Comparative Analysis of Treatment of Textile Wastewater by Electrocoagulation in Horizontal Continuous and Horizontal Batch Reactor

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ABSTRACT:
Electrocoagulation using iron electrode was investigated to have optimized combination of affecting parameters like applied voltage, detention time and current supplied. Set of experiments were conducted using simulated sample prepared by dissolving basic red dye 5001 BC in tap water. An attempt was made to find out the electric work and specific energy requirement for unit removal of COD. Effect of applied voltage and detention time on COD removal efficiency was investigated for horizontal continuous plug flow reactor and horizontal batch plug flow reactor. A comparative study between horizontal continuous plug flow reactor and horizontal batch plug flow reactor was made to predict their effectiveness in term of COD removal efficiencies and economics of treatment. The results show that continuous reactors have better removal efficiency and economics of treatment.

1 INTRODUCTION

The amount and characteristics of wastewater from any textile industry depends on processing steps employed during manufacturing of textile fibers. High COD, large amount of suspended solids, low biodegradability, high salt concentration, strong dark color, and broadly fluctuating pH characterizes the textile wastewater (Umran TEZCAN UN and Ersin AYTAC, 2011), where COD concentration may exceeds 1600 mg/l (A. Alinsafi et al, 2004). Due to the presence of strong dark color & high amount of suspended solids, textile wastewater also found to have high turbidity (M. Kobya et al 2003). A number of dyes, chemicals, sizing agents are used in processing of textile fibers. A considerable amount of these dyes & chemicals remain unused and comes out with effluent, consequently leading to environmental problems (A. Alinsafi et al, 2004). About 10,000 pigments/dyes are used in textile industries & most of them are toxic (K. Charoenlarp and W. Choyphan, 2009) so when textile wastewater containing such dyes is released in environment, it could be toxic to human and aquatic life. Low biodegradability & more stability in nature of dyes impart an enhancement in its toxicity (C. Phalakornkule et al, 2009). Azo dyes are known to have high toxicity (Merzouk B, 2009). It has been found that dyes also have carcinogenic capability (Gregory P, 1986). On taking both volume & composition of wastewater into account textile industry comes into the category of most polluting industries (S.Sena, and G. N.Demirer, 2003).

In order to protect environment from textile wastewater a wide range of conventional wastewater treatment technologies have been employed. These methods include chemical degradation, precipitation, flocculation, biodegradation & adsorption (A. Cerqueira et al, 2009). Some time various combination of physical, chemical and biological process have been tested like coagulation with alum, magnesium chloride and ferric chloride (M.T. Kennedy et al 1992), adsorption using activated carbon & biosorbent, chemical oxidation, photolysis and electrophotocatalysis (A. Alinsafi et al, 2004). However among these conventional techniques, chemical techniques require addition of chemicals for treatment & lead to generation of secondary pollutants. Physical techniques like precipitation & adsorption are costly and time taking in relation to textile wastewater treatment. (C. Phalakornkule et al, 2009). Biological techniques have been reported to have very low efficiency for treatment of concerned wastewater because of the toxicity of dyes for macro organisms (C. Phalakornkule et al, 2009 and A. Alinsafi et al, 2004). Moreover, these conventional techniques are becoming inadequate & insufficient because of a large variation in composition of waste (M. Kobya et al 2003).

Electro-chemically based techniques like electrocoagulation have been proved to be an efficient & economically attractive method for treatment of such hard to treat textile wastewater (A.H.Esssdki et al 2008). Beside textile wastewater, electro-chemically based techniques like electrocoagulation and electrolysis have been reported to be efficient in treatment of waste water from various other industries (M. Kobya et al 2003). Treatment in electrocoagulation is carried out through coagulation, adsorption, precipitation and flotation mechanism. According to G.Chen, 2004 in electrocoagulation technique metallic anode dissolves electrically to produce metal ions in wastewater. These metal ions in wastewater get associated with hydroxide ions to form metal hydroxides which have coagulating property. P. Holt et al1999, explained the electrochemistry involve in treatment. Treatment takes place through following steps of reactions.

$$\text{At anode} \quad M_{(s)} \rightarrow M^{n+} + ne^- \qquad (1)$$

$$\text{At cathode} \quad 2H_2O_{(l)} + 2e^- \rightarrow 2(OH^-) + H_{2(g)} \qquad (2) \quad \text{(under neutral or alkaline pH).}$$

$$\text{Under acidic condition} \quad 2H^+ + 2e^- \rightarrow H_{2(g)} \qquad (3)$$

