values ranged from 1 to 3 to determine the optimum pH value for alum recovery as shown in figure (4) and figure (5). Samples were mixed at rotational speed of 150 rpm for mixing time of 60 minutes. These results are compatible with that obtained from Xu et al., (2009)

It can be observed that Al concentration in recovered alum increases with the descending of pH values because of releasing of aluminum from sludge. With the descending of pH values from 3 to 1.25, Al concentration increases from 35.68mg/L to 401.64 mg/L and added acid increases extremely from 0.47mL to 26.82mL. However, it is noticed that the slight increase in Al concentration in recovered alum when pH values are less than 2.0. For example, the multiplied increase in added acid volume at pH value from 2 to 1.5 (4.73 folds) results slight increase in Al concentration in recovered alum (305.53 mg/L to 364.42 mg/L). Also, figure (5) shows that reduction of sludge volume reached up to maximum value at pH of 1.50 and it can be noticed that slight increase in reduction of sludge volume from 80.6% to 81% if pH decreases from 2 to 1.50. Hence, optimum pH value for alum recovery process is 2.0. These results are compatible with that acquired from Nair and Ahammed (2014). From the previous results, alum recovery provides reduction of sludge volume and results in improving the settling velocity and dewaterability of residual solids. Hence, the area required for drying beds will be reduced and the residual solids after alum recovery are more suitable for landfilling without possible concerns due to metal accumulation (AWWA, 1991; Babatunde and Zhao, 2007). At pH of 2.0, aluminum concentration in the recovered alum solution was 305.53 mg AL/L measured using ICP-OES apparatus and COD of recovered alum was 26 mg/L.

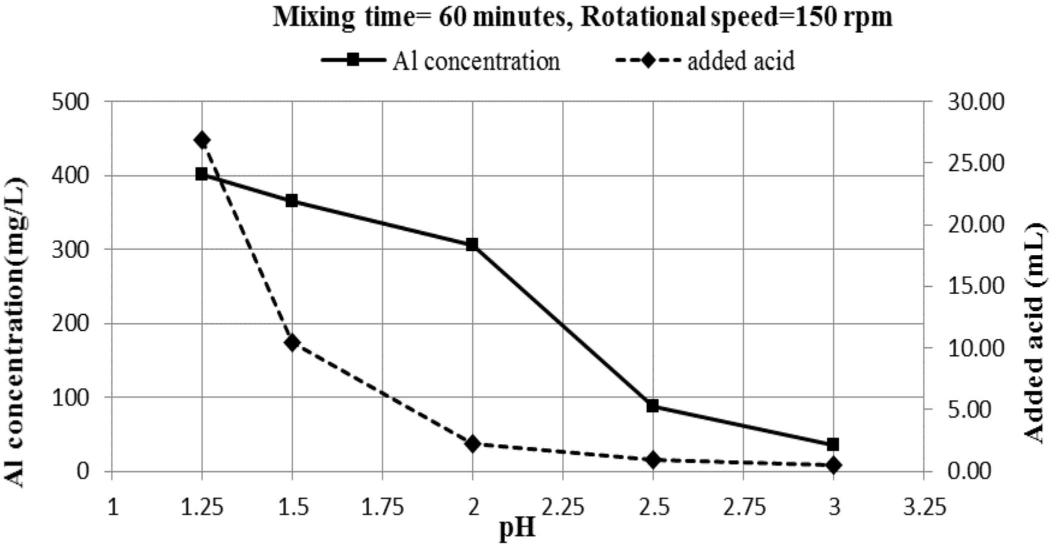

Figure 4. Aluminum (Al) concentration in recovered alum at different pH values with corresponding added acid volume

