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Pollutants removal using electro coagulation in meat and poultry processing wastewater

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Abstract:* *This is a combination of a review paper on the pollutants removal using electrocoagulation (EC) in meat and poultry processing wastewater. Experiments are conducted on the removal of pollutants from Chicken processing plant (CPP) wastewater using EC. EC is very efficient for wastewater treatment as the pollutants are easily taken in or exchanged with the anions in the interlayer. Chicken processing plant (CPP) produces large amount of wastewater containing variety of readily biodegradable organic compounds, carbohydrates, proteins, and fats. The possible re-use of properly treated CPP wastewater would be economic and environment friendly. In this study, we present our work on treatment of CPP wastewater using EC. Analysis of the EC-treated water for reuse in the same plant is discussed considering the U.S.EPA regulations. Two types of EC-reactors were used for this purpose. To better understand the treatment mechanism, EC-floc was also characterized using XRD, SEM-EDS, and FTIR.

***Index Terms*— Coliform, Electrocoagulation, Pollutants, and Wastewater.**

I. INTRODUCTION

Wastewater generated during meat and poultry processing is composed of a number of pollutants. These wastewaters constitute a variety of readily biodegradable organics. The biodegradable organics are composed of proteins, carbohydrates, and fats. Biodegradable are measured in terms of BOD (Biological Oxygen Demand) and COD (Chemical Oxygen Demand) [7]. There are a number of conventional parameters that characterize the pollutants in the wastewaters. The US's Clean Water Act (CWA) Section 304(a) (4) defines conventional pollutant parameters to include biochemical oxygen demand (BOD), total suspended solids (TSS), oil and grease, pH, and fecal coliform bacteria. These pollutants are regulated by U.S Environmental Protection Agency [4].

The wastewater has to be treated before it is discharged into the drainage system. EPA, 2009 [1] gives Maximum daily effluent limitations for the following regulated parameters in poultry first processing: Ammonia (as N), 8.0mg/L; BOD_5, 26mg/L; Fecal Coliform, Maximum of 400MPN; O&G, 14mg/L and TSS, 30mg/L. Effluent limitations for meat and poultry processors are BOD_5, 2.0g/kg; Fecal Coliform, No limitation; O&G, 1.0g/kg and TSS, 2.4g/kg.

Biodegradable organics are removed by aerobic, anaerobic, lagoon, physical-chemical systems, and chemical oxidation, advanced oxidation and membrane filtration processes [7]. Aerobic or Anaerobic methods are biological processes. Physico-chemical processes include dissolved air flotation (DAF) and coagulation-flocculation (CF) units. Coagulation (using metal salts addition: $FeCl_3$, $Fe(SO_4)_3$, $Al_2(S_4O)_3$ or $Ca(OH)_2$) is a process of aggregating suspended particles to form settling flocs, whereas flocculation (using cationic, non-ionic or ionic organic polymers) is a process of agglomerating coagulated-particles into large flocs [2]. These methods have limitations in their operations. Anaerobic treatment processes require high energy consumption for aeration and high sludge. Anaerobic method of poultry slaughterhouse wastewater is often slowed or impaired due to the accumulation of suspended solids and floating fats in the reactor, which lead to a reduction in the methanogenic activity and biomass wash-out. Both biological processes require long hydraulic retention time and large reactor volumes, high biomass concentration and controlling of sludge loss, to avoid the wash-out of the sludge [3].

Even though Biological processes are effective and economical, long hydraulic retention time and large area requirements make sometimes these processes less attractive than physico-chemical treatments, which require shorter retention time. Physico-chemical treatments produce large volumes of putrefactive and bulky sludge that requires special handling and further treatment [2].

Electro-chemical techniques such as, electro flotation (EF), electrode-cantation, electro coagulation (EC), electro kinetic remediation (for contaminated soil) offer the possibility to be easily distributed, require minimum amount and number of chemicals [6]. Electrochemical processes have lower operating costs compared to the conventional process, due to the low electric current required [11]. Electrocoagulation (EC) is a promising technique for treatment of meat and poultry wastewater. The EC process has attracted a great deal of attention in treating industrial wastewaters because of its versatility and environmental compatibility. This method is characterized by simple equipment, easy operation, a shortened reactive retention period, a reduction or absence of equipment for adding chemicals, and decreased amount of precipitate or sludge which sediments rapidly. The process has been shown to be an effective and reliable technology that provides an environmentally compatible method for reducing a large variety of pollutants [3].

The purpose of this review is to understand the effects of process parameters in the treatment mechanism of Electro coagulation.

