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Domestic Wastewater Treatment Using a Modified Electrocoagulation Process.

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DOMESTIC WASTEWATER TREATMENT USING A MODIFIED ELECTROCOAGULATION PROCESS

معالجة مياه الصرف الصحى باستخدام عملية الترويب الكهربى المعدلة

Kassem El- Alfi, *Kamal Radwan, Moharram Fouad* and Mohamed Al Nady

KEYWORDS:
Wastewater, treatment, modified electrocoagulation, iron and aluminum electrodes, retention time, earthen plate

***الملخص العربي*:- تم معالجة مياه الصرف الصحى باستخدام طريقة الترويب الكهربى المعدلة باستخدام جهاز معملى . تم تعديل وحدة الترويب بإضافة لوح معدنى (حديد) متصل بالأرض كنظام أرضى و مقارنته بالنظام العادى للترويب الكهربى تحت نفس الظروف التشغيلية . و كانت تركيزات الأكسجين الكيميائى الممتص من 500 الى 700 مجم/لتر. تم تشغيل الجهازالمعملى بنظام الدفعات خلال حوالى تسعة اشهر. وتتكون وحدة الترويب الكهربى من حوض زجاجى شفاف به مجموعة أقطاب كهربية من الحديد والالومنيوم متصلة بوحدة امداد بالقوى الكهربية. تم استخدم جهد كهربى بقيم 9، 18، 27 فولت. وزمن بقاء اثناء التجربة يتراوح من 30 الى 60 دقيقة مع تغيير القطبية من موجب الى سالب والعكس بالعكس كل عشر دقائق. تم تعديل وحدة الترويب باضافة لوح معدنى (حديد) متصل بالارض كنظام أرضى و مقارنته بالنظام العادى للترويب الكهربى تحت نفس الظروف التشغيلية. النتائج العملية تؤكد أن نظام الترويب الكهربى المعدل يلعب دورا حيويا في الحصول بسرعة على كفاءة إزالة يمكننا الاعتماد عليها مقارنة بالنظام العادى. حقق نظام الترويب الكهربى المعدل ازالة 97% من الاكسجين الكيميائى الممتص بزمن بقاء 30 دقيقة وجهد كهربى 9 فولت (6 ألواح) بالمقارنة بزمن بقاء يصل الى 60 دقيقة بنظام الترويب الكهربى العادى تحت نفس ظروف التشغيل. كفاءة ازالة الملوثات يمكن التحكم فيه من خلال التحكم فى عدد الالواح وزمن البقاء وقيم الجهد الكهربى . نظام الترويب الكهربى المعدل يوفر استهلاك مادة الأقطاب و الطاقة و تقليل زمن التفاعل الى 30 دقيقة بالمقارنة بنظام الترويب الكهربى العادى**

***Abstract*—A raw domestic wastewater (DWW) was treated using a modified electrocoagulation and conventional electrocoagulation (EC) experimentally. The EC process was modified by providing the plate connected by earth as earthen system and compared it with the conventional system under same operational conditions.**

The initial medium strength COD ranged from 500 to 700 mg/l was used. A bench scale electrocoagulation unit has been operated under batch operational conditions along nine months. The electrocoagulation unit has been consisted of transparent basin containing iron and aluminum electrodes which are connected to a power supply unit. The system was operated under different operational conditions by applying voltages 9, 18, and 27 volts. The treatment retention time ranged from 30 to 60 min. and inter change the polarity of plates periodically every 10 min.

The experimental results confirm that, earthen system plays a vital role to get fast reliable removal efficiency compared with the conventional system. The modified earthen system achieved removal of 97% for COD with retention time of 30 minutes and volts of 9 V (six plates) instead of 60 min in case of conventional system under same operational conditions. The removal efficiency was controlled accurately by changing the number of charged plates, retention time, and volt values. The modified system save the consumption material electrodes and energy and reduced retention time to 30 min. compared with the conventional electrocoagulation system.