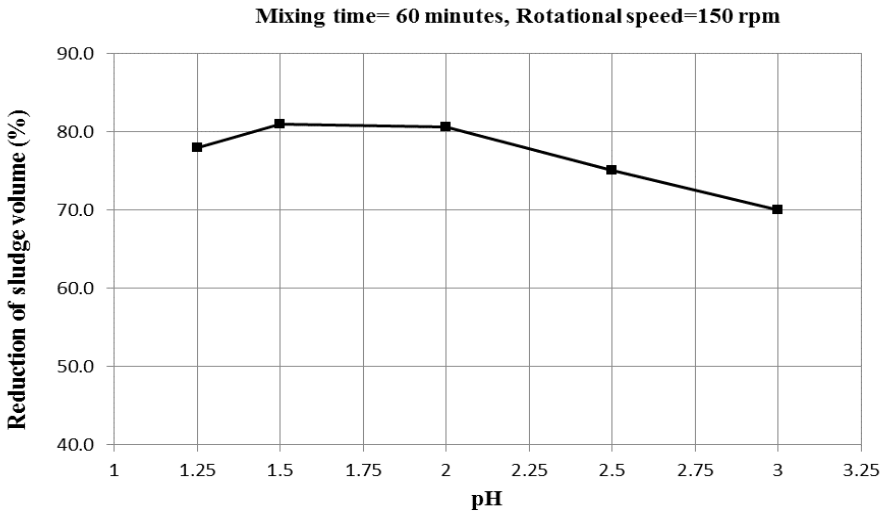

Figure 5. Effect of pH range on reduction of sludge volume

3.2 Optimum alum dose for post treatment of wastewater using jar test apparatus

Fresh alum was applied as a coagulant for post treatment of secondary wastewater effluent with different doses varied from 2.5 mg Al/L to 35 mg AL/L using jar test apparatus. Figure (6) shows the effect of using fresh alum on post treatment of wastewater. It is noticed that removal efficiencies of BOD_5, COD, and TSS were ranged between 37.1-62.9%, 38.5-50.8%, and 33.3-77.8%, respectively. In addition, maximum removal efficiencies for PO_4 and NO_3 reached up to 71.1% and 36.8%, respectively. Moreover, it can be noticed that removal efficiencies of these parameters slightly increase after 10 mg Al/L of fresh alum dose. For example, BOD_5 removal was 57.1% at 10 mg Al/L of fresh alum, while it was 62.9% at 35 mg Al/L. Thus, results confirmed that application of fresh alum at dose of 10 mg Al/L obtained reasonable removal efficiencies for all parameters. At this dose, COD, BOD_5, TSS, PO_4 and NO_3 removal efficiencies were 46.2, 57.1, 63, 64.5 and 15.3% ,respectively.

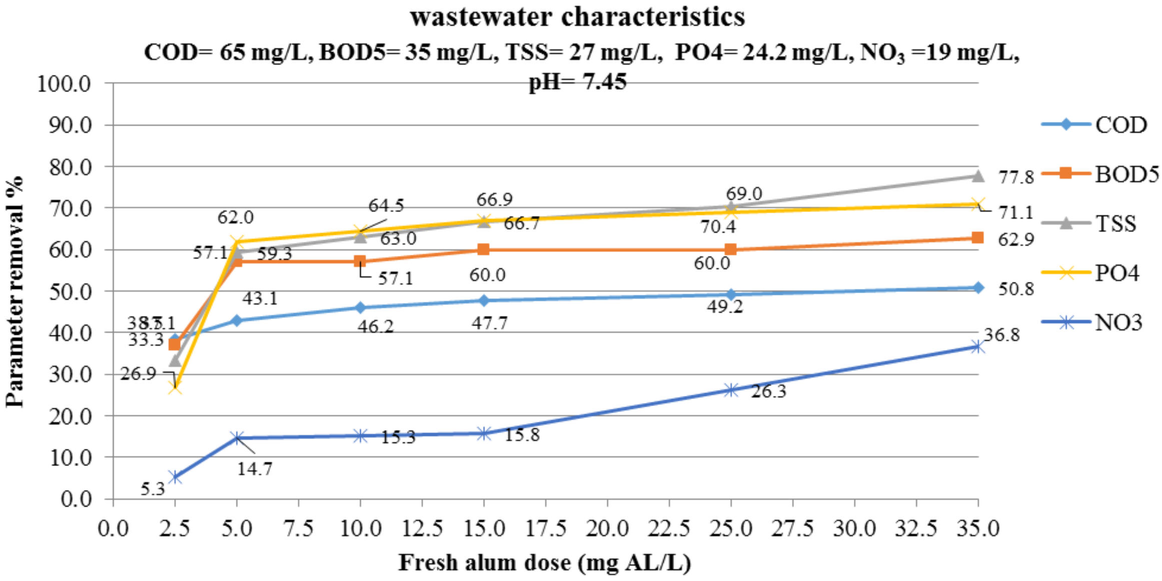

Figure 6. Effect of fresh alum dose on pollutants removal in post treatment of wastewater

