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Application of Aluminum Electrodes for Wastewater Treatment via Electrocoagulation

Hanan A. Fouad[1], Rehab M. El-Hefny[2], Mohamed Nabil Ali[3], Mostafa Etgany Youns Ahmed[4]

[1]Associate Prof. Faculty of Engineering– Shoubra, Benha University, Egypt.
[2]Assistant prof., Faculty of Engineering– Shoubra, Benha University, Egypt.
[3] Assistant prof., Faculty of Engineering, Beni- suef University, Egypt.
[4] Demonstrator at, Pyramids higher institute for Engineering and Technology, Egypt.

ملخص البحث

يتناول هذا البحث امكانيه استخدام أقطاب الالمونيوم الاحاديه القطب لمعالجه مياه الصرف المنزلية الخام في ظل ظروف علاجيه مختلفه. وقد تم جمع عينات مياه الصرف من محطه أبو الرواش لمعالجه المياه العادمة. وقد شيد نموذج مصغر لعمليه العلاج. وأجريت تجارب باستخدام أقطاب الالمونيوم علي مسافات مختلفه بين الأقطاب الكهربائية (10 و 15 سم). وقد درست عوامل مختلفه لتعزيز عمليه المعالجة بالتخثر الكهربي التي تشمل فتره الترسيب (3 و 5 ساعات) ، وفترات التخثر الكهربي المختلفة (30 و 60 دقيقه) ، والفولتية الكهربائية المختلفة (12 و 24 فولت). واستخدم الشبه كماده تخثر وتم تطهير المياه المعالجه النهائية بالكلور. وأظهرت النتائج ان أقطاب الالمونيوم كانت فعاله للعلاج والمسافات بين الأقطاب لعبت دورا في عمليه العلاج حيث ان مسافه 10 سم كانت أكثر فعاليه من 15 سم. وأظهرت أقطاب الالمونيوم مع مسافة 10 سم بين أقطاب الحد الأقصى لأزاله النسبة المئوية من المعلمات الفيزيائية الكيميائية مثل (93.2 %) TSS، (83.0 %) COD، (86.0 %) TKN ، (93.5 %) BOD ، (80.0%) TP. وقد عززت الشبه كفاءه المعالجة وكان التصرف النهائي بعد عمليه الكلوره النهائية قابله للمقارنة مع القوانين المحلية لأغراض أعاده الاستخدام.

Abstract

The present study deals with the possibility of using aluminum monopolar electrodes for raw domestic wastewater treatment under different treatment conditions. Wastewater samples were collected from Abu Rawash wastewater treatment plant, Egypt. A mini model was constructed for the treatment process. Experiments were carried out using aluminum electrodes at different distances between electrodes (10 and 15 cm). Different factors were studied to enhance the electrocoagulation treatment process which include sedimentation period (3 and 5 h), different electrocoagulation periods (30 and 60 min), and different electrical voltages (12 and 24 V). Alum was used as a coagulant and the final effluent was disinfected with chlorine. The results showed that aluminum electrodes were effective for treatment and the distances between electrodes have played a role in the treatment process since 10 cm was more effective than 15 cm. Aluminum electrodes with 10 cm distance between electrodes showed the maximum removal percent of physicochemical parameters such as TSS (93.2%), COD (83.0%), TKN (86.0%), BOD (93.5%) and total phosphorus (80.0%). Alum enhanced the treatment efficiency and the final chlorinated effluent was in comparable with the local laws for reuse purposes.

Keywords: electrocoagulation, wastewater treatment, aluminum electrodes.

Introduction

Egypt is suffering from water scarcity since Egypt receives only 55 billion cubic meters annually while the population increases and subsequently water demand increases. As a result, Egypt is searching for new resources of water. Wastewater treatment and reuse i.e. recovery, is one of the suggested solutions as a new source for water. On the other hand, wastewater usually contains high concentrations and levels of chemical, physical and biological pollutants which require proper treatment before discharge into environment or for reuse purposes (Hussien et al., 2015).