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I. INTRODUCTION

WATER is very important to keep life on the bioactivity. However; with the increasing population and industrial growth, its resources are becoming limited and/or contaminated. By virtue of growing request globally more than a billion people lack access to adequate water of good fineness. Domestic wastewater (DWW) is at all event treated by aerated biological methods. Activated sludge, existence the most widespread method, produces high quality effluent—90% biological oxygen demand (BOD) and suspended solids (SS) removal (Metcalf and Eddy, 2003). But this widespread used method has some disadvantages, such as requiring continuous air sources, high operating and maintenance costs (skilled labor, energy, etc.), sensibility versus shock toxic loads, longer treatment time, and needful sludge disposal. Some lab-based environmental studies have been accomplished to treat DWW chemically by coagulation. Chemical oxygen demand (COD) treatment between the ratios of 55 and 75%, especially if it includes SS substances in the wastewater, can be achieved by this method (Debik, 1999). The chemicals that are used in this type of treatment and the chemical characteristics of the sludge produced are the more refined problems encountered using this method. Accordingly a desk study, Due to the structural approach on how to make more sustained treatment process. From environmental perspective, the sewage treatment process is still far from being environmentally sustainable. Some of the preferences are the amelioration of the alleviation of poisonous pollutants, high-temperature sludge treatment processes, and membrane separation processes (Rulkens, 2006). Electrochemical treatment seems to be arising treatment method due to its high effectiveness, its lower maintenance cost, less need for labor and rapid achievement of results (Feng et al., 2003). Electrocoagulation-flotation treatment is scrupulous, as it has greater capability for the removal of COD and SS from effluents in arbitrage with treatment by conventional coagulation (Jiang et al. 2002). At the end of the studies it is determine the most suitable method to EC used, electrocoagulation (EC) is shown to be one of the distinguished methods for the wastewater treatment. Reusing of wastewater has become an absolute necessity, so there is urgent need to innovation development, more efficacious and low-cost technics for treatment of wastewater (Feng et al., 2003). Electrochemical treatment technics are one of these. A steward of very promising technics based on electrochemical technology is being advanced, and existing ones are being amended that do not require chemical additions (Mollah et al., 2001). EC can be used to eliminate irons, silicates, humus, dissolved oxygen (Chen, 2004), reduction of copper (Comninellis and Pulgarin, 1993) and removes color (Bechtold et al., 2002). EC has also been applied successfully to treat drinkable water, food, and protein wastewater, leaven wastewater, urban wastewater, restaurant wastewater, tar sand, and oil shale wastewater, nitrate containing wastewater, heavy metals, textile dyes, fluorine, polymeric wastes, organic matter from landfill leachate, suspended particles, chemical and mechanical polishing wastes, aqueous suspensions of ultrafine particles, and phenolic waste (Mollah et al., 2004).Currently, EC technologies are more efficient and more compact. Removal mechanisms of the EC process include coagulation, adsorption, precipitation, and flotation (Kobya et al., 2003). Similarly, the effect of DC electric current on COD in aerobic mixed sludge processes has been investigated, and optimum operational conditions were specific. (Alshawabkeh et al., 2004). In different study, reduction of nitrogen component has been successfully accomplished using a rotary electrobiological contactor; an enjoyable study, in which over 83% efficiency of the denitrification was observed at a nitrification efficiency of 68.9 % (Krzemieniewski and Rodzievicz, 2005). When the literature is scanned for studies of treatment by electrocoagulation of DWW, it is nearly an untouched area. That is to say, there is a research requirement in that subject. In EC process, coagulation is created in location by electrolytic oxidation of a suitable anode material. Through this process, charged ionic species are reduction from wastewater by allowing it to react with an iron having opposite charge, or with drift metallic hydroxides created within the effluent. EC treatment methods submit an alternative to the use of metal salts or polymers and polyelectrolyte addition for breaking stable emulsions and suspensions. The EC treatment mechanism gives highly charged polymeric metal hydroxide to aquatic media, so the electrostatic charges on suspended solids and oil cluster are equality to easiness coagulation and their resultant separation from the aquatic body.

The treatment claims are the precipitation of certain metals and salts. Treatment performances of the system are studied by optimum utilization of electrical current and of electrodes materials, which are the two most important parameters for the method (Chen et al., 2002; Chen, 2004). For the EC treatment method, dissolvable For the EC treatment method, the electrodes melting in wastewater so it must be that determine anode materials carefully. Electrocoagulation is a substitutional technology for wastewater treatment besides its other conventional applications. The main advantages of electrocoagulation over other conventional techniques, such as chemical coagulation and adsorption, are “in situ” delivery of reactive agents, no generation of secondary pollution, and compact fixture. The previously studies have mention the possibility of electrocoagulation to treat a various kinds of industrial and domestic wastewater (Vlyssides et al., 2000; Kobya et al., 2003; Holt et al., 2006; Bensadok et al., 2008; Merzouk et al., 2009; Virkutyte et al., 2010).

II. THEORY OF ELECTROCOAGULATION

As shown in Fig. 1, aluminum or iron is usually used as electrodes and based on the implementation of a direct current their cations are generated by resolved of exchanged anodes. The metal ions creative are decomposition in the electrochemical cell to create metal hydroxide ions according to anodic and solution reactions and the solubility of the metal hydroxide complexes formative depends on pH and ionic power. Insoluble flocs are generated at pH range between 6.0 and 7.0. Positive metal fraction is reacting with negatively charged colloidal in the wastewater to form unstable colloids and then flocs. The on-site reproduction of coagulants means that electrocoagulation operations do not needed any addition of the chemicals. The gases produced at the cathode during the electrolysis of water and metal dissolution according to cathodic reaction permit the resulting flocs to float and it may be removed by any skimming technique.

