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Domestic greywater treatment by electrocoagulation using hybrid electrode combinations

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ABSTRACT

Greywater (GW) treatment by the electrocoagulation (EC) process was investigated in this study. Eight different electrode combinations were evaluated. The effect of such important parameters as current density, initial pH (pH_i) and supporting electrolyte concentration (SEC) on the GW treatment by EC were researched. The highest COD removal was obtained with the Al–Fe–Fe–Al hybrid combination. Current density of 1 mA/cm^2 provided the highest efficiency. Further increase of current density did not show better performance. The original pH value (7.62) was found to be the most suitable condition. SEC did not affect the removal efficiencies. The EC process showed good performance to treat GW and provided allowable limits to reuse. The energy consumption was 9.46 kWh/m^3 for optimum conditions.

1. Introduction

Any wastewater produced in household facilities except toilet (Blackwater, BW) is called greywater (GW). GW includes wastewaters from kitchen and bathroom sinks, showers, washing machines and dishwashers. GW represents a very high volume of wastewater produced in domestic areas, so that it represents a great potential source of water saving. Greywater generation could be up to 75% of the wastewater volume produced by households [1]. The amount of GW produced in total is about 69% of overall water consumption [2].

The characteristics of GW depend on the number of residents, their age distribution, and living standards, social and cultural traditions. GW contains surfactants (anionic, cationic and amphoteric) coming from shampoos and detergents, and high concentrations of chemicals from soaps (such as sodium, phosphorous, surfactants and nitrogen), as well as suspended solids, turbidity and organic matter. In literature, the mean range of some pollutant concentrations in domestic GW were found as follows: pH 6–9, turbidity 12–2131 NTU, conductivity 1.4–703 mS/m, total suspended solids (TSS) 11–2180 mg/L, biochemical oxygen demand (BOD) 23–942 mg/L, chemical oxygen demand (COD) 55–2000 mg/L, methylene blue active substance (MBAS) 0.3–118 mg/L, oil and grease (O&G) 7–328 mg/L, total P 0.012–51.58 mg/L, PO_4-P 0.53–1.21 mg/L, total N 1.1–40.3 mg/L, NO_3-N 0.93–6.6 mg/L, NO_2-N 0.1–0.36 mg/L, total coliforms (TC) 200–2.2 × 10^7 MPN, faecal coli forms (FC) 13–1.9 × 10^7 MPN and *Escherichia coli* 10–3.9 × 10^{5}MPN [2,3].

The existent wastewater treatment systems collect all the wastewater including GW and BW. Those treatment systems target to remove the contaminants which are mainly a part of BW. Collecting and treating GW and BW separately reduces the wastewater load at wastewater treatment plants and also reduces drinking water consumption where there is no need to use water of drinking quality (toilet flushing, car washing and irrigation, in some cases).

Treatment methods applied for GW include physical systems such as filtration, screening and ultra-filtration (UF) membranes; chemical systems such as coagulation/flocculation and ion exchange resins; biological systems such as constructed wetlands, rotating biological reactor (RBC), membrane bioreactor (MBR) and sequencing batch reactor (SBR). Physical treatment systems alone do not provide the desired microbial quality, and they are used together with disinfection steps or combinations of other methods.

In a study conducted by Pidou et al., coagulation and ion exchange resin processes were applied for the GW treatment. Coagulation with aluminium salt reduced COD, turbidity, TN and PO_4^{3-} from 791 mg/L, 46.6 NTU, 18 mg/L and 1.66 mg/L in the influent to 287 mg/L, 4.28 NTU, 15.7 mg/L and 0.09 mg/L, respectively, at optimum conditions. The total coliform value in the treated greywater was less than 1/100 mL. Coagulation with ferric salt provided similar removal efficiencies to that obtained with aluminium salt. COD, turbidity, TN and PO_4^{3-} were decreased by ion exchange resin to 272 mg/L, 8.14 NTU, 15.3 mg/L and 0.91 mg/L, respectively. The total coliform value in reclaimed greywater was 59/100 mL. The ion

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exchange resin process failed to reduce the turbidity to the levels required for both unrestricted and restricted reuses. Both processes were found to have minor effects on the removals of TN and PO_4^{3-} [4]. The flocculation process for the GW treatment was investigated in another study. 64% COD and 89% BOD removals were gained. Total-N was removed by only 13%. The study indicated that the flocculation process alone is not able to remove the organic substances efficiently for providing the reuse standard; thus, it should be combined with other processes [5].

Many biological processes were investigated for GW treatment in the literature. These systems were usually used with physical pre-treatment such as filtration and screening and a disinfection step as a post-treatment to meet non-potable reuse standards. Friedler et al. studied combined RBC, sand filtration and chlorination for the greywater treatment. TSS, turbidity, COD, BOD and faecal coliforms were reduced from 43 mg/L, 33 NTU, 158 mg/L, 59 mg/L and 5.6×10^5/100 mL in the influent to 16 mg/L, 1.9 NTU, 46 mg/L, 6.6 mg/L and 9.7×10^3/100 mL, respectively, in the effluent of the sedimentation step. The sand filtration step provided further decrease of the TSS, turbidity, COD and BOD values. The faecal coliform level was reduced to 0.1/100 mL by the chlorination step in the final effluent. The whole system reduced the TP, TKN, ammonia and organic nitrogen from 4.8 mg/L, 8.1 mg/L, 4.9 mg/L and 3.2 mg/L in the influent to 2 mg/L, 1 mg/L, 0.16 mg/L and 0.97 mg/L, respectively, in the final effluent [6]. In another study, constructed wetland was applied successfully for GW treatment resulting in 98% TSS, 81% COD and 92% MBAS removal efficiencies [7]. Liu et. al., studied MBR process for GW recycling. The results showed that MBR process provided the required quality of treated greywater for reuse applications, as most of the pollutants were removed, and membrane separation reduced further the rest of the pollutants [8].

