Energy consumption, operating cost and treatment of tea effluent using electrocoagulation

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Abstract

The effluents from tea processing plants are characterized by a strong colour and high turbidity due to the presence of large amounts of suspended solids, dissolved organic matter and inorganic wastes which include detergents, grease/waste oil from machine parts. These altogether poses an environmental and legal challenge calling for appropriate means of treatment. In this regard the study was designed to evaluate energy consumption, operating cost in treatment of tea effluent using electrocoagulation method at optimum conditions of electrode distance 6 mm, electrolysis time 18 min, Current intensity 250 mA The study adopted an experimental research design. From the study findings Energy consumption was found to be 0.0018Kwh/m^3 at an operating cost of $US\$ \, 0.004179032 \, /m^3$at laboratory scale. The findings further showed that at industrial scale design parameters such as Diameter, height, electrode spacing, retention time, current intensity and reactor volume were 100 cm, 150 cm, 60 mm, 59.94 minutes, 25 Amps and 1.2 m^3 respectively which equally reduces COD and Colour removal at 99.43 % and 98.62 with energy consumption of 4.8Kwh/m^3 at an operating cost $US\$ \, 0.744$. In conclusion EC provides the most feasible alternative for treatment of tea effluent with a view of COD reduction and colour removal.

Key words: Energy Consumption, Electrocoagulation And Operating Cost

1.Background of the study

Globally the removal of pollutants from industrial waste remains the most essential in terms of protection of health as well as the environment. Some of the pollutants have heavy metals which pose serious health hazard, and are environmentally-unfriendly because they are not biodegradable and tend to accumulate in living organisms (Saha & Sanyal, 2010). Wastewater regulations were established to minimize human and environmental expo- sure to hazardous chemicals which limits on the types and concentration of heavy metals and organic wastes that may be present in the discharged wastewater (Barakat, 2011).This altogether calls for knowledge on the cost effective and environmental friendly techniques of treating waste water.

Like other biomass residues, tea waste is an unused resource and poses increasing disposal problems (Arvanitoyannis & Varzakas, 2008). According to Maghanga, Segor, Etiégni and Lusweti, (2009) during the cleaning operations, flushing steps in operations and production processes, 18-20 m^3 of water is used per cleaning operation releasing large amounts of tea factory effluents. These effluents are characterized by a strong colour and high turbidity due to

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the presence of large amounts of suspended solids, dissolved organic matter and inorganic wastes which include detergents, grease/waste oil from machine parts (Ochari, 2010).
Recently, numerous approaches have been studied for the development of cheaper and more effective technologies, both to decrease the amount of wastewater produced and to improve the quality of the treated effluent (Barakat, 2011). It is therefore important to note that the overall treatment cost of industrial waste water varies, depending on the process employed and the local conditions. In general, the technical applicability, simplicity and cost-effectiveness are the key factors in selecting the most suitable treatment of industrial waste water (Kurniawan, 2006) . Socio-cultural and environmental objectives that are recognized to be of the same importance as the economic objective in selecting the optimal wastewater treatment alternative (Ellis and Tang, 1991 and 1994) cited in (Karimi, Mehrdadi, Hashman, Nabi, & Tavakoli, 2011). Physical methods such as ion exchange, reverse osmosis and electro dialysis have proved to be either too expensive or inefficient to remove cadmium from water (Vasudevan & Lakshmi, 2011).

Literature surveys indicates that electrocoagulation is an efficient process for different types of waste, e.g. soluble oils, liquids from food, textile industries and effluents from the paper industry (Calvo, *et al*., 2003; Carmona, *et al*., 2006). During the past few years, EC has been proposed as an effective method for treating many types of effluents such as wastewater charged with heavy metals (Kumar et al., 2004), natural water charged with Fluor (Emamjomeh & Sivakumar, 2006), surface water (Lai & Lin, 2006.), suspended solids, oil and fat in restaurant wastewater, black liquor from paper industry, and cigarette factory wastewater. All these investigations demonstrated that EC could achieve a significant reduction of major pollutants and has become of growing interest for the industrial scale (Zaieda & Bellakhala, 2009). The operating cost includes material (mainly electrodes) cost, electrical energy, cost of labour, maintenance and other cost. The later cost items are largely independent of the electrode material (Kobya *et al*., 2006). Besides EC as waste water treatment technique is an empirically optimized process that requires more fundamental knowledge on operating cost and energy consumption to realize its full potential. This without prejudice have motivated the current study to evaluate energy consumption, operating cost and treatment of tea effluent using electrocoagulation at Emrok tea factory.