Hydrogen gas produced at cathode helps flocs containing pollutant to float out from water (P. Holt et al1999 and G.Chen, 2004). Flocs produced in electrocoagulation process are of higher size & density with less amount of bound water therefore these flocs have high sedimentation velocity and get more easily separated from treated water. In electrocoagulation process there is no need of chemical addition & it produces less amount of sludge (M.F. Ni'am, 2007). Work of numerous other researchers indicates that electrocoagulation can be efficiently used for treatment of waste from various other industries e.g. effluent from electroplating process, oil/water emulsion. Electrocoagulation has been found to be a promising technique for treatment of high strength biorecalcitrant organic collides (A. Gadd et al, 2010). Electrocoagulation technique has been also employed for treating wastewater from catering, petroleum

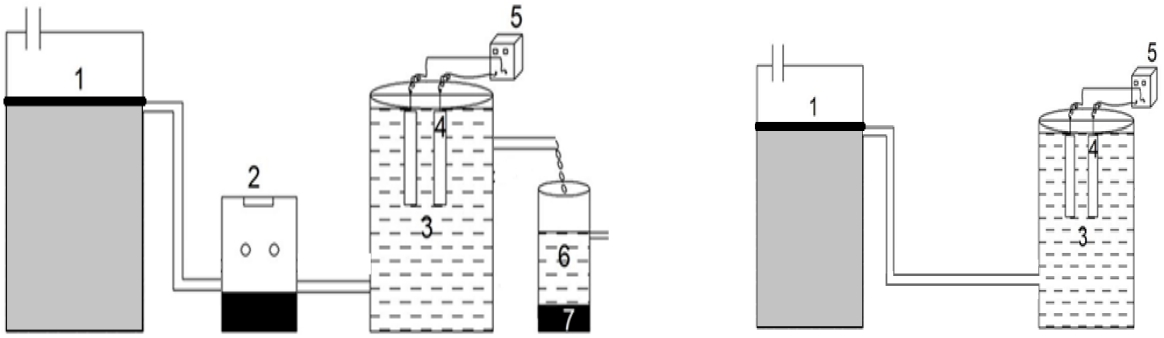
(A. Dimoglo et al 2004), tannery wastewater & leachate water (S. Kongjao et al,2008 and V. V. Goncharuk et al,2010). In removal of metals like Cu(II), Zn(II), Ni(II), Ag(I) & Cr(IV) (I. Heidmann et al,2008) and other elements like arsenic, phosphate, nitrate & fluoride(N. S. Kumar et al,2010, J. H. Choi 2010, Mohammad M. Emamjomeh et al,2009 and C.Y. Hu et al 2003) when present in aqueous solution electrocoagulation was also found effective.

This study has focused to investigate the treatment capability of electrocoagulation process using iron electrode for simulated wastewater sample in horizontal continuous reactor & horizontal batch reactor. Further effects of various operating parameters on efficiency of electrocoagulation process were explored.

2 MATERIALS AND METHODS

2.1 Reactor Design

The experimental setup used in this study to carry out treatment in horizontal continuous & horizontal batch plug flow modes has been shown in fig 1(a) and fig 1(b).



(a) **(b)**

Fig. 1: (a) Experimental setup of horizontal continuous EC cell**. (b)** Experimental setup of horizontal batch (1: wastewater tank; 2: peristaltic pump; 3: inlet of the first compartment; 4: electrodes; 5: DC power supply; 6: treated effluent outlet; 7: sludge).