Electrochemical treatment systems such as electrocoagulation (EC), electrooxidation and electroflotation are promising technologies for wastewater treatment. So far, these technologies have been applied for the removal of various pollutants efficaciously [9–12]. Amongst them, electrocoagulation is a simple and highly effective method for water and wastewater treatment. While oxidation reactions take place on the sacrificial anode, reduction reactions occur on the cathode. When current is given to the process, the electrodes start to dissolve, and cations such as Al^{3+}, Fe^{2+} and Fe^{3+} are produced. Those cations form metal hydroxides in aqueous media. Metal hydroxide species provide effective destabilization of suspended solids. The removal mechanism could be via adsorption, charge neutralization, and sweep coagulation. The EC method offers many benefits, compared to chemical coagulation, due to its compactness, no need for chemicals, less sludge production and cost-effectiveness. Aluminium and iron electrodes are commonly used in EC processes to produces aluminium and iron hydroxide flocs. There are limited studies in the literature using a combination of aluminium and iron electrodes. Yavuz et. al., studied hybrid electrode pairs (Al–Fe) to treat dairy industry wastewater, and 79.2% COD removal was reported in [13], while Tchamango et. al., achieved 61% COD removal by using only aluminium electrodes for similar wastewater [14]. The study conducted by Lakshmi and Sivashanmugam showed that Al–Fe hybrid electrode pairs provided better efficiency in COD removal for oil tanning effluent than aluminium electrodes [15].

There are only a few studies that investigated the EC method for GW treatment in literature. Vakil et al., investigated the EC process using aluminium electrodes for the treatment of GW.The COD value was reduced to 160 mg/L from 380 mg/L, and turbidity was reduced to 15.6 NTU from 104 NTU. The study also indicated that 2 log reductions were provided on total coliform removal [16]. In another study, the combination of EC using aluminium electrodes and SMBR processes were used for GW treatment. COD, turbidity, TSS and total coliform values were 463 mg/L, 133 NTU, 78 mg/L and 43×10^4 CFU/100 mL in the influent, respectively, and for COD, turbidity and total coliform their values were reduced to 51 mg/L, 4.1 NTU and 49CFU/100 mL, respectively in the effluent. The TSS value was non-detectable in the effluent [17]. Lin et. al., studied the EC process using bipolar aluminium electrodes together with a disinfection step [18]. COD was reduced to 22 mg/L from 55 mg/L, and complete coliform removal was gained in this study.

Here, domestic GW treatment by EC was investigated by using different types of electrodes, such as aluminium, iron and hybrid (Al–Fe) ones. Only aluminium, only iron and hybrid electrodes (Al–Fe) with different ordering were used to see the effect of the order. There are no published research studies to date that use iron and hybrid electrodes in the EC process for GW treatment and investigate the effect of the electrodes order on the GW treatment. Optimum operating conditions, such as current density, pH and supporting electrolyte concentration were studied on the removal of chemical oxygen demand (COD) from GW along with the change of pH during GW treatment. Also the removal of other indices, such as total suspended solids (TSS), turbidity, total nitrogen (TN), total phosphorus (TP), anionic surfactant (MBAS), phosphate, nitrate and nitrite were discussed. Besides, operating costs of the GW treatment by EC in terms of energy and electrode consumptions were explored.

Table 1
Characteristics of greywater used as feed to EC process.

Water quality indexes	Average value with standard deviation
pH	7.62 ± 0.032
Conductivity (μS/cm)	802.2 ± 0.073
NO_3^--N (mg/L)	0.375 ± 0.12
NO_2^--N (mg/L)	0.067 ± 0.08
COD (mg O_2/L)	229 ± 3.21
TSS (mg/L)	33.5 ± 0.98
TN (mg/L)	11.1 ± 0.26
Turbidity (NTU)	53.4 ± 1.12
TP (mg/L)	1.07 ± 0.054
PO_4^{3-} (mg/L)	0.311 ± 0.011
SO_4^{2-}	155.8 ± 6.5
Cl^-	726 ± 10.2
MBAS (mg/L)	72 ± 0.76

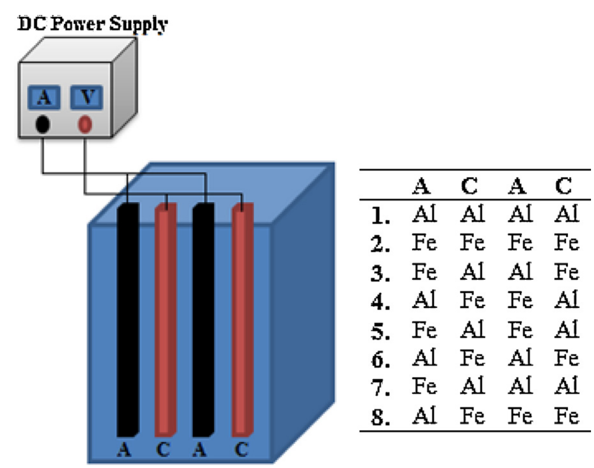

Fig. 1. Experimental set-up for EC process.

2. Material and methods

2.1. Greywater

GW samples were collected from TUBITAK public housing in Gebze, Turkey. The main contributions to GW at the public housing were from cleaning, showers, sinks, and kitchen activities. All