1.1 Objectives

i. To evaluate the energy consumption at the optimal electrocoagulation operating conditions in the treatment of tea effluent at Emrok tea factory.
ii. To analyse the operating cost at the optimal electrocoagulation operating conditions in the treatment of tea effluent at Emrok tea factory.

2. Methodology

2.1 Research Design

A research design includes the structure of a study and the strategies for conducting that study (Leedy & Jeanne, 2013). This study adopted an experimental research design which is a systematic and scientific approach to research in which the researcher manipulates one or more variables, controls and measures any change in other variables (Oskar, 2018). Experimental designs offer the best method available to researchers to be able to investigate causality due to the high degree of control (Robin, 2009). In experimental research designs subjects are always both randomly allocated into the different groups and randomly sampled. Statistical techniques are used in the development of an adequate functional relationship between variables of interest. In experimental research designs regression considers the effect upon one variable when another is held fixed at each of several levels (Cook & Campbell, 1979).

2.2 Energy consumption

The energy consumption during the EC process was determined as follows:

$$Energy\ consumption = \frac{V \times I \times T}{60V} \qquad (2.11.1)$$

Where Energy Consumption V, I, t and V are energy consumptions (kWh/m^3) ,V is the voltage (Volt), I is the current (Ampere), t is EC time (s) and V is volume of treated water in m^3

$$Electrode\ Consumption(wear) = \frac{I \times t \times M_w}{z \times F} \qquad (2.11.2)$$

Where F is faradays constant (96,485C/mol), Mw is molar mass of the iron (55.845g/mol) and z is the number of electron transfer (Z_{Fe}: 2) (Ozyonar & Karagozoglu, 2011).

2.3 Calculation of operating cost.

EC operational cost was determined according (Geraldino, et al., 2015).

$$Operating\ cost\ (oc) = a.c_{en} + b.c_{el} \qquad (2.12.1)$$

a = energy cost

c_{en} = energy consumption

b= cost of the plate

C_{el} = electrode consumption

Where, Energy consumption and Electrode consumption are consumption quantities per M^3 of treated wastewater (Kobya et al., 2006).

2.4 Industrial scale design parameters

The industrial scale parameters were adopted from (Sawhney, 2008). The effluent flow rate will be determined by

$$Q_h = \frac{Q_P}{24}\ m^3/hr \qquad (2.13.1)$$

Q_h : Hourly Flow rate

Q_P : Daily Flow rate of effluent

To determine industrial velocity the continuity equation of fluid flow was adopted

$$Q_p = A_p V_P \qquad (2.13.2)$$

$$V_P = \frac{Q_P}{A_p} \qquad (2.13.3)$$

Where

Q_p: rate of effluent flow

A_p : Cross sectional area of fluid flow

V_P: Velocity of fluid flow

Geometric Similarity was used to determine the prototype height and diameter. Geometric Similarity: implies similarity of shape between the model and prototype .the model is an exact replica of the prototype having identical shape but smaller in size .The model and prototype have same ratio for all corresponding linear dimensions.

$$\frac{h_p}{h_m} = \frac{w_p}{w_m} = \frac{L_p}{L_m} = \frac{D_p}{D_m} = L_r \qquad (2.13.4)$$

Where

h_p: Height of prototype
h_m: Height of the model
W_p: Width of the prototype
W_m: Width of the model
L_p: Length of the prototype
D_p: Diameter of the prototype
D_m: Diameter of the model
L_r: Length scale ratio

Batch (industrial scale) Retention Time T_r (Froude's Model Law)

$$T_r = \sqrt{L_r} = \frac{T_p}{T_m} \qquad (2.13.5)$$

$$T_r = \frac{T_p}{T_m} \qquad (3.13.6)$$

T_r : Time scale ratio
T_P : Retention time of the prototype
T_m : Retention time of the model
Industrial Scale (prototype) Voltage
the voltage of model (lab scale) is P_m and prototype P_p

$$L_r = \frac{P_p}{P_m} \qquad (2.13.7)$$

$$P_P = L_r \times P_m \qquad (2.13.8)$$

3. FINDINGS

3.1 Evaluation of energy consumption and operating cost at the optimal electrocoagulation operating conditions.

3.1.1 Energy consumption

The energy consumption during the EC process was determined as follows: in this study at optimum conditions of electrode distance 6 mm, electrolysis time 18 min, Current intensity 250 mA the energy consumption was found to be 0.0018 kwh/m^3 with a removal efficiency 98.62 % COD and 99.43 % Colour. This denotes low energy consumption with higher removal efficiency using iron electrodes in tea effluents as compared to the findings of Zaroual *et al* (2009) who found out that a treatment efficiency of 91% could be completed with an energy consumption of 3.536 kWh/m^3.