Most of the wastewater treatment plants apply the biological treatment technologies for wastewater treatment. However, biological treatment technologies have some disadvantages such as the need for higher oxygen volume for aeration as a result of increased biological oxygen demand (BOD) concentration, which in turn leads to increasing the capital, running, and energy costs. Additionally, biological treatment technologies require huge treatment areas, long retention time and qualified technicians (Grau, 1996).

Electrocoagulation treatment is considered as one of the promising cheap, efficient and simple methods for wastewater treatment (Chen et al., 2000). This electrochemical treatment method has some advantages including lower maintenance cost, high effectiveness, rapid achievement of results and less need for labor (Feng et al., 2003). Many researchers reported the promising and effective treatment capability of electrocoagulation method for treating different types of wastewater including tannery wastewater (Pouet and Grasmick, 1995), food wastewater (Zheng and Chen, 2010), textile wastewater (Kobya et al., 2006; Phalakornkule et al., 2010; Hussein et al., 2014), restaurant wastewater (Chen et al., 2000), urban wastewater (Pouet and Grasmick, 1995), potato chips wastewater (Kobya et al., 2006), and heavy metals removal (Meunier et al., 2009; Akbal and Camci, 2011; Shafaei et al., 2011).

Electrocoagulation method is an alternative for coagulation chemicals such as polymers or metal salts because during the treatment process, the electrode generates metal hydroxides and coagulated species which destabilize and aggregate suspended particles and precipitate. Also, the released hydrogen gas from cathode helps to float the flocculated particles away from the water (Kobya et al., 2006).

In Egypt, Abu Rawash wastewater treatment (ARWTP) plant is one of the largest wastewater treatment plants which operated in 1992 and is located at the north-west side of 6th of October city. ARWTP contains only pretreatment and primary treatment for wastewater then discharge wastewater directly to a series of drains which finally discharge into Rasheed Nile river branch. This incomplete treated wastewater pollutes the Nile river. Thus, ARWTP was chosen to study the application of electrocoagulation treatment method for wastewater treatment. The aim of the present study was to install a mini model for wastewater treatment from ARWTP using electrocoagulation method. Aluminum electrodes were used under different conditions such as sedimentation period (3 and 5 h), different electrodes distances (10 and 15 cm), different electrocoagulation periods (30 and 60 min), and different electrical voltages (12 and 24 V). Alum was used as a coagulant. The final effluent was disinfected with chlorine.

Material and methods

1. Abu Rawash wastewater treatment plant (ARWTP).

ARWTP is located at north-west side of 6^{th} of October city, Egypt with area of 520 acre including the expansion area. ARWTP design capacity is 1.2 million cubic meters per day. The current stage (first stage) uses pretreatment and primary treatment only for wastewater. ARWTP receives wastewater from different areas via lift stations in Egypt which include Imbaba, Boulaq, Janoob Almoheet, Alwaslah, Abu Rawash, Khufu and Alharam.

2. Samples and sampling.

Four samples were collected from ARWTP, each sample was consisted of 10 containers with a capacity of 20 liters for each container. Samples were collected after the aerated girt removal chamber because it was hard to collect them after the circular settling tank. Samples were acidified to fix BOD and COD values. Samples were transferred directly to the experimental site where the mini model was installed.

3. Measured parameters.

Collected raw wastewater samples were analyzed for characterization. Also, samples collected after each treatment stage from the mini model were analyzed. The measured parameters were biological oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), pH, total phosphorus (TP), total Kjeldahl nitrogen (TKN) and ammonia-nitrogen (NH_3-N). All parameters were measured according to standard methods (APHA, 2010).

4. Mini model components.

Figure (1) showed components of the mini model. The mini model consists of four tanks. The first tank (primary sedimentation), the second tank (electrical coagulation) which contains aluminum electrodes, the third tank (alum coagulation), and the fourth tank (chlorination and final sedimentation).