Setup mainly consisted of a beaker of 1liter working volume and a pair of rectangular iron electrodes as anode & cathode connected to a DC power source (Testronix, 230 V DC regulated power supply). This power source has inbuilt ammeter & voltmeter to read current & voltage. Each electrode had an active surface area of 82cm^2 and the electrodes were arranged at a spacing of 3 cm. A peristaltic pump (Miclins, PP-20) was used to supply wastewater from reservoir tank in case of continuous plug flow mode. A closed reflux apparatus (Thermoreactor CR3000) was used to digest pollutants before measuring COD of samples. Closed reflux colorimetric method mentioned in the standard methods APHA-AWWA (1998) was practiced using a UV/VIS spectrophotometer (Schimadzu model 6800), to measure COD. A pH meter (Lutron model PH-201) was used to measure pH of samples. Conductivity of samples was measured by using a conductivity meter (Lutron model CD-4302). All set of experiments were conducted using synthetic waste samples having 0.3gm/l basic red dye 5001 BC (commercial name of direct red dye) along with NaCl salt 3gm/l, hydrolyzed starch .00556gm/l, ammonium sulfate 11.74gm/l, disodium hydrogen phosphate 11.74gm/l & 6-8 drops of liquid detergent. Samples were prepared by mixing all the chemicals in tap water & heating at 80 ^{o}C for 1.5 hr to hydrolyze the added chemicals (A. Alinsafi et al, 2004) in order to simulate the prepared sample with actual wastewater. The physiochemical properties of simulated samples are tabulated in table 1. A thermometer was used to measure temperature of samples. All set of experiments were carried out at room temperature with temperature of samples varying in a close range of 25 -27 ^{o}C.

Table 1: Physicochemical characteristics of simulated wastewater

Parameter	Wastewater (average value)
pH	9
COD (mg/l)	600-650
Temperature (^{0}C)	25-27^{o}C
Color	Dark orange
Conductivity (mS cm^{-1})	4.7

Electrodes were thoroughly cleaned to remove dirt & corrosion from surface before each experimental run. Treated water samples were collected at 10 min of interval to record COD. Experiments were continued till the pseudo steady state condition achieved, where COD of three consecutive samples were almost same. COD removal was expressed in percentage removal (Y_{COD}) instead of depicting values of COD for raw & treated samples due to a very little difference in COD values of initial samples.

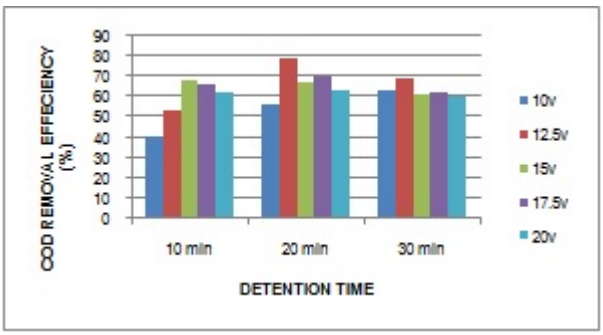
3 RESULTS

Results obtained from experiments showed that maximum COD removal was 78.91% at 12.5 V for 20 min of DT while in case of batch process it was 78.972% at 17.5 V for 20 min of DT. Results also revealed that COD removal was increased with increase in applied voltage & DT, while this increment in COD removal was not linear in case of continuous process.

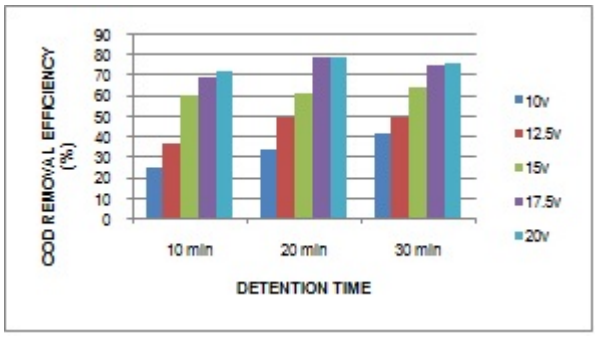
4 DISCUSSION

4.1 Effect of Detention Time

There is a significant effect of detention time on treatment efficiency in an electrochemical technique (M.F. Ni'am, 2007). In order to investigate the effect of detention time on COD removal set of experiments were conducted for three different detention time viz.10 minutes, 20 minutes, 30 minutes. In case of continuous plug flow mode, flow rate was varied to achieve designated detention time. For each detention time experiments were carried out at different voltages, 10 V, 12.5V, 15V, 17.5V & 20V to analyze COD removal. It has been observed that increase in detention time has resulted in an increase in removal efficiencies, when other affecting parameters were kept constant. In a set of experimental run having continuous plug flow mode, when detention time was increased from 10 minutes to 30 minutes for a constant applied voltage of 10V, an increase in removal efficiency from 40.41% to 63.60% was reported, while in case of batch mode this increment was from 25.90% to 42.43%. This effect can be explained by the Faraday's law, according to which an increase in detention time will lead more generation of metal ions and hence more metal hydroxides generation ultimately resulting in increased removal efficiencies (A.H. El-Shazly et al, 2011). Figure 2(a) and figure 2(b) shows the effect of detention time on removal efficiency for continuous & batch process respectively.