The oxidation - reduction reactions involved in the electrochemical cell are as follow:

Anodic (oxidation) reactions:

$$Al_{(solid)} \rightarrow Al^{+3}_{(aquatic)} + 3\,e^-$$

$$Fe_{(solid)} \rightarrow Fe^{+2}_{(aquatic)} + 2\,e^-$$

$$Fe^{+2}_{(aquatic)} + 2\,OH^-_{(aquatic)} \rightarrow Fe(OH)_{2(solid)}$$

Cathodic (reduction) reactions:

$$2\,H_2\text{O} + 2\,e^- \rightarrow H_2\text{(gases)} + 2\,OH^-_{(aquatic)}$$

In the solution:

$$AL^{+3}_{(aquatic)} + 3\,H_2\text{O} \rightarrow Al(OH)_{3(solid)} + 3\,H^+_{(aquatic)}$$

$$Fe^{+3}_{(aquatic)} + H_2\text{O} \rightarrow \text{Fe}(OH)^{+2}_{(aquatic)} + 2\,H^+_{(aquatic)}$$

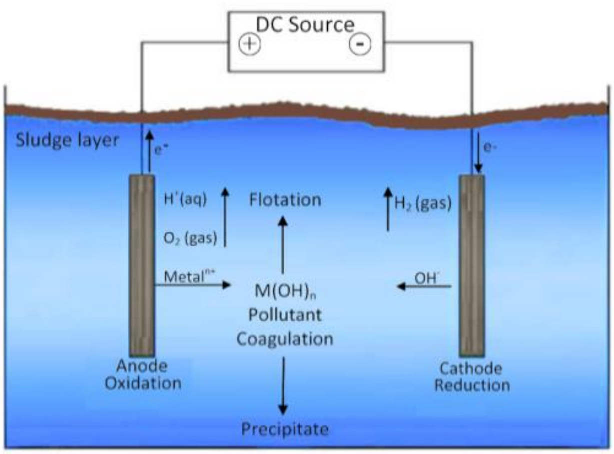


Fig. 1 Electrochemical Cell Reactor

The main objective of the present work is to investigate the effect of the presence (modified electrocoagulation) and absence (conventional electrocoagulation) of earthen plate as a technique for the treatment of domestic

Wastewater and also investigate the effect of electrodes number, material of electrodes, varying the volts and retention time on the COD removal efficiency.

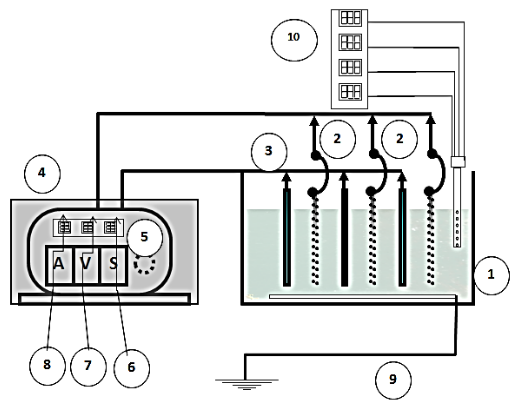
III. MATERIAL AND METHODS

A small scale set up electrocoagulation unit has been used for the present work. The experimental unit consists of a glass tank containing two sets of aluminum and iron plates. The glass tank has dimensions of 55 cm, 45cm and 35cm with effective water volume of 50 liters. Two sets of aluminum and iron plates have been submerged in the tank with dimension 17*23 cm. Each set consist of three parallel plates arranged one aluminum and other iron mutually. A small power unit has been connected to each set of plates .The output voltage from this unit is 10, 20, 30, volts DC and current is 10 amperes open circuit (when the power supply unit is working the output voltage and current was decreases and it go down to the 9, 18, 25 volts respectively and the current loading ranging from 0.185 Amperes to 0.68 Amperes. A device used for measuring voltage and current is a multi-meter. An earthen plate with dimensions of 50*25 cm has been placed in the bottom of the tank. Chemical oxygen demand COD is defined as the amount of a specified oxidant that reacts with the run sample and it is measured by standard methods for the examination of water and wastewater. Due to the reaction the erosion in metals can be obtained, it can be measured by Sensitive balance model FA2004 that accuracy 0.1 mg.

The earthen plate has connected directly to earthen rod. A measuring device has been connected directly to the tank for continuous monitoring pH, temperature and conductivity. Raw domestic wastewater characteristics and operational conditions are shown in table (1). An experimental program has been extending for six months to measure the effect of the earthen plate inside the tank on the COD removal and the consumption of electrodes material and power. The operational conditions have been included three groups by changing the number of plates, applied voltages and retention times. Thus, in each batch 50 liters sample of the domestic wastewater from Mansoura wastewater treatment plant was used to be treated for the experimental. The electrodes and other accessories were arranged and are shown in (Fig. 2). The photos 1 & 2 the experimental set up and during running.