II. MEAT AND POULTRY WASTEWATER CHARACTERISTICS

A. Volume of wastewater generated

Slaughterhouses generate large wastewater volumes [8]. The source of wastewater in meat processing is from carcass washing after hide removal from cattle, calves, and sheep or hair removal from hogs and again after evisceration, for cleaning, and sanitizing of equipment and facilities, and for cooling of mechanical equipment such as compressors and pumps [4]. The mean wastewater flow for the operations of producing fresh meat is 639 gallons per 1,000 lb LWK [4]. Poultry processing plants use relatively high amount of water with an average consumption of 26.5 L/bird during primary and secondary processing of live birds to meat. Most poultry processors use an average of 26.5 L of water/2.3 kg bird and this quantity ranges from 18.9 to 37.8 L/bird based on the plant facilities [5]. The typical minimum water usage figures worldwide appear to be 1.3-2.5 m^3/beast for beef slaughtering plants, assuming an average live weight 0.5 tonne/beast in the US and Germany [8].

B. Wastewater Constituents and Concentrations

The principal sources of wastes in meat processing are from live animal holding, killing, hide or hair removal, eviscerating, carcass washing, trimming, and cleanup operations [3]. Meat processing wastes include blood not collected, viscera, soft tissue removed during trimming and cutting, bone, urine and feces, soil from hides and hooves, and various cleaning and sanitizing compounds. The principal constituents of meat processing wastewaters are a variety of readily biodegradable organic compounds, primarily fats and proteins, present in both particulate and dissolved forms. Proteins and fats which come from carcass debris and the blood are the major pollutants in the wastewater [5]. The pollutants of concern in meat and poultry processing wastewaters are biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), nitrogen, and phosphorus. Meat processing wastewaters remain high strength wastes, even after screening, in comparison to domestic wastewaters. Blood not collected, solubilized fat, urine, and feces are the primary sources of BOD in meat processing wastewaters. Beef cattle blood has a reported BOD of 156,500 mg/L with an average of 32.5 pounds of blood produced per 1,000 pounds LWK [4].

The raw Poultry Slaughter Wastewater mainly consists of several organic compounds including carbohydrates, starches, proteins, suspended particles, and other ingredients. Characteristics of the Poultry Slaughter Wastewater are as follows: chemical oxygen demand (COD) 29,000–26,000 mg/L, biochemical oxygen demand (BOD) 12,000–10,000 mg/L, turbidity 600–550 NTU, oil–grease 1800–1500 mg/L, total suspended solids (TSS) 1200–840, and initial pH 6.7, conductivity 1.99 mS [3].

1) Biochemical Oxygen Demand

BOD is an estimate of the oxygen-consuming requirements of organic matter decomposition under aerobic conditions. When meat and poultry processing wastewaters are discharged to surface waters, the microorganisms present in the naturally occurring microbial ecosystem decompose the organic matter contained in the wastewaters. The decomposition process consumes oxygen and reduces the amount available for aquatic animals. Severe reductions in dissolved oxygen concentrations can lead to fish kills [4].

2) Chemical Oxygen Demand

COD is an estimator of the total organic matter content of both wastewaters and natural waters. It is the measure, using a strong oxidizing agent in an acidic medium, of the oxygen equivalent of the oxidizable organic matter present. COD is usually higher than BOD because COD includes slowly biodegradable and recalcitrant organic compounds not degraded microbially during the duration of the BOD test. COD is most useful; however as a control parameter for wastewater treatment plant operation because it can be determined in 3 hours as opposed to the 5 days or more required by BOD (4).

3) Chloride

Chloride (Cl-) is a common anion in wastewaters and natural waters. However, excessively high chloride concentrations in wastewater discharges can be harmful to animals and plants in non-marine surface waters and can disrupt ecosystem structure. It can also adversely affect biological wastewater treatment processes. Furthermore, excessively high chloride concentrations in surface waters can impair their use as source waters for potable water supplies. If sodium is the predominant cation present the water will have an unpleasant taste due to the corrosive action of chloride ions [4].Sodium concentrations of greater than 1500mg/L in the influent caused poorly settling sludge and poor effluent quality lab-scale studies, however, found that sludge could acclimatize to sodium levels as high as 7000mg/L without deleterious effects [8].

4) Oil and Grease

In meat and poultry processing wastewaters, oil and grease is primarily an estimate of the concentration of animal fats and oils lost during processing activities, but it may also include lubricating oils and greases [4].

Oil and grease in discharges of meat and poultry processing wastewaters is of concern for several reasons. One is the high BOD of animal fats and oils, which are readily biodegradable, and the impact on the dissolved oxygen status of receiving waters and related impacts on aquatic biota. In addition, a film of oil and grease on the surface of receiving waters can be unsightly and reduce natural re-aeration processes. Soluble and emulsified oil and grease can also inhibit the transport of oxygen and other gases necessary for plant and animal survival, also causing in aquatic ecosystem disruption.