Recovered alum was applied as a coagulant for post treatment of secondary wastewater effluent with different doses varied from 2.5 mg AL/L to 35 mg AL/L using jar test apparatus. Figure (7) shows the effect of using recovered alum on post treatment of wastewater. It is noticed that COD removal efficiency reached up to 44.6% for recovered alum at dose of 15 mg Al/L. In addition, maximum BOD_5 removal efficiency was recorded to be 60% with recovered alum dose of 15 mg Al/L. Removal efficiencies for COD and BOD_5 increase with the increase in recovered alum dose until it reached at 15 mg Al/L. After it, additional recovered alum dose leads to a decrease in removal efficiencies of COD and BOD_5. The effect of recovered alum dose on TSS, PO_4 and NO_3 removal efficiencies are also shown in figure (7). The increase in recovered alum dose up to 5 mg Al/L increases TSS, PO_4 and NO_3 removal efficiencies. After it, additional recovered alum dose leads to a decrease in removal efficiencies. The results show that maximum removal efficiencies of TSS, PO_4 and NO_3 were 66.7, 52.1 and 36.8%, respectively at dose of 5 mg Al/L. In general, the decrease in removal efficiencies after optimum dose was due to the restabilization of colloidal particulates and the content of TSS, organic matter and nutrients in recovered alum (Yeom et al., 2008; Daud et al., 2015).

From the previous results, the optimum recovered alum dose is between 5 mg Al/L and 15 mg Al/L for all removal efficiencies and it is selected to be 10 mg Al/L as indicated by reasonable removal efficiencies for all parameter. At this dose, COD, BOD_5, TSS, PO_4 and NO_3 removal efficiencies were 41.5%, 54.3%, 59.3%, 36.4% and 23.7%, respectively.

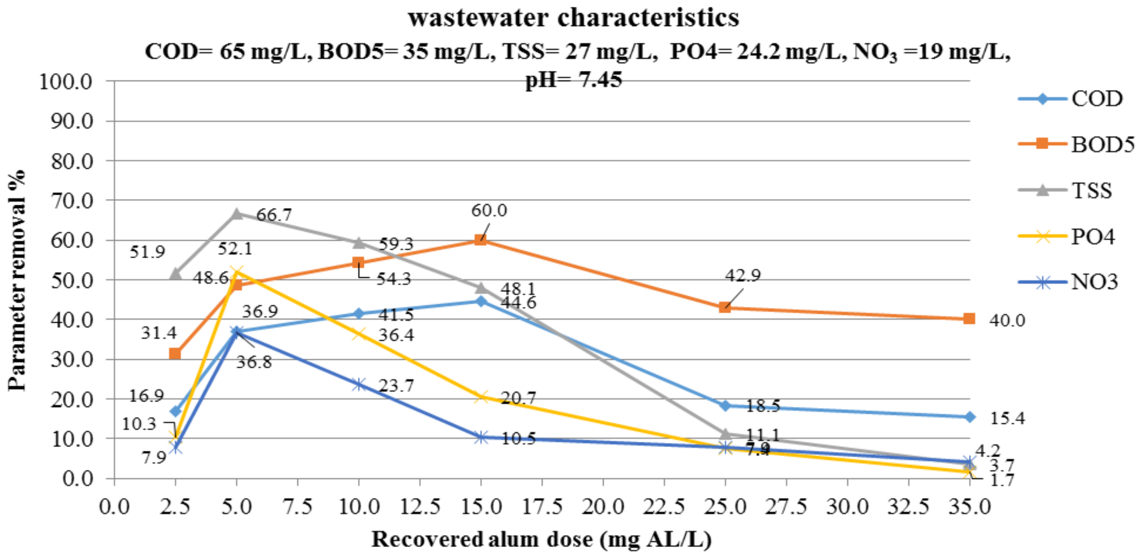

Figure 7. Effect of recovered alum dose on pollutants removal in post treatment of wastewater.