TABLE (1)
RAW DOMESTIC WASTEWATER CHARACTERISTICS AND OPERATIONAL CONDITIONS

Group No.	Voltages applied, volts	Average initial COD, mg/l	pH	Conductivity µmho/m	Average temperature
Group 1: Two plates	9 volts	500	6.5	1150	**27° C**
	18 volts	500	7	1200	
	27 volts	500	6.5	1100	
Group 2: Four plates	9 volts	600	6.5	1150	
	18 volts	600	7.5	1250	
	27 volts	600	7	1200	
Group 3: Six plates	9 volts	700	6	1100	
	18 volts	700	7.5	1200	



Legend

1. Basin of wastewater
2. Fe Electrodes
3. Al Electrodes
4. Control panel
5. DC power supply
6. S switch
7. V voltmeter
8. A Ammeter
9. Earthen system
10. Digital kit for temperature, conductivity, and pH

Fig. 2 Schematic diagram of the experimental set up

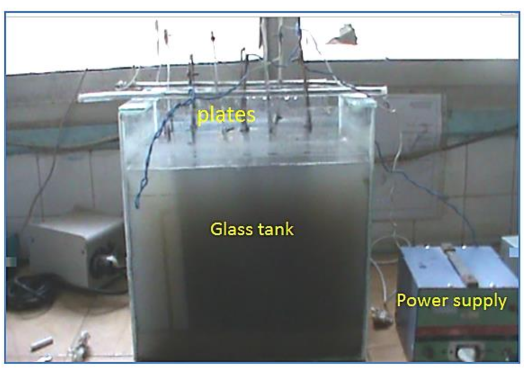


Photo (1) shows the experiment al set up

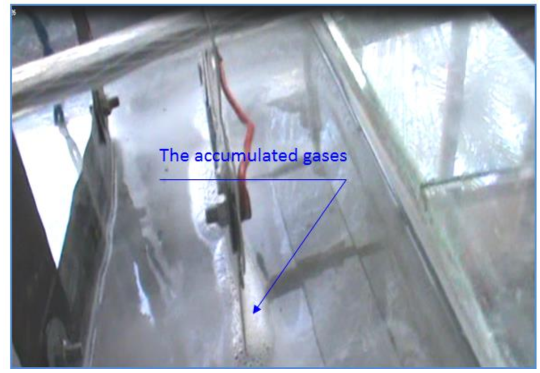


Photo (2) shows the experimental set up during operation

IV. Results and Discussion

The results can be classified to three groups according to the number of plates under the operational conditions for modified and conventional systems

The earthen system (modified) has been achieved very important features which was observed from the beginning of the experiments and initially tested and can be summarized in the following tables. Table.2 shows the experimental results under the used operational conditions with and without earthen plates (Conventional and modified EC). Also Table.3 shows the overall best results for Conventional and modified Electrocoagulation

TABLE (2)

THE EXPERIMENTAL RESULTS UNDER OPERATIONAL CONDITIONS WITH AND WITHOUT EARTHEN PLATES.

	Number of plates		2			4			6	
	Volts V		9	18	27	9	18	27	9	18
Result of modified system (0.5 hr. reaction time)	Current A		0.22	0.41	0.55	0.52	0.65	0.95	0.74	0.92
	Energy consumption, Watts/1m3		19.8	77.9	154	46.8	113	240	66.6	174.6
	Metals consumption gm/m3	Fe	12.6	33	36	30	53	79.6	52	80
		Al	3.2	8	11.6	13	17.6	30	30	46
	% COD Removal		60	68	85	87	88	93	97	98
Result of conventional system(1.0 hr. reaction time)	Current Amperes		0.19	0.3	0.46	0.42	0.75	1.23	0.64	0.86
	Energy consumption, Watts/1m3		33	108	248.4	75.6	255	615	115.2	309.6
	Metals consumption gm/m3	Fe	9	15.4	18	24.44	39	47	76	94
		Al	2	2.6	4.6	4.88	10	20	54	63.6
	% COD Removal		57	65	84	88	91	97	97	98

TABLE .3
THE OVERALL BEST RESULTS FOR CONVENTIONAL AND MODIFIED ELECTROCOAGULATION

	Number of plates	Volts, V	Current, A	Energy consumption, Watts/1m3	Retention time, min	Metals consumption gm/m Fe	Metals consumption gm/m Al	% COD Removal
Result of modified system (0.5 hr. reaction time)	6	9	0.74	66.6	30	52	30	97
Result of conventional system (1.0 hr. reaction time)	4	27	1.23	615	60	47	20	97
	6	9	0.64	115.5	60	76	54	97

The following group results can be illustrated for the conventional and modified systems

- Group 1: Two plates: (9, 18 and 27 V)

The figures (3&4) shows the using two plates with average initial COD of 500 mg/l for both the conventional and modified systems using volt values of 9, 18, and 27 volts. The changing of COD with time is shown in Fig. 3 COD reduced rapidly with increasing retention time and reach to a constant value. There is a sharp decrease in COD at the first 10 minutes of the process and after that there is a gradual decrease in the level. It is clear that, the removal efficiency increases with increasing volts and ranged from about 60% to 85% in 30 minutes with modified system (earthen plate) whereas the removal efficiency ranged from 57 to 84% in 1.0 hr. reaction time as shown in (table 2).

