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Electrocoagulation/flotation followed by fluidized bed anaerobic reactor applied to tannery effluent treatment

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ABSTRACT

A series operation of electrocoagulation/flotation (ECF) and fluidized bed anaerobic reactor (FBR) was conducted to treat tannery wastewater. Although both reactors were operated in fill- and-draw (batch) mode, effluent from ECF was fed to FBR in order to remove the remaining soluble biodegradable organic matter. Operating with a hydraulic residence time of 65 min, the ECF reactor reached 59% COD removal and FBR reached 74% COD removal with an 8 h residence time. Time profiles for wastewater treatment of 65 min in ECF plus 12 h in FBR, showed 39% removal of COD in the first 10 min and 84% in the remaining 775 min of the overall operation cycle. Although turbidity in the raw influent reached levels beyond the upper limit of detection for the turbidimeter, values as low as 10 uT were detected after 65 min treatment in ECF. However, after being treated for 8 h in FBR, the efficiency of turbidity removal was affected by solids settling in the recirculation basin.

Keywords: Fluidized bed; Anaerobic treatment; Electrocoagulation; Flotation; Tannery effluent; Biofilm

1. Introduction

Tannery effluent treatment has always demanded a series of facilities in order to reduce pollutants to levels that are not offensive to environmental and human health. Several studies have been devoted to optimizing the performance of systems treating this liquid waste, although few have tested electrocoagulation/flotation (ECF) effectiveness [1–5].

The industrial effluent studied in this research is not generated by a traditional tannery process; it is produced in a finishing plant involving blue sorting, conditioning, staking, buffing, coloring and drying; the presence of high concentrations of organic matter and suspended solids makes this wastewater a hazardous material, incompatible with environmental regulations.

Biological reactors are used for the treatment of these wastewaters, usually preceded by physical-chemical treatment in order to reduce organic loading and nutrient presence and remove other substances that can harm bacteria.

Electrocoagulation is an innovative process that combines an electrochemical process and chemical coagulation in order to form biological flocs. If combined with flotation as well, micro bubbles can effectively trap solids in their upward course and separate them from the liquid medium. Some soluble organic compounds are also removed as a consequence of adsorption [6–8].

Internal aluminum electrodes in electrochemical cell, permit the formation of gases (typically hydrogen) in cathode's surface at the same time that wastewater is dosed with in situ-generated coagulant metal cations.

Effluents of ECF units become more amenable for treatment in high rate biological processes, which can treat substantial volumes of wastewater in short periods

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of time, such as anaerobic fluidized bed reactors. In this units, granulated activated carbon (GAC) is commonly used as a support medium for the formation of biological films. As the bacteria present in the polymeric matrix are prevented from leaving the reactor, long cell retention times are achieved and the volume of the reactor is substantially reduced [9].

The aim of this work was to determine the performance of an electrocoagulation/flotation reactor operating in series with a fluidized bed anaerobic reactor (FBR) to remove pollutants from wastewater produced in a finishing tannery plant.

2. Materials and methods

2.1. Experimental devices

As shown in Fig. 1, the experimental system consisted of a feeding reservoir, an electrocoagulation/flotation reactor, a recirculation reservoir, a dosing pump and a fluidized bed anaerobic reactor.

The electrocoagulation/flotation (ECF) reactor consisted of an acrylic electrochemical cell with a total volume of 10 l (14.5 cm in diameter and 41 cm high) and six 15 cm × 15 cm × 0.5 cm aluminum plates used as electrodes. Only external electrodes were connected to the power supply (10V DC Equilab 1800), where the inner sacrifice electrodes were mounted on Teflon® cylinders with a 5 mm gap and isolated from the others. The ECF reactor scheme is depicted in Fig. 2.

The fluidized bed reactor (FBR) consisted of a glass tube, 5 cm in diameter and 1 m high, filled with GAC support medium. A settling device, placed at the top of the unit, was used to separate solids from the liquid phase and also served as s support for the gas capture device. A schematic diagram of FBR is shown in Fig. 3.