5) *Indicator Organisms*

The total coliform, fecal coliform, and fecal streptococcus groups of bacteria share the common characteristic of containing species that normally are present in the enteric tract of all warm-blooded animals, including humans. Thus, these groups of bacteria are commonly used as indicators of fecal contamination of natural waters and the possible presence of enteric pathogenic bacteria, viruses, and parasites of enteric origin. They are used as indicators of the possible presence of enteric pathogens because of their normal presence in generally high densities in comparison to enteric pathogens, such as *Salmonella* and *Shigella*, and their relative ease of enumeration [4].

6) *Nitrogen*

The discharge of high loads of nitrogen and phosphorus in slaughterhouse wastewater into sensitive water-bodies or onto permeable soills has emerged as a major problem for the industry worldwide [8]. Several forms of nitrogen are pollutants of concern in meat and poultry processing wastewaters. Included are total Kjeldahl nitrogen (TKN), ammonia nitrogen (NH4-N), and nitrite plus nitrate nitrogen (NO2 + NO3-N) [4]. Both ammonia nitrogen and ammonium nitrogen can be directly toxic to fish and other aquatic organisms; ammonia (as nitrogen) is the more toxic. In addition, discharges of ammonia nitrogen can reduce ambient dissolved oxygen concentrations in receiving surface waters because of the microbially mediated oxidation of ammonia nitrogen to nitrite plus nitrate nitrogen. This demand is known as nitrogenous oxygen demand (NOD). With the depression of ambient dissolved oxygen concentrations, populations of fish and other aquatic organisms are adversely affected, possibly causing a change in ecosystem composition and a loss of biodiversity. Ammonia nitrogen in wastewater discharges can also be responsible for the development of eutrophic conditions and the associated adverse impacts on ambient dissolved oxygen concentrations if nitrogen is the nutrient limiting primary productivity. As nitrate, nitrogen is readily mobile in soils and may therefore leach.

7) *Solids*

Meat and poultry processing wastewaters before and after treatment contain both suspended and dissolved solids, which are also known as nonfilterable and filterable residue. Thus, suspended solids have both organic (volatile) and inorganic fractions. Dissolved solids consist primarily of dissolved inorganic compounds (mainly calcium, magnesium, iron, manganese, and sulfur compounds), but they can also contain colloidal organic material. The principal sources of dissolved solids in meat and poultry processing wastewaters are potable water supplies used for processing; salts used in processing, such as sodium chloride; and cleaning and sanitizing agents. Usually, the organic, and therefore potentially biodegradable, fraction of suspended solids is substantially higher than the inorganic fraction; the reverse is typically characteristic of dissolved solids. Total solids are the sum of suspended and dissolved solids with total volatile solids, or total volatile residue representing an estimate of the organic fraction of total solids. Suspended solids that settle to form bottom deposits can create anaerobic conditions because of the oxygen demand exerted by microbial decomposition. They can alter habitat for fish, shellfish, and benthic organisms. Suspended solids also provide a medium for the transport of other sorbed pollutants, including nutrients, pathogens, metals, and toxic organic compounds such as pesticides, which accumulates and are stored in settled deposits.

III. PARAMETERS AFFECTING POLLUTANTS' REMOVAL EFFICIENCIES

A. *Effect of current density*

The commonly used electrodes are Aluminum and Iron. COD removal efficiency is higher for aluminum than for Iron electrodes. Above current density of 150Am^{-2}, COD removal efficiency reaches a limit value of 92% for aluminum, and 85% for Iron [3]. Use of Iron electrodes has higher efficiency for removing oil grease compared to Aluminum electrodes. Higher efficiencies are obtained; 94% with aluminum and 99% with Iron [3]. Using mild steel or aluminum electrodes, CODs removal efficiency was maximal at the 0.3A current intensity.

B. *Effect of time*

The COD decreased rapidly over the first 20min of the treatment and then remained quite stable until the end of experiment, using either aluminum or mild steel electrodes [2]. The maximal decrease of CODs decreased slightly between 20 and 60 min and remained quite stable until the end of the experiment.

C. *Effect of supporting electrode*

Excess Electrode imposes energy demands on the system without any significant effect on the performance (COD removal efficiency).

D. *Effects of pH*

High COD removal percent may be attained in acidic mediums, the efficiency decreasing with increasing pH; at pH 2, maximum COD removal attainable is 93% with aluminum electrode, and 85% with iron electrode. Meanwhile, when original PSW (pH 6.7) is treated by EC, COD removal is 70% for aluminum, and 60% for iron electrode [3].

