

Use of Electrocoagulation in Wastewater Treatment

Subjects: Environmental Sciences

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Electrocoagulation (EC) is a wastewater treatment method based on chemical reactions between a coagulant formed under the influence of an electric current released from a given electrode. Electrocoagulation is a technology that properly combines electrochemistry, coagulation, and flotation (or sedimentation). This technology consists of four main stages: electrolytic reaction on the surface of the electrode, formation of metal hydroxides (coagulants), adsorption of soluble (colloidal) particles on coagulants, and removal by sedimentation or flotation. Reactions between the coagulant and pollutants lead to precipitation of sediments which are removed by sedimentation or flotation.

Keywords: electrocoagulation ; wastewater ; coagulant ; coagulation ; flotation ; sediments

1. Introduction

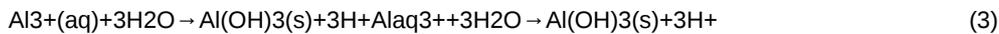
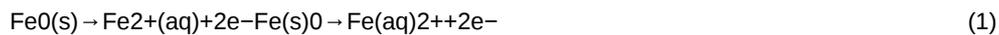
The amount of organic micro-pollutants introduced into the aquatic environment from anthropogenic sources is much greater than that resulting from natural processes. This applies mainly to industrial activities in which coal and metal ores are processed, crude oil is refined, and chemicals, pharmaceuticals, textiles, or cosmetics are produced [1][2]. The concentration of organic micro-pollutants in the industrial wastewater depends on the type of industrial activity, type of raw materials, production technology, as well as the applied methods of wastewater treatment. Many processes are used to pre-treat the contaminated outflows before they are put into sewage systems or into an aquatic environment. However, even highly pre-treated wastewater contains organic compounds that are difficult to degrade and is characterised by high chemical oxygen demand (COD) values and relatively low biochemical oxygen demand (BOD) values. The low values of the ratio between these indicators shows a low susceptibility to biodegradation [3]. Persistent organic micro-pollutants (POPs) include polycyclic aromatic hydrocarbons (PAHs), halogenated organic compounds (AOX), di-2-ethylhexyl phthalates (DEHP), nonylphenols (NPE) and nonylphenol ethoxylates (NPEO), as well as selected surfactants such as linear alkylbenzene sulfonate (LAS), pharmaceuticals (PhACs), cosmetics (PPCPs—pharmaceuticals and personal care products), flame retardants (FRs), and many more [4][5][6]. POPs accumulate in the tissues of living organisms and display carcinogenic, mutagenic, and other undesirable health effects, such as endocrine disorders [7][8]. The removal rate of organic compounds from wastewater by biological methods used in conventional treatment plants is insufficient; thus, the treatment requires additional processes to ensure effective removal of organic compounds [9][10][11][12][13]. These include those that provide only the separation of pollutants but do not solve the problem of their occurrence, and those that ensure the degradation of compounds that are difficult to decompose [14]. Separation methods include coagulation, adsorption, flotation, and membrane separation. Among the membrane methods, pressure methods such as ultrafiltration, nanofiltration, and reverse osmosis are the most widely used in wastewater technology [15]. Methods ensuring degradation of persistent organic compounds include advanced oxidation processes (AOPs) [16][17][18][19]. These include chemical and catalytic processes, supported by an additional source of energy, as well as ones that do not use the latter. In these processes, as a result of subsequent chemical reactions, free radicals are generated, mainly hydroxyl radicals (HO[•]) with a high oxidizing potential, facilitating the destruction of most organic compounds. However, a disadvantage of these processes consists of the formation of intermediate products with different activity toward test organisms. Therefore, new solutions are currently being sought and research is being undertaken to modify known and used processes to ensure complete oxidation of organic compounds and reduce the toxicity of post-reaction solutions. In this respect, the proposed solutions concern, among others, supporting classic processes with solar, ultraviolet, or gamma radiation, as well as electricity. In relation to methods supported by electricity, such processes as electrocoagulation, electroflotation, and chemical and photochemical AOP (electro-Fenton, sono-electro-Fenton, photo-electro-Fenton) can be included [20][21][22][23][24][25][26].

2. Electrocoagulation

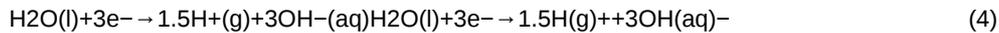
Flotation is caused by micro bubbles of gas released as a result of the redox reaction that takes place during the flow of electricity through the solution. The precipitates are collected in the form of scum on the surface and create sediments

after degassing. The materials most often used for constructing electrodes utilized in the electrocoagulation process are aluminium and iron. As a result of the flow of electric current through the solution (sewage), Al^{3+} aluminium cations and Fe^{2+} iron cations are released—Reactions (1) and (2). Aluminium ions form hydroxide (Reaction (3)), while hydrogen is released on the cathode (Reaction (4)) [23][27].