3.3 Post treatment of wastewater using the experimental model of swirl flow hydraulic clari-flocculator

Fresh and recovered alum were applied as coagulants in post treatment of wastewater at dose of 10 mg AL/L using the experimental model mentioned in figures (1) and (2). At different periods, the experimental model was operated through five runs and at each run, three samples were withdrawn from influent and effluent of the model for analysis. Results of five runs as shown in table (4) and figures (8-a) and (8-b). It can be noticed that all results of five runs shown in table (4) and figure (8) are less than the corresponding results of mechanical mixing using jar test apparatus shown in figures (6) and (7) at the same conditions of coagulant type and dose.

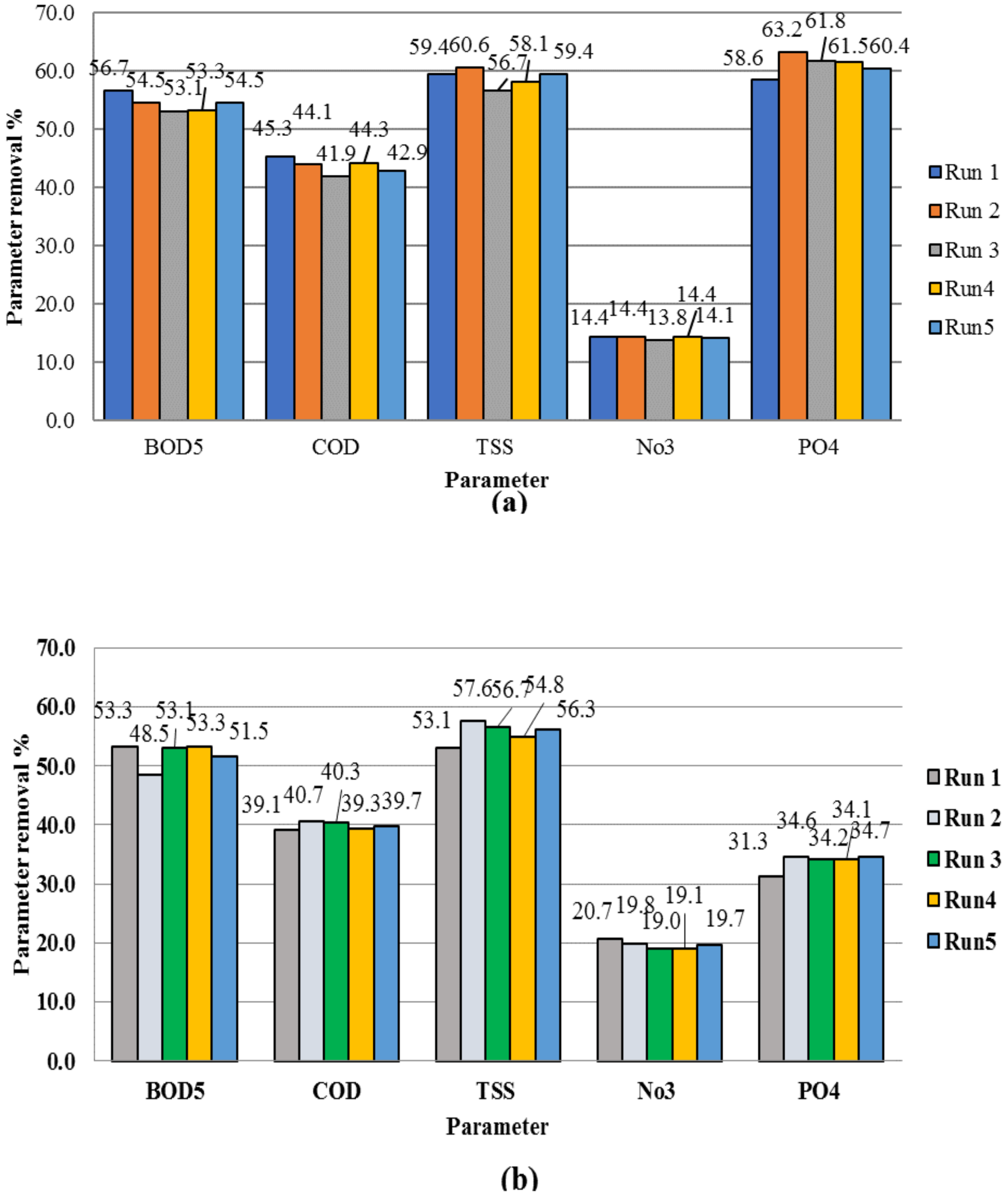

Figure 8. Pollutants removals in post treatment of wastewater using experimental model through different runs using (a) fresh alum, (b) recovered alum

Table 4. Post treatment of wastewater using experimental model through different runs at recovered alum and fresh alum dose of 10 mg Al/L.

parameter		Run1		Run2		Run3		Run4		Run5	
		Inff.	Eff.	Inff.	Eff.	Inff.	Eff.	Inff.	Eff.	Inff.	Eff.
BOD_5 (mg/L)	Recovered alum	30.0	14.0	33.0	17.0	32.0	15.0	30.0	14.0	33.0	16.0
	Fresh alum		13.0		15.0		15.0		14.0		15.0
COD (mg/L)	Recovered alum	64.0	39.0	59.0	35.0	62.0	37.0	61.0	37.0	63.0	38.0
	Fresh alum		35.0		33.0		36.0		34.0		36.0
TSS (mg/L)	Recovered alum	32.0	15.0	33.0	14.0	30.0	13.0	31.0	14.0	32.0	14.0
	Fresh alum		13.0		13.0		13.0		13.0		13.0
NO_3 (mg/L)	Recovered alum	18.8	14.9	20.2	16.2	19.5	15.8	19.4	15.7	19.8	15.9