IV. EXPERIMENTAL

Chicken wastewater of 2000 ml was used in Kaselco and Plexiglas continuous flow reactors. Five iron electrodes were used in each of the reactors. The electrodes were properly scrubbed and rinsed prior to each experiment to make their surface clean and free from passive oxide layers. These electrodes were in the shape of a rectangular. The surface area of each electrode was 600 cm^2.

In the Kaselco reactor [9], the electrodes are horizontally arranged, and one end is connected to anode and another end is connected to cathode. A peristaltic pump is used to flow the water through the reactor of 500 mL volume. On the other hand, in the Plexiglas reactor, the electrodes are vertically arranged. The volume of the Plexiglas reactor is 1250 mL.

A pH meter calibrated at 7-10 pH range was used to measure pH of wastewater before and after treatment. Conductivity meter was used to measure the conductivity in mS. Hach COD Reactor DRB 200 was used to digest the COD vials. Hach DR 3000 spectrophotometer was used for colorimetric measurement of COD Vials. Kaselco Power rectifier was used to supply current. SEM-EDS, XRD and FTIR were used to check the composition of the floc

EC Procedure: The electro coagulation unit was connected to Kaselco power electrifier with the anodes connected to the positive terminal and cathodes to the negative terminal. A volume of 2 liters of chicken plant process wastewater was used for these experiments. Two types of flow reactors were used namely; KASELCO unit and PLEXI-GLAS. A flow rate of 0.5 L per minute was applied. Effect of current and time were determined. Current was varied from 0.5A to 3A (0.5A, 1.0A, 2A, 3A). The current and voltage during the EC process were checked using Cen-Tech multimeters. For each current 4 samples were collected at an interval of 4 minutes. The samples were then tested for COD. The conductivity was increased by NaCl support electrolyte. The pH of the solution was measured during the EC by Oakton pH meter. The floc formation was observed. After EC, the final solution was filtered by funnel and filter paper. The filtrate was collected in clean flask containers for the COD estimation. The solid residue EC-floc was dried sufficiently and characterized using SEM-EDS, and FTIR.

COD Estimation: When using 0-15,000mg/L COD vials a 0.2ml of the filtrate obtained in EC was added to the Hach COD vials using a volumetric pipette. When using 0-1,500mg/L COD vials 2ml of filtrate was added. The Hach COD Reactor DRB 200 was used in digesting the samples. COD results were determined calorimetrically. Hach DR 3000 spectrophotometer was used for colorimetric determination.

V. RESULTS AND DISCUSSION

EC experiments were performed on CPP wastewater at different current density and residence time using vertical and horizontal EC reactors. Removal Efficiency (RE) and Electrical Energy Consumption (EEC) per volume of wastewater were calculated using equations 1 and 2 [6]:

$$RE\% = \left(\frac{C_0 - C}{C_0}\right) \times 100 \qquad (1)$$

where, C_0 and C are the concentrations of COD before and after EC, respectively, ppm.

$$EEC = \left(\frac{VIt}{v}\right) \qquad (2)$$

Where, EEC is the electrical energy consumption ($kWhm^{-3}$), V is the potential (V), I is the current (A), t is the time (h), and v is the volume of solution (m^3). Current density was changed from 0.4 mA/cm^2 to 2.5 mA/cm^2 at different residence time and it was found that at current density 2.5 mA/cm^2 the COD removal efficiency is the highest for both vertical and horizontal reactors. Figures 1 and 2 show the COD removal at different residence time using vertical and horizontal reactors, respectively. With the use of vertical EC unit, COD removal efficiency was found of 95% at 8 min residence time, whereas, with horizontal EC unit, it was 68.9% at 16 min residence time. This result indicates the better removal efficiency with vertical electrode assembly in the vertical unit than the horizontal assembly in the horizontal unit. It has been already theoretically determined that the maximum current density occurs at the edge or tip of the electrodes [10]. Since in the horizontal assembly edges of the electrodes are enclosed in the frames and not exposed to the electrolyte solutions, the removal efficiency is lower for this type of assembly. On the other hand, in the vertical electrode assembly, three edges of the electrodes are exposed to the electrolyte solutions and are more susceptible for producing more GR and thus better treatment of the pollutants present in CPP water.

Figure 3 shows the pH change against residence time using vertical unit. It shows that during EC, the pH increases from 7.0 and stabilizes at about 7.6. In case of horizontal unit, during EC the pH also increases from 7.0 and stabilizes a bit higher pH values, i.e., 8.4 as shown in Figure 4. The higher residual hydroxide concentration in the horizontal unit probably signifies the less consumption of these ions for GR formation and COD removal. GR has inherently hydroxide ions in its structure. COD removal in EC may also require the consumption of hydroxide ions.