(a)



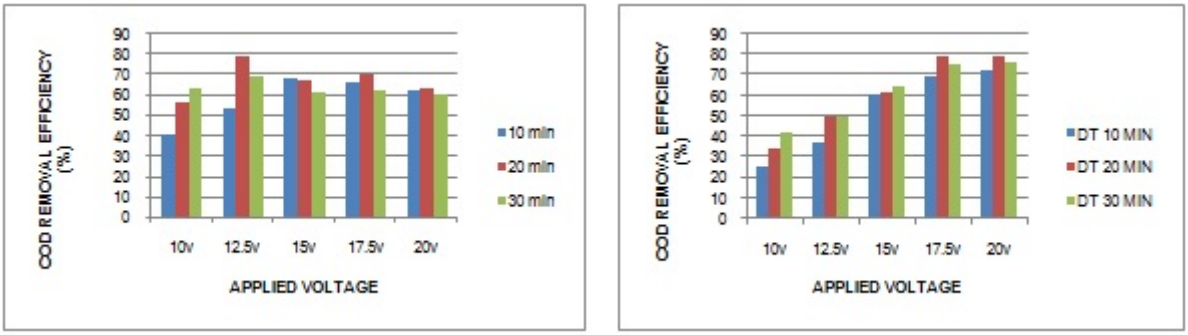
(b)

Fig. 2: (a) Effect of detention time on COD removal efficiency for horizontal continuous reactor. **(b)** Effect of detention time on COD removal efficiency for horizontal for batch reactor.

From figure 2(a) & (b) it is evident that electrocoagulation process in continuous mode provides Y_{COD} greater than 50% in all cases except for 10 minute of detention time at 10 V of applied voltage, while in case of batch Y_{COD} greater than 50% was achieved for all detention time only with 15V, 17.5V & 20V of applied voltages. Maximum Y_{COD} of 78.91% in case of continuous mode was achieved at 12.5 volt for 20 minutes of detention time and in batch mode maximum Y_{COD} 78.972% was reported for 17.5 V at 20 minutes of detention time.

4.2 Effect of Applied Voltage

Voltage affects electrocoagulation process by playing role in flocs formation. Keeping other affecting parameters constant, an increment in voltage results in release of more metal ions & hence more flocs formation takes place (M. Malakootian et al, 2011 and K. Charoenlarp et al, 2009). Similar effect of voltage on flocs formation also has been reported by Kopral et al, 2002 in case of nitrate removal by electrocoagulation. To explore the effect of applied voltage set of experiments were carried out for three different detention time of 10 minutes, 20 minutes & 30 minutes. Figure 3(a) & (b) shows the effect of voltage on COD removal efficiencies for continuous & batch mode of treatment process.



(a) **(b)**

Fig. 3: (a) Effect of voltage on COD removal efficiency for horizontal continuous reactor**. (b**) Effect of voltage on COD removal efficiency for horizontal for batch reactor.

From figure 3 (a) it is evident that in continuous mode of treatment process, for a constant detention time, when the voltage was increased initially an increment in COD removal efficiency was observed. After reaching a maximum it started decreasing for higher voltages. It was observed that more sludge formation was taking place at higher voltage which probably hindered the settling of flocs, consequently leading in reduced COD removal efficiency. Maximum Y_{COD} was obtained at 12.5 V for 20 minutes of detention time. Variation in Y_{COD} was less for higher applied voltages as in case of 20 V Y_{COD} for 10 minutes, 20 minutes & 30 minutes were almost same. The reason may be that with increase in applied voltage rate of metal ion generation increases and hence time required to achieve pseudo steady state decreases. Such result was also reported by (Kopral et al, 2002) in case of nitrate removal by electrocoagulation. In case of batch process from figure 3 (b) it is observed that increase in applied voltage has resulted in an increase in COD removal efficiency. Maximum Y_{COD} was obtained at 17.5 V for 20 minutes of detention time.

4.3 Energy Requirement

On analyzing effect of voltage & detention time it was found that COD removal at higher values of detention time and applied voltage were lesser than that of maximum removal efficiencies. Such result could be because of wastage of extra energy imparted to treatment system. In order to find out optimum energy requirement to achieve maximum removal efficiency set of experiments were conducted and energy supplied to the system was calculated as electric work, which may be calculated as

$$E = V*I*DT \quad (4)$$

Where;

E = Electric work for unit COD removal (Joule).