For conventional system, the material consumption of Fe electrodes ranged from 12.6 to 36 gm/ 1m^3 wastewater whereas Al electrodes ranged from 3.2 to 11.6 gm/ 1 m^3 wastewater. The power consumption ranged from about 20 to 75 watts / 1 m3 wastewater. Whereas for modified system, the material consumption of Fe electrodes ranged from 9 to 18 gm/ 1m^3 wastewater whereas Al electrodes ranged from 2 to 4.6 gm/ 1 m^3 wastewater. The power consumption ranged from about 33 to 248 watts / 1 m3 wastewater.

The percentage removal of COD amount is shown in Fig. 4. From the diagram the percentage removal of COD had incremented and progressively the percentage removal

decreases. This is due to the presence of flocculent that is produced with increase in current and retention time that participate to high removal of COD

- Group 2: Four plates: (9, 18 and 27 V)

The figures (5&6) shows the using four plates with average initial COD of 600 mg/l for both the conventional and modified systems using volt values of 9, 18, and 27 volts. The variance of COD with time is shown in Fig. 4. COD reduces with increasing retention time and arrives to a fixed value.

There is an acute decrease in COD at the initial 10 minutes of the reaction and after that there was a progressive decrease in the value. It was clear that, the removal efficiency increases with increasing volts and ranged from about 87% to 93% in 30 minutes with modified system (earthen plate) whereas the removal efficiency ranged from 88 to 97% in 1.0 hr. reaction time as shown in table 2.

For conventional system, the material consumption of Fe electrodes ranged from 30 to 80 gm/ 1.0m^3 wastewater, whereas Al electrodes ranged from 13 to 30 gm/ 1 m^3 wastewater. The power consumption ranged from about 46.8to 240 watts / 1 m^3 wastewater. Whereas for modified system, the material consumption of Fe electrodes ranged from 24 to 47 gm/ 1.0 m^3 wastewater whereas Al electrodes ranged from 4.9 to 20 gm/ 1 m^3 wastewater. The power consumption ranged from about 75.6 to 615 watts / 1 m^3 wastewater.

The effluent COD values for both systems were acceptable (> 80 mg/l) according to Egyptian code to discharge to drains. The percentage removal of COD values is shown in Fig. 5. From the figure, the percentage reduction of COD had increased and progressively the percentage removal decreases. This was by the existence of flocculent that was created with increase in current and retention time that participate to high removal of COD

- Group 3: Six plates: (9 and 18 V)

The figures (7&8) shows the using six plates with average initial COD of 700 mg/l for both the conventional and modified systems using volt values of 9, 18, and 27 volts. The changing of COD with time is shown in Fig. 7. COD decreases with increasing retention time and reaches to a fixed amount. There is an acute decrease in COD at the first 10

minutes of the process and after that there is a gradual decrease in the level. It is clear that, the removal efficiency increases with increasing volts and ranged from about 97% to 98% in 30 minutes with modified system (earthen plate) whereas the removal efficiency ranged from 97 to 98% in 1.0 hr. reaction time as shown in table 2. The effluent COD values for both systems were acceptable (> 80 mg/l) to Egyptian code to discharge to drain.

For conventional system, the material consumption of Fe electrodes ranged from 52 to 80 gm/ 1m3 wastewater, whereas Al electrodes ranged from 30 to 46 gm/ 1 m3 wastewater. The power consumption ranged from about 67to 175 watts / 1 m^3 wastewater. Whereas for modified system, the material consumption of Fe electrodes ranged from 76 to 94 gm/ 1m^3 wastewater, whereas Al electrodes ranged from 54 to 64 gm/ 1 m^3 wastewater. The power consumption ranged from about 115 to 310 watts / 1 m^3 wastewater. From Table .3 it is clearly that the treatment domestic wastewater using modified system with earthen plate better than the conventional system because it saves the energy, electrodes material and retention time. It was observed that the most of the sludge was collected on the water surface for the modified electrocoagulation. The earthen plates have pushed the sludge toward the surface of the liquid and help the system for sludge flotation and prevent the settling of some sludge in the bottom. For conventional electrocoagulation, it was observed that some small amount of sludge's settled on the bottom.

The modified system conducted on the electrocoagulation has proven highly effective in removing pollutants from domestic wastewater through the experiments. Finally, through various results, it was noted that ability of the modified system to reach the most appropriate and advantageous way to treatment domestic wastewater. It achieve higher efficiency in the removal of COD to acceptable level in one stage of treatment and reducing the consumption of energy, electrodes material and retention time. The efficiency 97% is the best result because of less energy consumption (table 3) compared with conventional system. From the point of financial view the selection of the modified system will be economic.