2.2. Experimental approach

The ECF unit worked in a fill-and-draw (batch) mode with electrolysis and settling stages clearly defined. Each cycle admitted 4 l of raw wastewater corrected for conductivity to 4 mS/cm. The addition of NaCl and a current density set at 22 A/cm^2 permitted satisfactory treatment during 45 min of electrolysis and 20 min of settling. The settling stage was defined as the period of time in which the power supply remained off and micro bubbles were allowed to reach the surface. All runs were conducted at room temperature and with no further chemical addition.

At the end of the cycle, effluent from ECF was withdrawn and allowed into a recycling reservoir in order to be introduced into the fluidized bed reactor (FBR) by means of a dosing pump (ECOSAN BDG).

The operation of FBR was also in the fill-and-draw mode, in which, initially, liquid remained recirculating for 12 h. Afterwards, the final effluent was withdrawn from the reservoir and samples were taken for physical-chemical

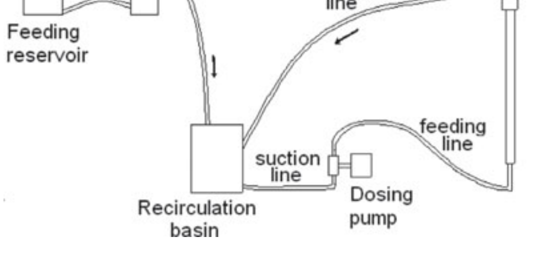

Fig. 1. Schematic diagram of system.

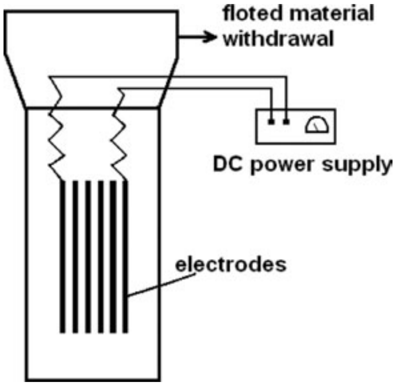

Fig. 2. ECF reactor schematic diagram.

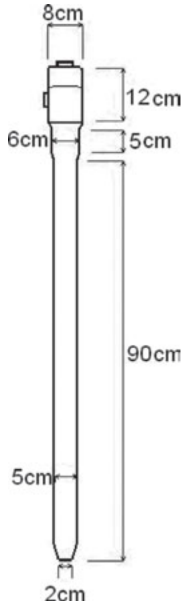

Fig. 3. Schematic diagram of FBR.

analysis. Hydraulic residence time was set at 0.09 h due to an upflow velocity of 12.9 m/s, necessary for GAC fluidization in this reactor.

FBR was inoculated with sludge from an anaerobic stabilization pond of a slaughterhouse. The sludge, 0.5 l, was introduced into the reactor, which was kept in recirculating mode for 24 h. Afterwards, on a daily basis, 1 l of effluent was withdrawn from the recirculation basin, which was replaced by 1 l of untreated tannery effluent. This process lasted two weeks until 60% of COD was removed from FBR's influent. From that point on, the reactor was considered inoculated, and further cycles were carried out feeding it with ECF effluent.

Chemical addition was avoided in order to simulate real operation conditions as much as possible, and for the same reason, there was no temperature (24 to 29 degrees Celsius) control in any of the reactors.

2.3. Analysis

Standard Methods for the Examination of Water and Wastewater were used for all quantitative estimations [10]. COD determination was conducted according to method 5220 D, turbidity by method 2130 B, conductivity using method 2510 A, total solids with method 2540 B, fixed and volatile solids by applying method 2540 E.

Samples were always taken from the raw influent, ECF effluent and FBR effluent. Typical characteristics of raw influent were: COD, 3500 mg/l; pH 9.6; conductivity, 3 mS/cm; and total solids, 5.5 g/l. Turbidity was always beyond the upper limit of detection for the turbidimeter.