	Fresh alum		16.1		17.3		16.8		16.6		17.0
PO_4 (mg/L)	Recovered alum	19.8	13.6	23.1	15.1	22.5	14.8	22.6	14.9	22.5	14.7
	Fresh alum		8.2		8.5		8.6		8.7		8.9

- Inff. Influent wastewater before treatment, Eff. Effluent wastewater after treatment.

The average removal efficiency of different pollutants using the experimental model through five runs at fresh and recovered alum dose of 10 mg Al/L was calculated from table 4. Figure (9) shows the effect of hydraulic clari-flocculation on post treatment of wastewater using fresh and recovered alum at dose of 10 mg AL/L. Results showed that removal efficiencies of BOD_5, COD, TSS, PO_4 and NO_3 using fresh alum were 54.4, 43.7, 58.9, 61.2, and 14.2%, respectively, whereas removal efficiencies of BOD_5, COD, TSS, PO_4 and NO_3 using recovered alum were 51.9, 39.8, 55.7, 33.8, and 19.7%, respectively. In general, results reveal that fresh alum was more efficient in removal of BOD_5, COD, TSS and PO_4 than that obtained using recovered alum. This was due to the organic matters and impurities found in recovered alum (keely et al., 2016). On the other hand, recovered alum exceeded fresh alum in NO_3 removal efficiency. From figures (6), (7), (8) and (9), It can be noticed that jar test results have a slight increase in removal efficiencies when compared with experimental model results at dose of 10 mg Al/L. Furthermore, the differences in removal efficiencies between jar test results and experimental model results may be due to quality and high control of mixing in jar test (mechanical mixing) whereas mixing in experimental model was achieved by swirl flow of water.