V = Applied voltage (Volt).

I = Current supplied (Ampere).

DT = Detention Time (minute).

Electric work for both continuous & batch processes were calculated and drawn against total COD removed for each experimental run as shown in figure 4 (a) & (b). In case of continuous treatment process electric work to achieve maximum removal at detention time of 10 minutes, 20 minutes & 30 minutes were 444 J, 552 J & 306 J respectively. Curve of 10 minutes detention time in figure 4 (a) shows that COD removal increases with electric work, while curve of 20 minutes detention time COD removal increases with electric work till the maximum removal, then after it shows decrement with increase in electric work. The pattern of 20 minutes detention time curve indicates that extra energy imparted after maximum removal point was not utilized in removal & was wasted in heating up the system.

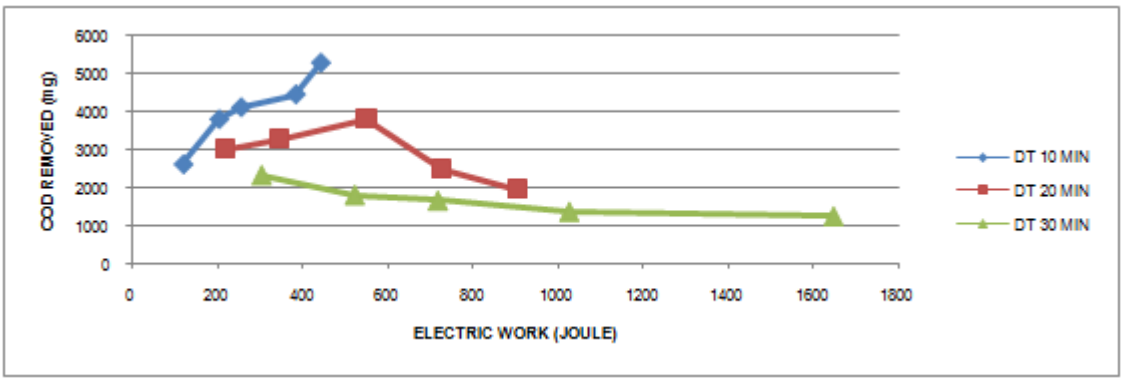


Fig. 4 (a): Electric work done for COD removal in horizontal continuous reactor.

The curve of detention time 30 minutes shows COD removal decreases with increase in electric work & become nearly stable after 15 V. From figure 4 (b) it is evident that in case of detention time 10 minutes, a continuous increase in COD removal was obtained with increase in electric work. Curve of detention time 20 minutes shows increment in COD removal up to 15 V and then decrement. COD removal again increases between 17.5 V to 20 V, achieving maximum removal at 20 minutes. Curve of detention time 30 minutes shows a non linear increase in COD removal with electric work.