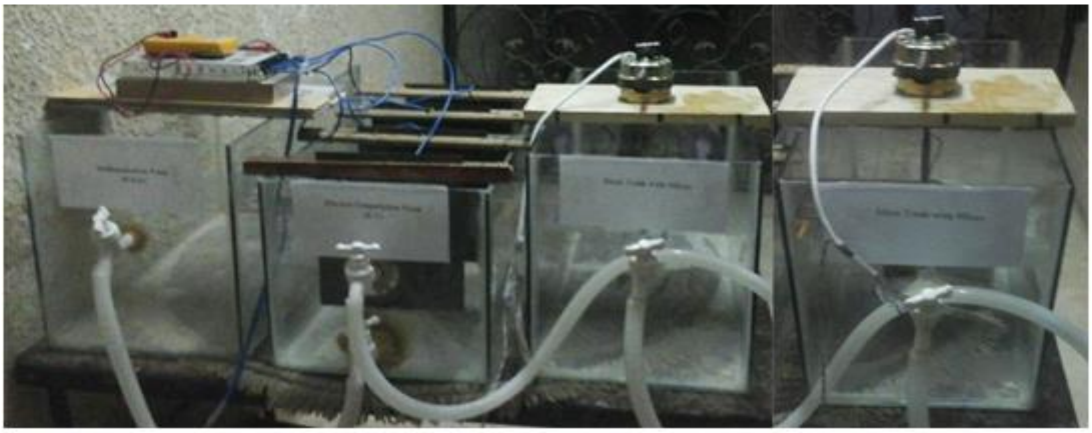

Figure 1. components of the mini model

Power supply used in E.C unit is LRS-350W series Ultra thin single switching power supplyas shown in figure (2) and its fetchers is as follow:

AC input range selected by switch (115/230)

- Withstand 300VAC surge input for 5 second
- Miniature size and 1U low profile, low weight
- Protections: Short circuit/Overload/Over voltage/Over temperature
- Forced air cooling by built-in DC fan
- Built-in cooling fan ON-OFF control
- No load power consumption＜0.75W
- Operating altitude up to 5000 meters（Note6）
- LED indicator for power on
- 100% full load burn-in test
- High efficiency, long life and high reliability
- 3 years warranty

And its technical specifications is as follow

Model		LRS-350-12	LRS-350-24
Out put	DC voltage	12V	24V
	Rated current	29A	14.6A
	Current range	0~29A	0~14.6A
	Rated power	348W	350.4W
	Ripple&noise	150mVp-p	150mVp-p
	DC voltage ADJ. range	±10%	±10%
	Voltage toleranceNote.3	±2%	±1%
	Line regulationNote.4	±0.5%	±0.5%
	Load regulationNote.5	±1%	±0.5%
	Setup,rise,hold up time	800ms,50ms,16ms/230VAC(full load)	
	Voltage range	90~132VAC/180~264VAC(selected by switch), 240～373VDC	90~132VAC/180~264VAC(selected by switch), 240～373VDC
input	Frequency range	47~63HZ	47~63HZ
	AC current	6.8A/115VAC 3.4A/230VAC	6.8A/115VAC 3.4A/230VAC
	Inrush current	Cold start 55A/230VAC	Cold start 55A/230VAC
	Leakage current	2>mA/240VAC	
protection	overload	Rated output power110%~140% start over load protection	Rated output power110%~140% start over load protection
		protection type:hiccup mode, auto-recovery after fault condition is removed	protection type:hiccup mode, auto-recovery after fault condition is removed
	Over voltage	Rated output voltage 115%~135% Start over voltage	Rated output voltage 115%~135% Start over voltage

		protection	protection
		Protection type：hiccup mode, auto-recovery after fault condition is removed	Protection type：hiccup mode, auto-recovery after fault condition is removed
	Over temperature	100℃±10℃（RTH3 detect beside magnetic core）	100℃±10℃（RTH3 detect beside magnetic core）
		Protection type:cut off the output,auto-recovery after the temperature become normal	Protection type:cut off the output,auto-recovery after the temperature become normal
Function	Fan ON-OFF control	RTH3≥50℃Fan ON,≤40℃Fan OFF	
environment	Working temp,humidity	-25℃～+70℃(Please refer to“derating curve”) 20%~90%RH Non-condensing	
	Storage temp,humidity	%95~%10，℃85+~℃40-RH non-con densing	
	Withstand vibration	500~10HZ，2G10min/1cycle，period for 60 minutes，each axes	
safety	Withstand voltage	I/P-O/P:3KVAC I/P-FG:2KVAC O/P-FG:1.25KVAC	
	Isolation resistance	I/P-O/P,I/P-FG,O/P-FG:100Mohms/500VDC	
Fit standard	Safety standards	Compliance to UL60950-1,TUV EN60950-1,GB4943	
	EMC emission	Compliance to EN55022(CISPR22)Class B，GB9254 Class B,EN55014,EN61000-3-2,3	
	EMC immunity	Compliance to EN61000-4-2,3,4,5,6,8,11, EN55024,EN61000-6-1	