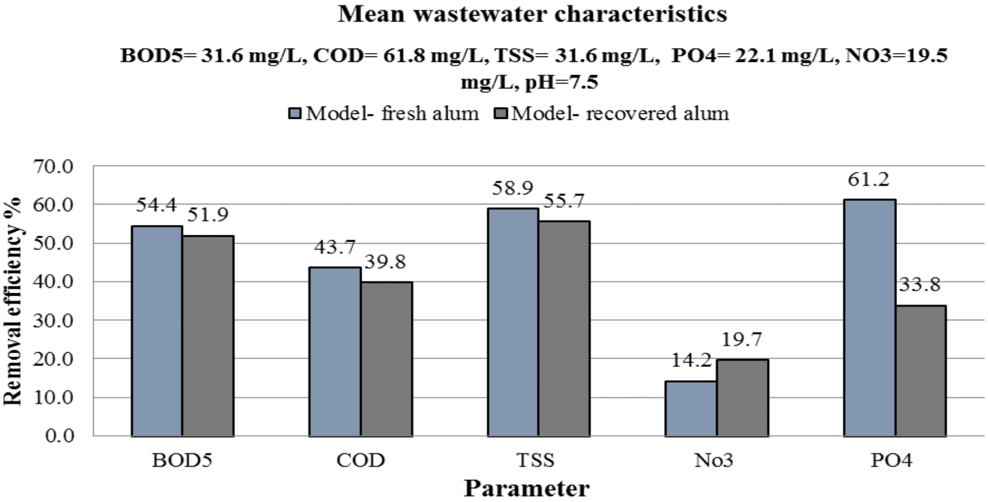

Figure 9. Comparison between average results of the fresh and the recovered alum in post treatment of wastewater using experimental model

Table 5 represents characteristics of treated wastewater using experimental model and Egyptian standards for irrigation reuse. Fifteen samples were collected from influent and effluent of the experimental model for analysis of BOD_5, COD, TSS, PO_4 and NO_3. The results showed that the levels of BOD_5, COD, and TSS for treated wastewater using fresh alum and recovered alum were below the levels of BOD_5, COD, and TSS stated by Egyptian Law no. 44/2000 for irrigation reuse. Hence, BOD_5, COD, and TSS of treated wastewater using experimental model for fresh alum and recovered alum met Egyptian standards for irrigation reuse. Post treated wastewater compatible with Egyptian standards can be used in irrigation of cortical plants, grassland and fodder.

Table 5. Characteristics of treated wastewater using the experimental model compared with Egyptian standards for irrigation reuse.

Parameter	**Influent**	**Effluent (fresh alum)**	**Effluent (recovered alum)**	**Egyptian standards**
pH	7.5	6.7	5.5	--
BOD_5, mg/L	31.6	14.4	15.2	20
COD, mg/L	61.8	34.8	37.2	40
TSS, mg/L	31.6	13	14	20
Phosphate, mg/L	22.1	8.6	14.6	--
Nitrate, mg/L	19.5	16.8	15.7	--

- Results based on analysis of 15 samples.

4 CONCLUSIONS

The present study provides a cost-effective and an environmentally friendly approach for post treatment of wastewater. This approach based on optimization of the operating condition for alum recovery from WTS and utilization of the recovered alum from WTS as a coagulant in post treatment of wastewater. Optimum alum recovery was obtained at mixing time of 60 minutes and pH of 2. Moreover, alum recovery process causes sludge volume reduction (80.6%) and improves the settling and dewatering characteristics of residual solids. Subsequently, the area required for drying beds will be reduced. The results of post wastewater treatment obtained from the fabricated model showed that removal efficiencies of BOD_5, COD, TSS, PO_4 and NO_3 using the recovered alum were 51.9, 39.8, 55.7, 33.8 and 19.7%, respectively, at 10 mg Al/L alum dose. In addition, the recovered alum results slightly lower removal efficiencies for COD, BOD_5, TSS and PO_4 than the fresh alum at the same dose. This may occur due to the impact of the organic matters and impurities in the recovered alum, which does not exist in the fresh alum solution. Swirl flow clariflocculator model had a slight decrease in removal efficiencies compared with jar test results. Hence, swirl flow clariflocculation can be applied as a cost-effective technique for post treatment of wastewater because of less energy and maintenance costs are required when compared with mechanical flocculation. In addition, the levels of BOD_5, COD and TSS in model effluent using fresh alum and recovered alum met Egyptian standards for irrigation reuse.

ACKNOWLEDGMENTS

The authors thankfully acknowledge to the staff of EL-Korashia WWTP for their support and participation for the laboratory activities and the experimental program.

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