3. Results

A prior stage, intended to define proper electrolysis and settling times, was conducted in the ECF reactor, while FBR was in inoculation phase. Electrolysis time intervals of 10, 15, 20, 25, 40, 45 and 50 min were tested. Based on the results of COD and turbidity removal, an optimal time of 45 min was established. pH remained on average 9.6 for the time intervals tested in this stage of the study.

Once electrolysis time was defined, the time interval for settling was studied to determine the best COD and turbidity removal after 45 min of DC current application. According to the results obtained, a time of 20 min was established for settling in the ECF unit. Thus, the total residence time of liquid in ECF reactor was 65 min.

3.1. Series operation of ECF and FBR units

Series operation was divided into three stages, Stage 1 being considered as a test stage where influent COD was measured only when raw liquid was taken from the plant, and its value was used as a reference for removal calculations in all the cycles tested. Overall hydraulic residence time for the system in this stage was 65 min in ECF plus 12 h in FBR. In Stage 2, hydraulic residence times for both reactors were kept unchanged, but raw influent COD was analyzed for each cycle tested. Finally, Stage 3 was characterized by a hydraulic residence time of 65 min in ECR (same as Stage 2) plus a 4 h reduction in FBR, totaling 8 h plus 65 min for the whole system.

Recorded variations of COD and turbidity, from 120 h to 130 h (with a hydraulic residence time of 12 h in FBR) and from 264 h to 330 h (with a hydraulic residence time of 8 h in FBR), are shown in the time axis of Figs. 4 and 5. As mentioned before, residence time in FBR was modified during the experimental period, but residence time of the ECF reactor remained unchanged.

As shown in Fig. 4, during Stage 1, average values of COD removal were 90 and 30% for ECF and FBR, respectively. This behavior suggested the possibility of good overall performance in treating the residue in the applied residence times. Thus, Stage 2 was initiated with the same operating times, but with monitoring of COD of raw influent for each batch performed. In this stage, both reactors behaved as expected, with higher turbidity removal in ECF and higher COD removal in FBR, where there was an increase in turbidity caused by the settling of solids carried from the recirculation basin. From an overall mean value of 85%, each reactor was responsible for almost half of COD removal, which suggests that particulate and soluble COD were present in similar proportions in the raw industrial effluent.

The fact that maximum COD removal reached 71% for ECF and 91% for FBR, marked the beginning of Stage 3. In this stage, the organic loading in the biological reactor was raised by means of reduction of batch duration from 12 to 8 h. Even with this operation, overall COD reached 90%. However, Figs. 4 and 5 show contrasting trends. COD removal behavior was as expected in both cases, but turbidity had isolated peaks in the effluent of ECF.

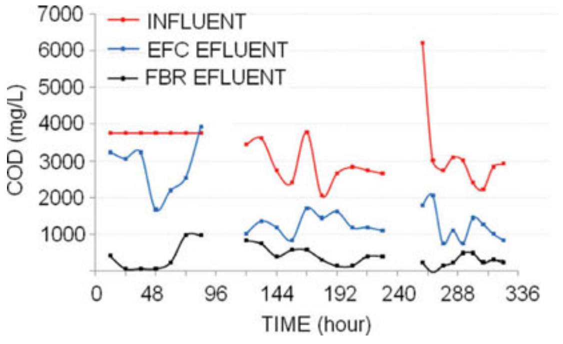

Fig. 4. Overall Variation of COD in pilot system.

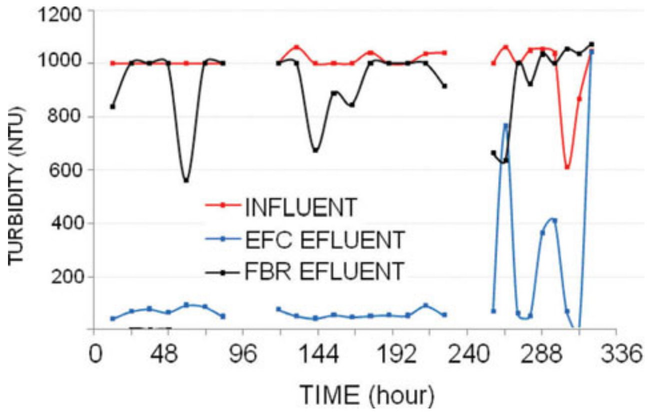

Fig. 5. Overall variation of turbidity in pilot system.