Figure No. (3.38): power supply device

Mixer used in the alum and chlorine tanks. It is used to mix and distribute the chemical solution which is the alum solution (aluminum sulphate) and to mix irregularly with water which exits from the electrical coagulation tank, and that guarantee the distribution of the alum solution in the water. The mixer is turned on inside the alum tank for half an hour, also the mixer device has been butted on the chlorine tank to mix the chlorine with the water and guarantee the distribution of the chlorine around the entire tank.

The mixer device composed of electrical motor with a resistance equal 1000 ohm. the wires are extracted from the electrical motor as follows: the first wire is extracted at a resistance equal 700 ohm which is used for the slow speeds, the second wire is extracted at a resistance equal 500 ohm which is used for the moderate speeds and the third wire is extracted at a resistance equal 300 ohm which is used for the high speeds. These wires has been connected to an electrical switch which has several velocities to be able to control the rotator speed of the mixer as shown in the figure (3).

The electrical motor is also supplied with a condenser to gather the electrical charge from the electrical circuit and transmit it to the rotator file which rotates the rotator axis of the mixer device. The design of the mixer is modified and it was provided with an axis with a length equal 27 cm and a paddle from the bottom to fit the model. The axis and the paddle are made up of stainless steel and painted with an anti-rust material as shown in figure (3).

The paddle dimensions are 22*3 cm to fit with the dimensions of the tank. Also the mixer device contain a wood plank with a dimension equal 35*18 cm and a thickness equal 2 cm. this plank is used to fix the motor on it then the mixer is fixed on the model using wooden planks to prevent short circuit . These wooden planks are provided with metallic weights to prevent the vibration during the experiment as shown in figure (3).