Table I shows results of those experiments performed at optimal operating conditions providing highest COD removal efficiencies. The current density 2.5 mA/cm^2 indicates the current intensity of 3 A. Table I also shows the calculations of EEC per volume of wastewater for the horizontal reactor and the vertical reactor. It was found that EEC per volume for vertical unit at highest COD removal efficiency is lower (3.4 kWh/m^3) than that for horizontal unit (3.8 kWh/m^3). That means, less electrical energy was consumed in the vertical EC unit than in the horizontal EC unit. The reason for this fact may be the design of the reactor.

Materials Characterization: The SEM micrograph of EC treated CPP wastewater floc shows the presence of carbon, oxygen, aluminum, silicon, potassium, sodium, chlorine, calcium and iron elements (Figure. 5). Carbon, oxgyen and iron represent 34.73%, 17.49% and 43.39% by weight in the floc, respectively.

The presence of carbon and oxygen indicates that CPP wastewater contains organic compounds. The presence of iron with highest percentage indicates the iron hydroxide that is produced as green rust. Figure 6 shows the XRD diffraction pattern of the EC-floc. The XRD pattern indicates the presence of magnetite (Fe_3O_4), goethite (FeO(OH)), and wuestite (FeO). The green colored and the pale-red colored patterns are for the EC-floc produced by the horizontal reactor and by the vertical reactor, respectively.

The equivalent absolute COD value for the COD removal efficiency of 95% with the vertical reactor is 180 mg/L. U.S. EPA does not mention any COD threshold value or limit for drinking water criteria or effluent discharge from CPP. We need further studies on BOD, TSS, ammonia and other parameters for coming to the conclusion for re-use of EC-treated CPP wastewater. These investigations are in progress.

VI. CONCLUSION

Electro coagulation technique removes most of the pollutants in meat and poultry waste water. The removal of the pollutants achieves the set effluent limitations by EPA. Most of the results show aluminum electrodes are more efficient compared to iron electrodes. However, from the literature review no work has been done to evaluate the removal of (Ammonia as N), Chloride, Phosphorus and Total coliform using Electrocoagulation. Also not much work has been done to evaluate the removal of TSS and BOD_5 in meat and poultry processing wastewater. The effect of flow rate on the removal has also not been evaluated. There more investigation needs to be done to determine the removal efficiency of TSS, BOD_5, coliform, Chloride, Ammonia (as Nitrogen) and phosphorus. The effect of flow rates need to be determined.

The EC process using vertical and horizontal reactors demonstrates that green rust, the layered double hydroxides consisting of Fe(II)-Fe(III) ions are effective in treating pollutants in chicken processing plant wastewater. The maximum COD removal was achieved with the current density of 2.5 mA/cm^2 when EC was performed with Fe-Fe electrodes. With vertical EC reactor, 95 % COD removal efficiency was attained with a residence time of 8 minutes, whereas, with horizontal EC reactor, 68.9 % COD removal efficiency was realized with a residence time of 16 minutes. The higher removal efficiency with vertical EC reactors may be justified for the occurrence of highest current density at the exposed edges of the vertical electrodes and thus forming larger amount of GR, while for the horizontal EC reactors, the edges of the electrodes are enclosed to the frame of EC reactor. The electrical energy consumption per volume of wastewater was calculated and obtained as 3.8 and 3.4 kWhm^{-3} for the horizontal and vertical reactors, respectively, for highest COD removal.

No reports of phosphorus removal from a slaughterhouse wastewater have been published.

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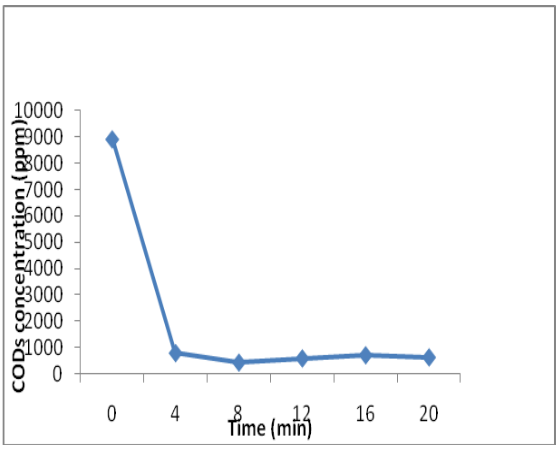

Fig 1. COD removal with residence time using vertical EC unit reactor at 2.5 mA/cm^2 current density