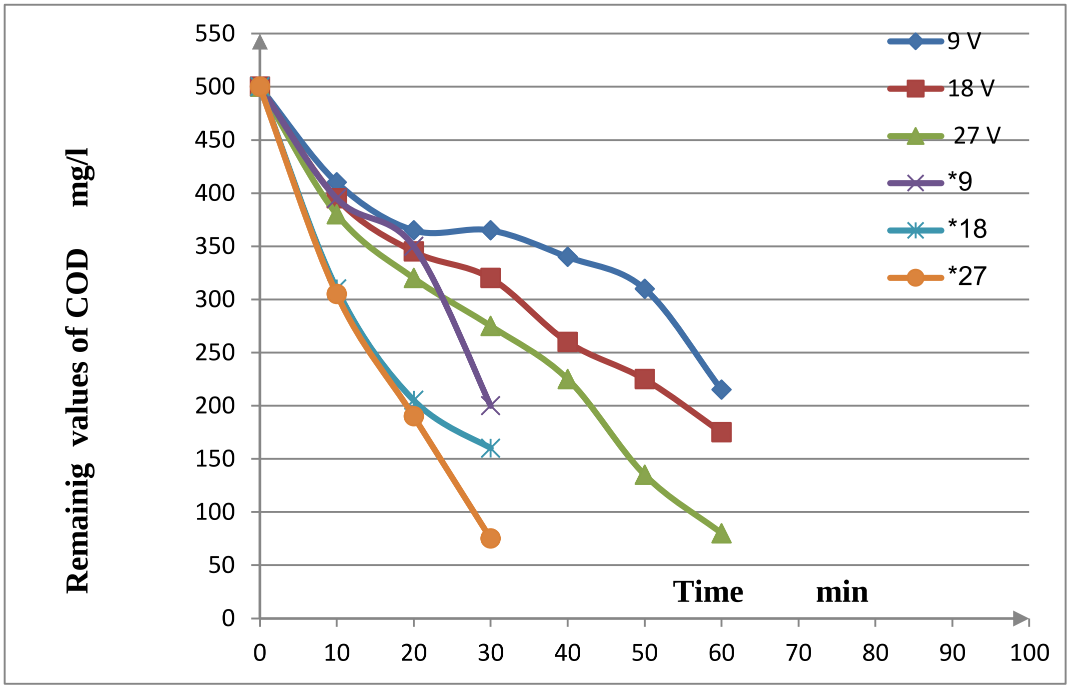


Fig. 3 Shows the remaining value of COD with the retention time (Group 1) modified system using (9*, 18*and27*volts) & Conventional system using (9, 18 and 27volts)

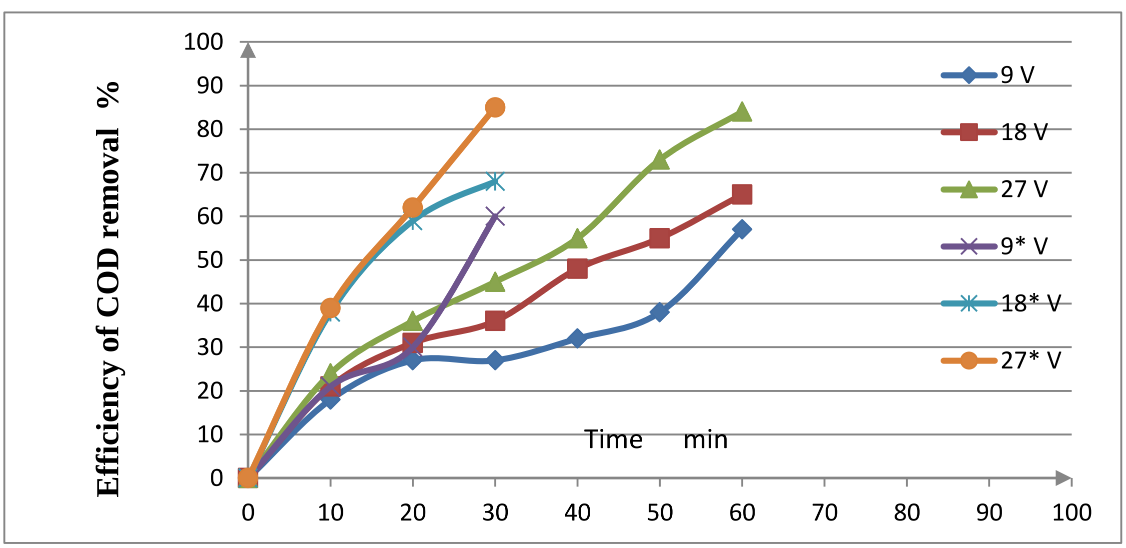


Fig. 4 Shows the efficiency of COD removal with the retention time (Group 1) modified system using (9*, 18*and27*volts) & Conventional system using (9, 18 and 27volts)