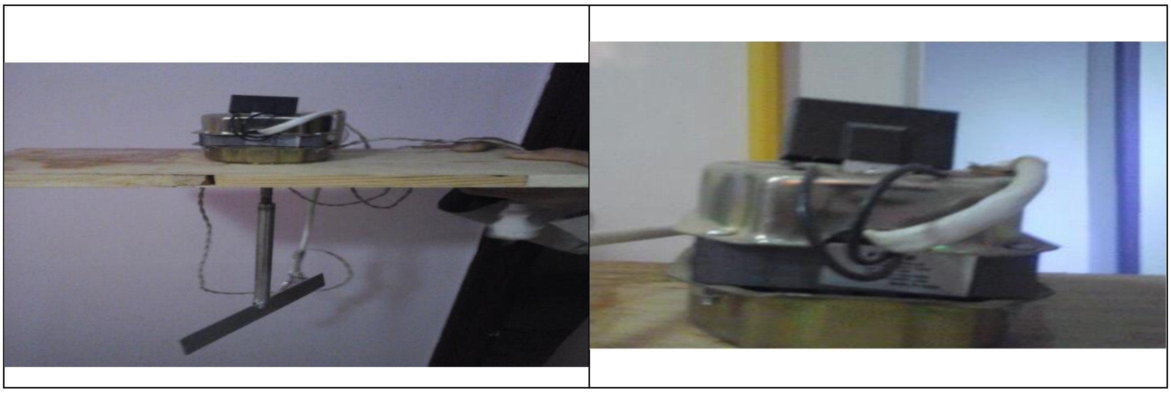

Figure No. (3.34): the mixer device

5. Experimental method.

The first tank was filled with 54 liters of wastewater. The wastewater was left (1 hour) for sedimentation. Wastewater then physically transferred into the second tank. Inside the second tank, aluminum monopolar electrodes were set separately in pairs. Monopolar electrodes were connected in parallel with a DC power supply (LRS-350W series ultra-thin single switching). The electrochemical treated wastewater transferred into the third tank where alum was added (30 mg/l) and mixed through a mixer for 15 min and left for 2 h for sedimentation. The alum dose was determined using Jar test method. After that, treated wastewater was transferred into the fourth tank where disinfection was carried out using powdered chlorine (5 ppm) with a contact time of 40 min. Sediments were withdrawn from the mini model through pipes. Some variables were examined to study their effects on the electrocoagulation process. These variables include; sedimentation period in first tank (3 and 5 h), the distance between electrodes (10 and 15 cm), electrocoagulation period (30 and 60 min) and the electrical voltage (12 and 24 V).

Results and discussion

1. Raw wastewater characterization.

Table 1. Raw wastewater characterization from ARWTP.

Parameters	Unit	Samples				Min.	Max.	Average
		1st	2nd	3rd	4th			
COD	mg/l	383	365	375	370	365	383	372.5
BOD	mg/l	330	305	300	310	300	330	307.5
pH	-	7.7	7.7	7.7	7.7	7.7	7.7	7.7
TSS	mg/l	126	120	122	125	120	126	123.5
NH_3-N	mg/l	46	52	49	45	45	52	47.5
TKN	mg/l	65	75	70	67	65	75	68.5
TP	mg/l	7.2	7.5	7.0	7.2	7.0	7.5	7.2

Table 1 summarizes the characteristics of the four different samples used during the experiments. The samples were symmetric and no significant differences were observed.

2. Aluminum electrodes efficiency for electrocoagulation.

Table 2 summarizes the efficiency of primary sedimentation tank for removal of pollutants from wastewater samples collected from ARWTP using aluminum electrodes spaced by 10cm. It was clear that by increasing the sedimentation period from 3 h to 5 h, the removal percent increased for all measured parameters. TSS showed the maximum removal percent of 44.3% after 5 h. Also, BOD and COD showed the same behavior during sedimentation periods with a maximum removal percent of 33.3% for COD and 32.7% for BOD after 5 h. In addition, it was clear the proportional relationship between increasing the current voltage from 12 V to 24 V and the contact time from 30 min to 60 min. By increasing the current voltage and increasing the contact time, there was an observed enhancement in the removal efficiency of measured pollutants. The maximum removal percentages using electrical current of 24 V for 60 min contact time, were 56.0%, 82.7% and 79.4% for COD, BOD and TSS, respectively. After the addition of alum as a coagulant, the overall removal percent enhanced significantly. The overall removal percentages reached to 83.0% for COD, 93.5% for BOD and 93.2% for TSS.

However, by increasing the distances between aluminum electrodes from 10 cm to 15 cm under the same treatment conditions, the same treatment behavior was observed for all measured parameters while the treatment efficiency slightly decreased (Table 3). The overall removal percentages decreased to 80.0% and 92.9% to 91.2% for COD, BOD and TSS, respectively. The obtained results were almost the same with the results reported by Tchamango et al. (2012) since they used aluminum electrodes for the treatment of artificial wastewater and reported removal efficiencies of 61.0% for COD and 100.0% for TSS. In another study (Bazrafshan et al., 2013), aluminum electrodes were used for electrocoagulation with potassium chloride as electrolyte for wastewater treatment and showed removal efficiencies of 97.95% for BOD, 98.84% for COD and 97.75% for TSS.

In the electrocoagulation process an electrical current flow between two electrodes and the coagulant is generated in situ via electrolytic oxidation of the anode material. The increasing in current density produces heavier and larger flocs (Yengejeh et al., 2017). The effect of current density on pollutants removal was due to the higher amounts of ions produced on the electrodes promoting destabilization of the pollutant molecules (Hossain et al., 2013). The effect of contact (operating) time on the electrocoagulation process maybe attributed to the two stages involved in electrocoagulation process. These two stages are destabilization and aggregation. Destabilization stage is short while aggregation stage is relatively long. Metal ions (aluminum) as destabilization agents are produced at anode thorough electrochemical reactions which result in a low charge loading when the contact time is shortened. The metal ions dosage was not sufficient to stabilize all colloidal and suspended particles (Shammas et al., 2010; Hossain et al., 2013). Merzouk et al. (2009), El-Ashtoukhy et al. (2010) and Parsa and Vahidian (2011) reported that the contact time should not be more than 60 min because of economic reasons and formation of many clots. They suggested that the appropriate contact time for electrocoagulation is between 15 to 60 minutes.