This was unexpected since that batch duration remained the same in this reactor during the whole experimental period. This kind of event was attributed to changes in the quality of raw wastewater, which is a common characteristic of industrial effluents. On the other hand, FBR performance did not seem to be affected by this substantial change in influent solids content; the quality of treated water from this unit remained the same as in the previous stage. Solids were not expected to be retained in the fluidized bed, as they remained in the recirculation basin, increasing in concentration there.

As shown in Fig. 6 and Fig. 7, COD and turbidity removal profiles were accomplished during Stage 2. The results showed 50% removal of COD in ECF in a batch of 65 min and 50% in FBR in a 12 h batch.

Turbidity dropped from 1000 to 160 in 65 min in ECF and rose back to 750 after a 12 h residence time in FBR. As samples for analyzing FBR performance were taken from the recirculation basin, one can infer that the accumulation of solids in this unit was responsible for high turbidity as well as low COD removal in this unit in the overall process.

Removal of COD occurred in ECF as a consequence of the capture of suspended solids by the ascending micro bubbles. In this way, total COD, consisting of soluble COD and particulate COD, remained in the effluent basically in its dissolved form. Turbidity variation in the ECF reactor was consistent with this observation, as the presence of particulates diminished during coagulation and flotation, and since turbidity was depleted along with organic matter measured as COD.

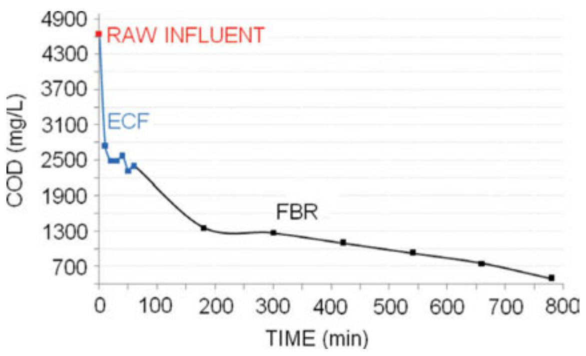

Fig. 6. COD removal profile for HDT of 12 h.

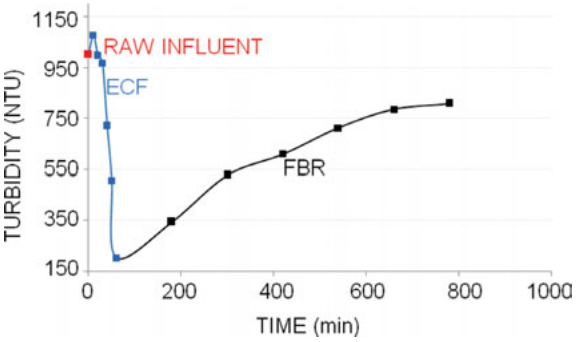

Fig. 7. Turbidity removal profile for HDT of 12 h.

In FBR, Turbidity and COD showed different trends. As turbidity increased as a consequence of suspended solids carried from the recirculation basin, soluble COD remaining in the ECF effluent diminished as a consequence of biological activity.

4. Conclusions

From results obtained, we determined that ECF operating in series with FBR attained 90% efficiency with a hydraulic residence time of 545 min: 65 min in EFR and 8 h in FBR.

Solids accumulation in the FBR recirculation basin hinders FBR and overall performance, causing a rise in COD and turbidity levels.

As expected, room temperature variation had no significant effect on EFC, and more importantly, it did not substantially affect the biological reactor, even when the temperature decreased below 30°C. The results showed that the effect of pH on FBR was also not significant. In order to enhance waste removal, the addition of chemicals and temperature control would be recommended upstream from the biological reactor.

COD characteristics of treated effluent permit its disposal in s sewage system, according to local environmental regulations.

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