Energy consumption was determined According to equation 3.11.1 below during the EC process.

$$Energy\ consumption = \frac{V \times I \times T}{60V}$$

The energy consumption at optimum electrode distance 6 mm, electrolysis time 18 min, and Current intensity 250 mA (laboratory scale) was therefore

$$= \frac{24 \times 0.25 \times 18}{60 \times 1000}$$

$$= 0.0018\ kwh/m^3$$

3.1.2 Electrode consumption (wear)

To calculate the maximum amount of electrode material that was consumed during the EC process, in which the molar mass of iron is 55.845 g mol^{-1}, faradays constant 96,485C/mol, electrolysis time 18 min, and the oxidation number of the element is 2. From equation 3.11.3

$$Electrode\ Consumption = \frac{I \times t \times M_w}{z \times F}$$

$$= \frac{18 \times 60 \times 0.25 \times 55.845}{2 \times 96485}$$

$$= 7.8 \times 10^{-2} g\ Fe$$

3.1.3 Operating cost at laboratory scale

In this study the operating cost using iron electrodes at optimum electrode distance 6 mm, electrolysis time 18 min, and Current intensity 250 mA the cost was $US\$\ 0.004179032\ /\ m^3$ which removed (98.62) % COD and (99.43) % Colour. This compares fairly with the findings of Drogui *et al* (2009) who found that using the optimum conditions to remove color (97%) and COD (77%) it would cost \$0.29 USD/m^3 of wastewater. This result showed that the EC process for the treatment of tea effluent under optimum conditions is quite economical. This result is in agreement with (Ozyonor & Karagozoglu, 2011).

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OC of the batch reactor in the EC system was calculated using eqn.3.12.1 a formular adopted from (Geraldino, et al., 2015). The cost of a kg of iron plate is US\$ 0.25, but the mass estimated cost of a plate (200 g) is US\$ 0.05. Therefore,

$$OC\ = a.c_{en}\ +\ b.c_{el}$$

Where

a = energy cost is US\$ 0.1550178
c_{en} = energy consumption is 0.0018 kwh
b= cost of the plate (200 g) US\$ 0.05
C_{el} = electrode consumption is 0.78 g Fe

$$\left(0.0018\frac{kwh}{m^3 x 0.1550178}\right) + \ (7.8 \times 10^{-2} x\ 0.05) = US\$\ 0.004179032\ /m^3$$

3.1.4 Industrial scale design parameters

The industrial scale parameters were adopted from (Sawhney, 2008)

Daily Flow rate of Emrok effluent $Q_P = 20\ m^3$
Hourly Flow rate of Emrok effluent Q_h

$$Q_h = \frac{Q_P}{24}\ m^3/hr$$

$$Q_h = \frac{20M^3}{24}$$

$$= 0.83m^3/hr$$

Cross sectional area of the industrial scale pipe

$$Area = \frac{\pi D^2}{4} = \frac{\pi \times O.1016^2}{4}$$

$$A = 0.008107M^2$$

From continuity equation:

$$Q_p = A_p V_P$$

$$V_P = \frac{Q_P}{A_P}$$

$$= \frac{0.83M^3/hr}{0.008107m^2} = 102.79\ m/hr$$

Or

$$= 0.0286m/s$$

$$v_p = 0.0286m/s$$

From Geometric Similarity:

$$\frac{h_p}{h_m} = \frac{w_p}{w_m} = \frac{L_p}{L_m} = \frac{D_p}{D_m} = L_r \qquad (4.9.4)$$

$$L_r = \frac{100}{10} = 10$$

From Froude's Model Law

$$F_{Prototype} = F_{model}$$

$$V_{r = \sqrt{L_r}}$$

$$v_r = \sqrt{10} = 3.337$$

From Velocity scale ratio:

$$v_r = \frac{v_p}{v_m}$$

$$v_m = \frac{v_p}{v_r}$$

$$v_p = 0.0286m/s$$

$$v_r = 3.337$$

$$v_m = \frac{0.0286}{3.333}$$

$$velocity\ of\ the\ model(v_m) = 0.0086m/s$$

Also using geometric similarities to establish the height of prototype

$$L_r = \frac{h_p}{h_m}$$

$$10 = \frac{hp}{15}$$

$$h_p = (10 \times 15)cm = 150cm$$

$$h_p = 150cm = 1.5m$$

$$Reactor\ volume\ \ (R_v)\ = \frac{\pi D^2}{4} \times h_p$$

$$\frac{3.142\ \times 10^2}{4} \times 1.5 = 1.17\ \approx 1.2\ m^3$$

Batch (industrial scale) Retention Time T_r (Froude's Model Law)

$$T_{m\,=}\ 18\ min$$

$$L_r = 3.337$$

$$T_r = \ \sqrt{L_r}\ = \frac{T_P}{T_m}$$

$$T_r = \frac{T_P}{T_m}$$

$$T_P = 18 \times 3.33 = 59.94\ min$$

Time To process prototype (industrial scale) effluent at Q = Q_P = 20 m^3

$$1.2\ m^3\ \ \rightarrow 60\ min$$

$$20m^3\ \rightarrow ?$$

$$\frac{20\ \times 60}{1.2\ \times 60} = 16\ hr$$

Computation of prototype (industrial scale) current intensity

Prototype: model (Ratio 10:1)

$$if(model)\ :\ (20 \times 4.6)cm \times 2 \qquad \rightarrow \qquad 250mA$$

Industrial scale (Prototype): $(200 \times 46)cm \times 2\ \ \rightarrow\ ?$

$$\frac{200 \times 46 \times 250 \times 2}{20 \times 4.6 \times 2} = 25000mA/cm^2$$

$$= 25\ A$$

Distance between the electrodes (industrial scale): Where L is distance between electrodes

$$L_r = \frac{L_p}{Lm}$$

But for a model (laboratory scale), to get optimal efficiency, $L =\ 6mm$

$$L_P\ \ = \ L_r\ \times\ L_m$$

$$= 6\ x\ 10$$

$$=\ 60\ mm$$

Industrial Scale (prototype) Voltage

Let the voltage of model (lab scale) be P_m and prototype P_p but $P_m = 24\ v$

$$L_r = \frac{P_p}{P_m}$$

$$P_P = L_r\ \times\ p_m$$

Industrial Scale (prototype) $P_P = 10 \times\ 24$

$$=\ 240\ V$$

3.1.5 Industrial scale Energy Consumption:

It therefore implies that if Emrok tea factory adopts EC process at an industrial scale the energy consumption shall be:

The energy consumption at its current flow rate (Q) of 20 m^3 shall be

$$\frac{240 \times 25 \times 16}{20000} = 4.8\ kwh/m^3$$

Electrode consumption

$$\frac{1 \times 25\ \times\ 55.845}{2 \times 96485} = 7.2 \times 10^{-3} g\ Fe$$

3.1.6 Industrial operating cost

$$(4.8\ \times 0.1550178)\ +\ (7.2 \times 10^{-3} \times\ 0.05)\ = US\$\ 0.744$$

This implies that if Emrok adopts an EC system at flow rate of 20m^3 daily, the operating cost of the batch reactor in would translate to US$ 0.744 monthly the company would spend $US\$22.32$ Monthly expenditure on energy

$$0.744\ USD \times 30 =\ US\$22.32$$

Yearly expenditure on energy

$$US\$22.32 \times\ 12 = US\$267.84$$

4.0 Conclusion

The energy consumption was found to be 0.0018Kwh/m^3 at an operating cost of $US\$\ 0.004179032\ /m^3$ at laboratory scale with a removal efficiency 98.62 % COD and 99.43 % Colour. This would translate to energy consumption at 4.8 Kwh/m^3 and operating cost of $US\$\ 0.744$ at a flow rate of 20m^3 industrial scale at the sampled factory, Emrok. Using optimized EC with a view of balancing energy consumption and operational cost was found to be feasible for tea effluent treatment. This argument is further supported by the comparative analysis between EC and the method of waste treatment used by Emrok would translate to an increase of profit margin to 4.56%. This added to the un quantified benefits in terms of environmental and social gains of EC justifies its adoption in an industrial scale.

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