Table 2. Efficiency of aluminum electrode (10 cm distance between electrodes) for wastewater treatment.

parameter	Raw	PST				electrical coagulation								C & S	AC	OR %	Law 48 (1992)
		3h	R%	5hr	R%	12 volt				24 volt							
						30 min	R%	60 min	R%	30 min	R%	60 min	R%				
COD	375	295	21.3	250	33.3	226	9.6	152	39.2	127	49.2	110	56.0	72.5	64	83.0	30-40
BOD	300	250	16.7	202	32.7	100	50.5	82	59.4	63	68.8	35	82.7	24	19	93.5	20-30
PH	7.7	7.7	-	7.7	-	7.7	-	7.7	-	7.6	-	7.6	-	7.6	7.6	-	
TSS	122	81	33.6	68	44.3	32	52.9	26	61.8	22	67.6	14	79.4	8.7	8.2	93.2	30
NH3-N	49	38	22.4	30	38.8	25	16.7	23	23.3	20	33.3	17	43.3	10.6	10	79.5	30
TKN	70	52	25.7	40	42.9	30	25.0	21.5	46.3	18	55.0	16	60.0	10.2	9.8	86.0	25
TP	7	6	14.3	4.8	31.4	4.3	10.4	4.1	14.6	4	16.7	2.6	45.8	1.7	1.4	80.0	

PST: primary sedimentation tank, R%: removal percent, OR%: overall removal percent, C & S: coagulation and sedimentation, AC: after chlorine

Table 3. Efficiency of aluminum electrode (15 cm distance between electrodes) for wastewater treatment.

parameter	Raw	PST				electrical coagulation								C & S	AC	OR %	Law 48 (1992)
		3h	R%	5hr	R%	12 volt				24 volt							
						30 min	R%	60 min	R%	30 min	R%	60 min	R%				
COD	370	290	21.6	255	31.1	232	9.0	168	34.1	141	44.7	127	50.2	87.5	74	80.0	30-40
BOD	310	260	16.1	206	33.5	111	46.1	92	55.3	70	66.0	40	80.6	27.5	22	92.9	20-30
PH	7.7	7.7	-	7.7	-	7.7	-	7.7	-	7.6	-	7.6	-	7.6	7.6	-	
TSS	125	80	36.0	71	43.2	37	47.9	29	59.2	24	66.2	19	73.2	11.2	11	91.2	30
NH3-N	45	36	20.0	28	37.8	24	14.3	21.5	23.2	20.5	26.8	18	35.7	12.5	12	73.0	30
TKN	67	49	26.9	42	37.3	34	19.0	27	35.7	20	52.4	17	59.5	11.5	11	83.5	25
TP	7.2	6.3	12.5	5	30.6	4.4	12.0	4.2	16.0	4	20.0	3.6	28.0	2.5	2	72.2	

PST: primary sedimentation tank, R%: removal percent, OR%: overall removal percent, C & S: coagulation and sedimentation, AC: after chlorine

Conclusion

The present study showed that:

- the ability of aluminum electrodes via electrocoagulation method for raw domestic wastewater treatment collected from Abu Rawash wastewater treatment plant, Egypt.
- The aluminum electrodes were effective for removal of pollutants.
- The distance between electrodes played a vital role in the treatment process.
- The maximum removal efficiency was observed by using aluminum electrodes with a distance of 10 cm.
- Electrocoagulation process for wastewater treatment can be a suitable technology for domestic wastewater treatment.
- The treated effluent after coagulation with alum and disinfection with chlorine was in comparable with the Egyptian law for reuse purposes.
- The physiochemical parameters for effluent match the law48 (1992) for reuse purposes except the COD, needs further treatment.

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