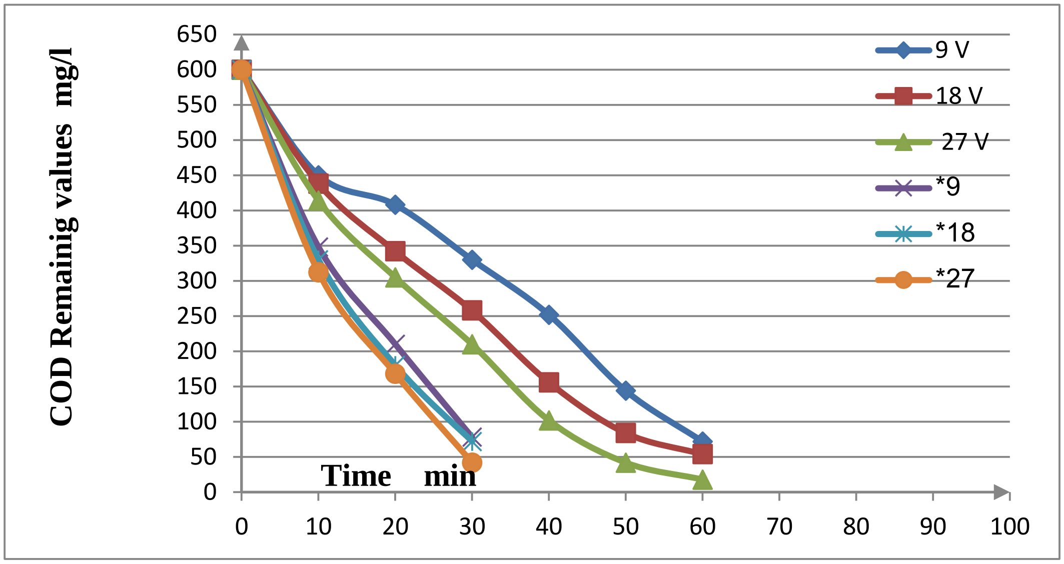


Fig. 5 Shows the remaining value of COD with the retention time (Group 2) modified system using (9*, 18*and27*volts) & Conventional system using (9, 18 and 27volts)

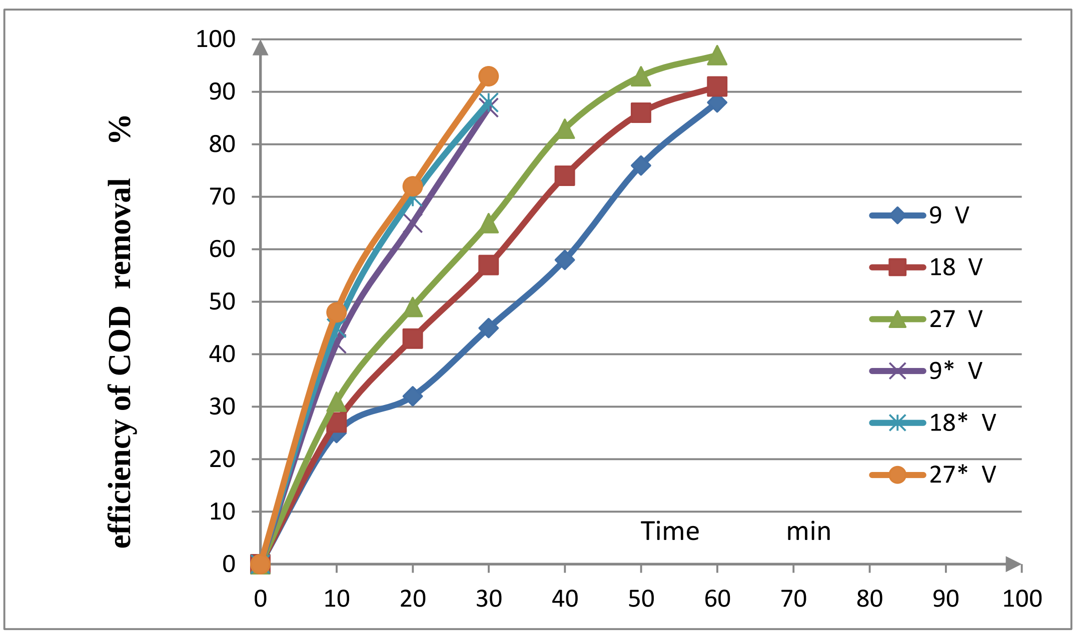


Fig. 6 Shows the efficiency of COD removal with the retention time (Group 2) modified system using (9*, 18*and27*volts) & Conventional system using (9, 18 and 27volts)