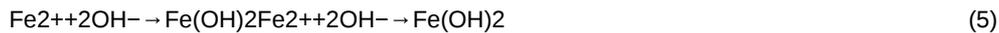
Anode:



Cathode:



During electrocoagulation, iron hydroxides are formed as a result of Reactions (1) and (5)–(7).



During the electrocoagulation process, depending on the reaction of the environment, transitional ionic forms of iron ($Fe(OH)_2^+$, $Fe(OH)_4^-$, $Fe_2(OH)_2^{4+}$, $Fe(H_2O)_4(OH)_2^+$) may be created, which then form iron (III) hydroxide [28]. The consumption of an aluminium electrode (C) in reference to the unit of treated wastewater ($kg\ Al/m^3$) is calculated using the Faraday law according to Equation (8):

$$C = \frac{I \cdot t \cdot M}{z \cdot F \cdot V} \quad (8)$$

where

- I the current intensity (A);
- t the retention time (s);
- V the volume of the treated wastewater (m^3);
- F the Faraday's constant (96.487 C/mol);
- M the mass of aluminium (26.98 g/mol) and mass of iron (55.847 g/mol);
- z the number of electron transfer (e.g., $z_{Al} = z_{Fe} = 3$).

Specific energy consumption, E, is calculated according to Equation (9) [27]:

$$E = \frac{U \cdot I \cdot t \cdot (COD_0 - COD_t)}{V} \quad (9)$$

where

- E the specific energy consumption (kWh/kg of COD removed);
- U the applied voltage (V);
- I the current intensity (A);
- t the retention time (h);
- COD_0 the chemical oxygen demand before treatment (g/L);
- COD_t the chemical oxygen demand after treatment (g/L);
- V the volume of the treated wastewater (L).

The system consists of a reactor equipped with a stirrer (or allowing the solution to be mixed), a set of electrodes, a source of electricity, and a system for dosing and discharging the polluted solution. The possibility of removing the post-coagulation sediment, and in some cases changing the electrode connection to the power source, is also taken into account. The basic parameters that affect the process are electrode material and distance between them, electric current intensity and density, pH value of the solution, and initial concentration of pollutants. The literature data indicate that the electrocoagulation process was used to remove pollutants occurring in wastewater such as: tannery, galvanic, and dyeing wastewater, waste from metal processing plants, waste containing oil emulsions, textile wastewater, wastewater from oil presses, and laundry wastewater [17][29][30][31]. This method has been shown to be useful for removing arsenic, polyvinyl alcohol, 4-nitrophenol, dyes, fluorine, nitrates, petroleum derivative hydrocarbons, chromium, phosphates, as well as phenol and phenolic compounds [22][26][32][33][34][35][36][37][38][39].

Example studies concerning using the EC method to remove dyes from solutions, and the results of these studies demonstrated that the efficiency of removal of these xenobiotics can reach 97%. The decrease in the value of COD was at the level of 92%. Example studies examining the application of the electrocoagulation process concerned removal of pharmaceutical residues from actual sewage [33] also demonstrated that this method can be used for removal of fluorides from contaminated water. The research was carried out in a labyrinth reactor, where properly set partitions ensured flow between them, which extended the reaction time. The reactor included six alloy electrodes and was powered by a 30 V direct current. The initial fluoride concentration was at the level of 20 mg/L. Three process parameters were optimized: current density (1.5, 2.5, and 3.5 mA/cm²), pH (4, 7, and 10), and the distance between electrodes (5, 10, and 15 mm). After 30 min of the process, the fluoride concentration did not exceed the limit value for drinking water determined by the WHO (<1.5 mg/L) at pH 7, current density of 2.5 mA/cm², and the distance between electrodes equal to 5 mm. The purification cost was estimated at 0.346 USD/m³ with energy consumption at the level of 5.03 kWh/m³. Smoczyński et al. conducted research concerning electrocoagulation of model wastewater using electrodes made of iron [28]. The research was carried out at a constant current intensity (0.3 A) analysing changes in pH, suspensions and turbidity, COD, and total phosphorus in the purified solutions. At fixed time intervals (256 s), the direction of current flow on the electrodes was changed in the system. Changing the role of the contaminated cathode into a soluble anode allowed it to be purified as a result of anodic dissolution. The efficiency of organic compound removal expressed by the COD index was 43%, and the removal of turbidity was equal to 62%. There was a decrease in the concentration of suspensions by 81% and phosphorus by 51–58%. It was determined that the most favourable conditions for phosphorus removal occur when the molar relationship Fe:P is greater than 1:3, which at the same time prevents the formation of post-coagulation sediments: Fe₃(PO₄)₂, FePO₄, (FeOH)₃(PO₄)₂, and (FeOH)₃PO₄.

In the EC process, the amount of sediment is smaller than in the classical coagulation process, the system is not complicated, does not require any large objects to be provided, and can also be mobile. There is no thickener required as there would be in chemical classic coagulation, which reduces the operation cost. Other advantages include: no risk of residual chemicals in the effluent (toxins and odours), metals can be recovered from the solution. In most cases, this process does not require much energy to operate the coagulation equipment. This low level can easily be produced using green energy sources.

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