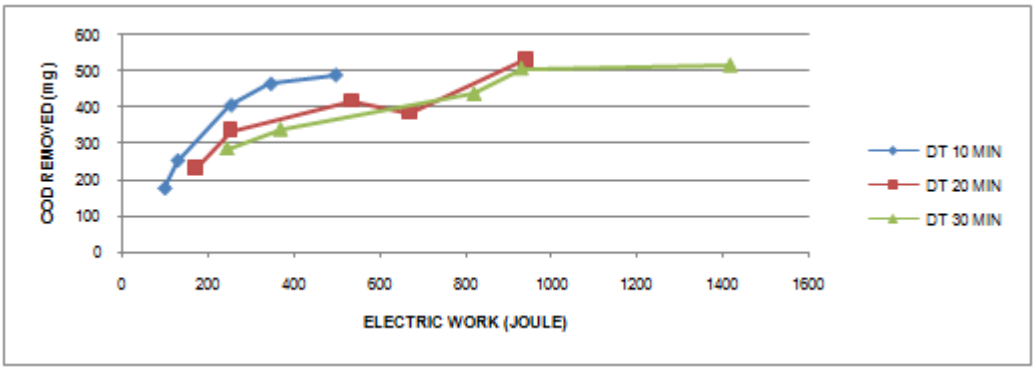
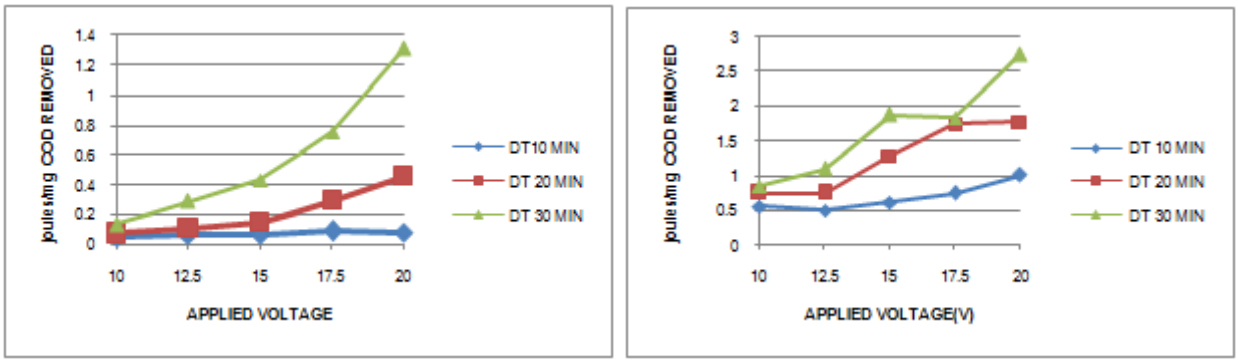


Fig. 4 (b): Electric work done for COD removal in horizontal batch reactor.

Work of researchers has shown that optimized combination of applied voltage, time and current assure high treatment efficiency. According to work of G. Chen, 2004, applied current directly affects metal ion generation, consequently treatment but if too high current is supplied it will be wasted in heating up of system i.e. efficiency of system will decrease. N. S. Kumar et al, 2010 also reported the same result in relation to denitrification and arsenic removal by electrocoagulation technique. The results obtained by analyzing unit COD removal against electric work also suggest that maximum removal could be achieved between 300J to 550J of electric work for continuous treatment process, while in case of batch treatment optimal treatment could be achieved between 500J to 950J. Therefore it may be concluded that energy requirement in batch process is higher than that of continuous process.

When specific energy required for unit removal of COD was analyzed, result showed that initially for horizontal continuous reactor specific energy requirement increases slowly with applied voltage from 10 V to 15 V & then after it increases sharply except for the treatment at detention time of 10 minutes. Results obtained have been shown in following figure 5 (a) & (b).



(a) **(b)**

Fig. 5: (a) Energy requirement for unit COD removal in horizontal continuous reactor**. (b)** Energy requirement for unit COD removal in horizontal batch reactor.

From above figure 5 (a) it may be concluded that for each detention time specific energy requirement for unit COD removal increases sharply beyond the point of maximum removal, as the curve of 20 minutes detention time showed an increase in specific energy requirement from 0.105 to 0.45J beyond the point of maximum removal at 15 V and 0.105 J of specific energy requirement.

In case of batch reactor results from figure 5 (b) have indicated that specific energy requirement increases non linearly with voltage for all detention time studied. It was found that specific energy requirement in batch reactor was much higher than that of continuous reactor for a given set of parameters. For example energy requirement in batch reactor at 20 V & 20 minutes of detention time was 1.7718J while it was just 0.45J for continuous reactor.

5 CONCLUSION

Set of experiments were conducted in batch and continuous plug flow mode in order to investigate the efficiency of electrocoagulation technique using iron as sacrificial anode. From the results it may be concluded that maximum COD removal efficiency of 78.91% was achieved at 12.5 V for 20 minutes of detention time in case of continuous process while in case of batch process maximum removal achieved was 78.972% at 17.5 V for 20 minutes of detention time i.e. batch process takes more energy to produce same amount of treatment. When detention time was increased voltage required to produce maximum removal decreased. For horizontal batch reactor COD reduction increase linearly with applied voltage, while for continuous reactor COD reduction does not depend linearly on detention time and applied voltage. Total electric work and COD removal were also found to increase with detention time & applied voltage in batch process while it was not a linear relationship in case of continuous process. Average

electric work required for sizable COD removal rate in continuous treatment process was found to be 300J to 550J while it was 500J to 950J for batch reactor. Continuous reactor was found to have more COD removal efficiency and more economic treatment than batch reactors.

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