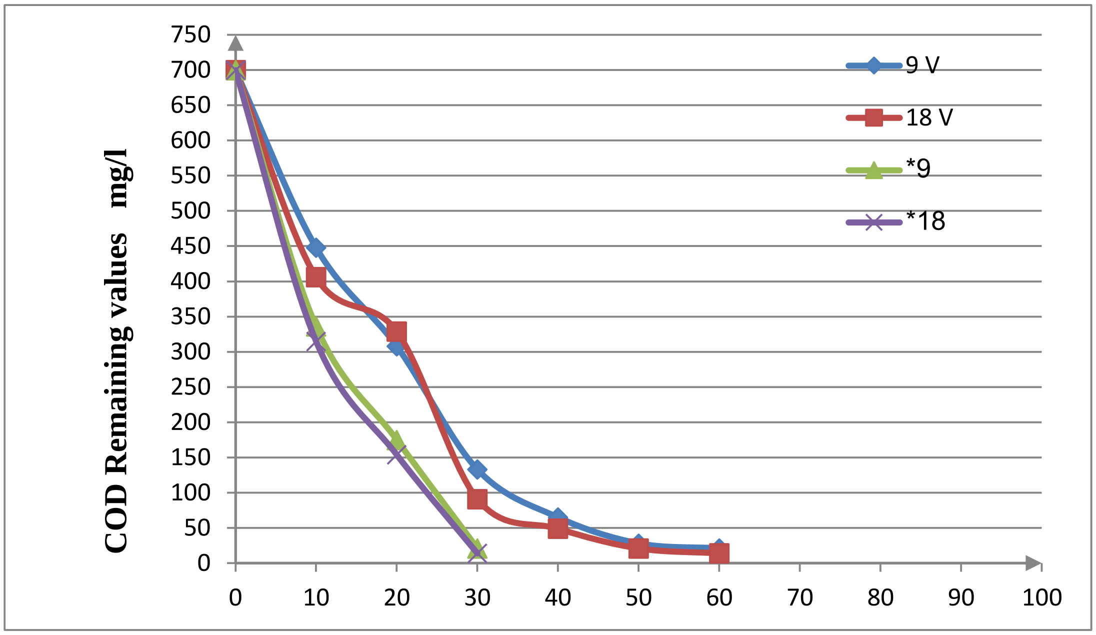


Fig.7 Shows the remaining value of COD with the retention time for (Group 3) modified system using (9*, 18* volts) & Conventional system using (9, 18 volts)

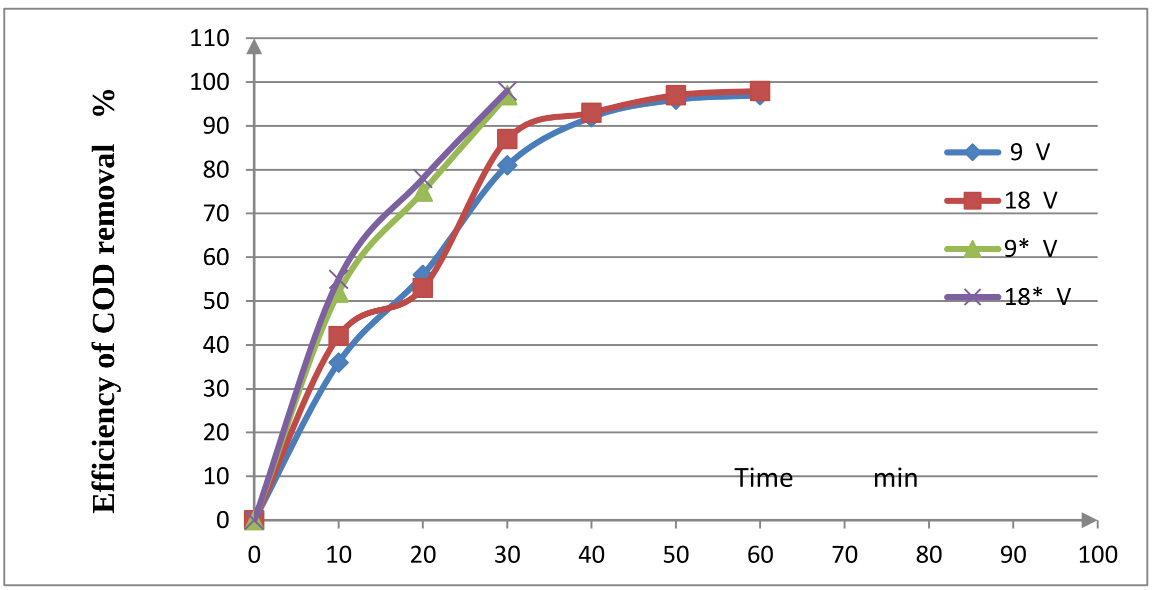


Fig. 8 Shows the efficiency of COD removal with the retention time for (Group 3) modified system using (9*, 18* volts) & Conventional system using (9, 18 volts

V. CONCLUSIONS

From the current study, it was clearance that:

- The treatment operation had shown suitable effectiveness in removing the COD present in the domestic wastewater to acceptable level for both the conventional and modified systems when using four and six plates of electrodes.
- The electrocoagulation process has been successfully treated the medium strength domestic wastewater using conventional with (60 min.) and modified electrocoagulation (30min) and achieved to 97% COD removal.
- The modified system compared with conventional system under same operation conditions has many advantages for saving retention time, energy and electrodes material consumption.

• The modified system can be used very easily and simple for the new wastewater treatment plant and upgrading the existing plants for saving the cost.

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