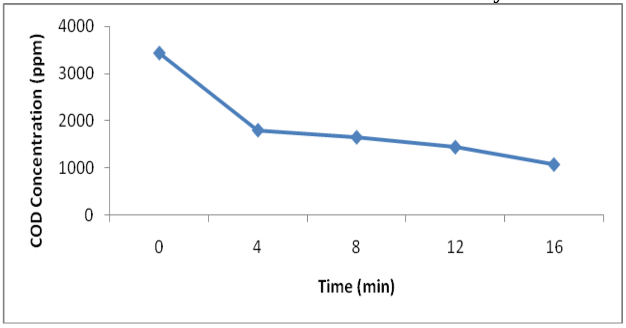

Fig 2. COD removal with residence time using horizontal EC unit Reactor at 2.5 mA/cm^2 current density

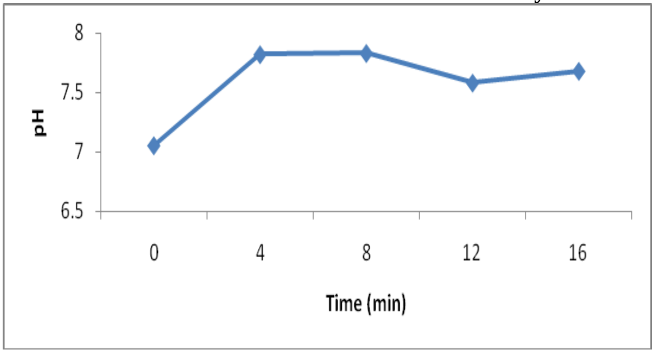

Fig 3. PH change with residence time in the vertical unit reactor at 2.5 mA/cm2 current density

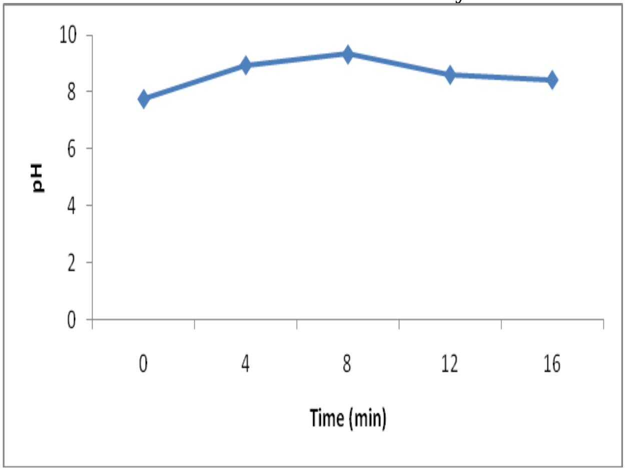

Fig 4. PH change with residence time in horizontal EC unit reactor at 2.5 mA/cm2 current density

Table I: The table below shows the COD removal efficiencies with 2 different kinds of Reactors.

Reactor type	Residence Time (min)	pH	Conductivity (mS)	Current density (mA/cm^2)	Poten-tial (V)	EEC per volume (kWh/m^3)	Removal efficiency(%)
vertical	0	7.05	0.015	2.5	34	3.4	0
	4	7.82	22.4	2.5	34	3.4	91.3
	8	7.83	22.5	2.5	34	3.4	95.3
	12	7.58	24.0	2.5	34	3.4	93.5
	16	7.78	23.2	2.5	34	3.4	92.2
horizontal	4	7.82	21.8	2.5	30	3.0	47.7
	8	7.83	22.3	2.5	37	3.7	52.0
	12	7.58	26.2	2.5	36	3.6	58.1
	16	7.68	26.1	2.5	38	3.8	68.9

Table 2: Current 1A, 1g/L Nacl Support electrolyte: Intial COD-470 ppm, Final COD-126ppm

Reactor type	Residence. Time (min)	pH	Conductivity (mS)	Current (A)	Potential (V)	EEC (kWhm^{-3})	Removal (%)
Plexiglas	0	7.86	2.89	1	0	0	**0**
	4	8.47	6.76	1	37	1.2	**67.9**
	8	8.5	7.20	1	38	1.3	**73.2**
	12	8.51	6.75	1	38	1.3	**68.9**
	16	8.8	6.90	1	38	1.3	**70.4**
	20	8.57	3.06	1	38	1.3	**71.9**
Kaselco	4	7.86	7.14	1	24	0.8	**72**
	8	7.97	6.80	1	28	0.9	**68.9**
	12	9.81	7.42	1	35	1.2	**72.3**
	16	10.69	6.54	1	37	1.2	**68.7**
	20	9.9	6.78	1	37	1.2	**71.9**

Table 3: Current 1.5A, 1g/L Nacl Support electrolyte: Initial COD-470 ppm, Final COD-140ppm

Reactor type	Residence. Time (min)	pH	Conductivity (mS)	Current (A)	Potential (V)	EEC (kWhm^{-3})	Removal (%)
Plexiglas	0	8.03	2.89	1.5	0	0	**0**
	4	8.36	6.73	1.5	50	2.5	**68.1**
	8	8.21	6.90	1.5	50	2.5	**69.8**
	12	7.93	7.32	1.5	50	2.5	**69.8**
	16	8.19	6.80	1.5	50	2.5	**70.2**
	20	8.94	6.93	1.5	50	2.5	**70.2**
Kaselco	4	10.35	12.53	1.5	50	2.5	**57**
	8	10.92	6.92	1.5	50	2.5	**66.6**
	12	10.40	6.94	1.5	50	2.5	**66.8**
	16	10.09	6.47	1.5	50	2.5	**64.9**
	20	10.42	6.35	1.5	50	2.5	**67.4**

Table 4: Current 2A, 2g/L Nacl Support electrolyte: Initial COD-470 ppm, Final COD-139ppm

Reactor type	Residence. Time (min)	pH	Conductivity (mS)	Current (A)	Potential (V)	EEC (kWhm^{-3})	Removal (%)
Plexiglas	0	8.03	2.89	2	0	0	**0**
	4	8.12	11.25	2	45	3	**70.4**
	8	8.88	11.31	2	44	2.9	**64.5**
	12	8.98	11.12	2	44	2.9	**68.1**
	16	9	11.65	2	44	2.9	**69.8**
	20	9.2	10.98	2	44	2.9	**70.0**
Kaselco	4	10.55	11.37	2	42	2.8	**56.4**
	8	11.16	11.46	2	50	3.3	**61.7**
	12	10.98	13.34	2	46	3.1	**60.9**
	16	11.06	11.37	2	46	3.1	**64.3**
	20	11.41	11.82	2	46	3.1	**63.6**

Table 5: Current 3A, 4g/L Nacl Support electrolyte: Intial COD-470 ppm, Final COD-150ppm

Reactor type	Residence. Time (min)	pH	Conductivity (mS)	Current (A)	Potential (V)	EEC (kWhm^{-3})	Removal (%)
Plexiglas	0	8.03	2.89	3	0	0	**0**
	4	7.78	17.98	3	30	3	**63.2**
	8	9.04	19.08	3	30	3	**63.8**
	12	9.23	18.28	3	30	3	**66.8**
	16	9.34	19.20	3	30	3	**67.4**
	20	9.99	18.78	3	30	3	**68.1**
Kaselco	4	11.32	20.20	3	30	3	**44.5**
	8	11.87	20.20	3	30	3	**57.9**
	12	11.65	22.7	3	30	3	**47.2**
	16	11.87	22.2	3	30	3	**49.8**
	20	11.65	18.60	3	30	3	**51.1**

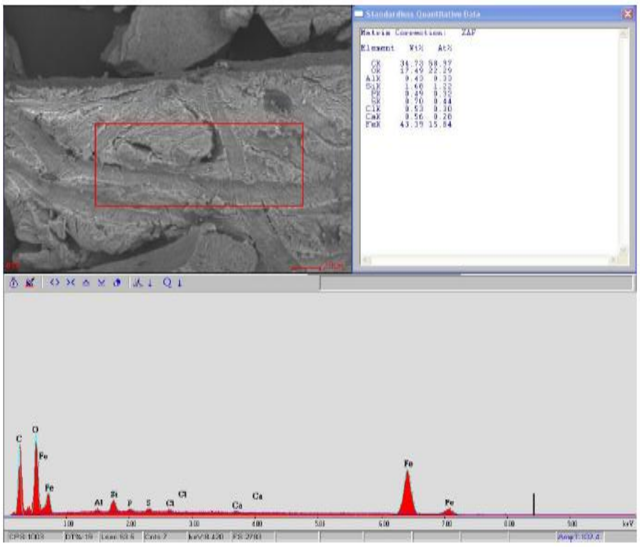

Fig 2. SEM micrograph of EC treated Chicken plant process wastewater floc

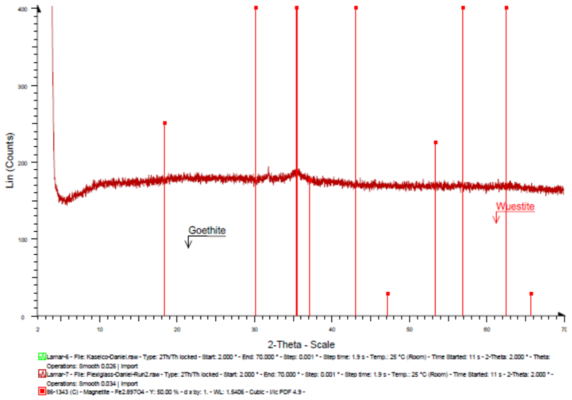

Fig 3. XRD patterns of the chicken plant process EC treated floc.

The red line pattern specifies magnetite

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Reference	**pollutants**	**pH**	**Current or current density or Electrical Energy Consumption (EEC)**	**Cell voltage (v)**	**Supporting Electrode Concentration**	**Electrode materials electrode Connections**	**Operating time (min)**	**Removal path**	**Flow rates**	**Treatment efficiency (%)**	**Reactor**
Un et al. (2009)	COD	7.8	$20mA/cm^2$	_	0.05M Na_2SO_4	Al	60		_	78.8	Batch
Un et al. (2009)	COD	7.8	$20mA/cm^2$	_	0.05M Na_2SO_4	Fe	60		_	68.5	Batch
Un et al. (2009)	COD	-	$25mA/cm^2$, $399kwh/m^3$	_		Al	60		_	81.7	Batch
Un et al. (2009)	COD	-	$10mA/cm^2$, $138kwh/m^3$	_		Al	10		_	65.4	Batch
Un et al. (2009)	COD	-	$15mA/cm^2$, $83kwh/m^3$	_		Fe	10		_	63.8	Batch
Un et al. (2009)	COD	-	$25mA/cm^2$, $124kwh/m^3$	_		Fe	10		_	70.2	Batch
Un et al. (2009)	COD	-	$547kwh/m^3$	_	0.05M Na_2SO_4	Al	60		_	86.4	Batch
Un et al. (2009)	COD	-	$158kwh/m^3$	_	0.1M Na_2SO_4	Al	60		_	50.5	Batch
Asselin et al., (2008)	COD	9.6	0.3-1.5A, $7.7-52.9kwh/m^3$	_	Na_2SO_4	Fe	90		_	49-81	Bipolar
Asselin et al., (2008)	COD	8.93	0.3-1.5A, $7.7-52.9kwh/m^3$	_	Na_2SO4	Al	90		_	46-83	Bipolar
Asselin et al., (2008)	COD	9.37	1.0-2.0A, $7.7-2.9kwh/m^3$	_	Na_2SO4	Fe	90		_	72-85	Monopolar
Asselin et al., (2008)	COD	8.7	1.0-2.0A, $7.7-2.9kwh/m^3$	_	Na_2SO4	Al	90		_	69-86	Monopolar
Kobya et al. (2006)	COD	2	$0.5-1.0kwh/m^3$, $150/m^2$	_	_	Al	25		_	93	Continuous
Kobya et al. (2006)	COD	2	$0.5-1.0kwh/m^3$, $150/m^2$	_	_	Fe	25		_	85	Continuous
Kobya et al. (2006)	COD	6.7	$0.5-1.0kwh/m^3$, $150/m^2$	_	_	Al	25		_	70	Continuous
Kobya et al. (2006)	COD	6.7	$0.3kwh/m^3$	_	_	Fe	25		_	60	Continuous
					_				_		
Asselin et al., (2008)	Oil-grease	6.15-6.46		_	_	Fe	60		_	99	Bipolar
Kobya et al. (2006)	Oil-grease	2	$150A/m^2$	_	_	Fe	25		_	99	Continuous
Kobya et al. (2006)	Oil-grease	2	$150A/m^2$	_	_	Al	25		_	94	Continuous
Kobya et al. (2006)	Oil-grease	2	$0.5-1.0kwh/m^3$	_	_	Al	25		_	92	Continuous
Kobya et al. (2006)	Oil-grease	8	$0.5-1.0kwh/m^3$	_	_	Al	25		_	64	Continuous
Kobya et al. (2006)	Oil-grease	2 8	$0.3kwh/m^3$	_	_	Fe	25		_	96-98	Continuous

Kobya et al. (2006)	Oil-grease	3 4	0.3kwh/m^3	_	_	Fe	25		_		Continuous
Kobya et al. (2006)	Oil-grease	2	150A/m^2	_	_	Al	7.5		_	90	Continuous
Kobya et al. (2006)	Oil-grease	2	150A/m^2	_	_	Fe	15		_	95	Continuous
Un et al. (2009)	Turbidity	-	158kwh/m3		0.1M NaSO4	Al	60		-	98.82	Batch
Un et al. (2009)	Turbidity	-	547kwh/m3		0.05M NaSO4	Al	60		-	99.71	Batch
Un et al. (2009)	Turbidity	7.8	-		-	Al	10		-	99.1	Batch
Un et al. (2009)	Turbidity	7.8	-		-	Fe	10		-	90.1	Batch
Asselin et al., (2008)	Turbidity	6.15-6.46	-		-	Fe	60		-	89	Bipolar
Asselin et al., (2008)	BOD	6.15-6.47	-		-	Fe	60		-	86	Bipolar
Asselin et al., (2008)	TSS	6.15-6.48	-		-	Fe	60		-	90	Bipolar