



# Investigation and optimization of a new electrocoagulation reactor with horizontal bipolar electrodes: Effect of electrode structure on the reactor performances

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## ABSTRACT

The performances of a new electrocoagulation reactor with bipolar horizontal iron electrodes were investigated. These electrodes were piled up in the reactor in order to maintain a low gap between them and to increase the electroflotation process. Electrodes were perforated to allow the passage of gas and effluents, and adjacent ones were separated by grids of polyamide or polytetrafluoroethylene. The performances of the reactor were investigated thanks to the weight lost of the electrodes. These performances increased with the number of holes in the electrodes, the current intensity, and the flow rate of the effluent, and mainly in the absence of a gap between the electrode edges and the walls of the reactor. More important, when the electrodes were not sealed with a system of tightness a decrease of the current efficiency was observed, leading to higher voltage and contributing to increase considerably the energy consumption. The use of eight-hole electrodes and a high flow rate reduced significantly the voltage and increased the current efficiency. Moreover in the absence of a gap between electrode edges and reactor walls, the current efficiency reached 100%; the voltage was stable and did not vary anymore and the energy consumption was minimized. The results showed that the sealing between electrode edges and the walls of the reactor was the most determinant factor in the optimization of the investigated reactor.

## 1. Introduction

Because of the strict regulations concerning the environment, clean technologies were developed and particularly electrochemical processes which do not lead to secondary pollution. As an example, the classical process of waste treatment by chemical coagulation generates a lot of mud and induces a secondary pollution due to the chemicals associated to the coagulant [1–3]. In the last decades, progresses have been achieved to improve electrocoagulation process, and nowadays this technique is in full flight and competes with the other classical methods of decontamination [4–6]. Electrocoagulation is an old industrial process of water treatment, because the first use goes back to 1889 [7]. Then in 1909 in the USA, J.T. Harries patented a reactor for the treatment of wastewaters by electrolysis with aluminum and iron electrodes [8], and electrocoagulation of drinking water by using aluminum electrodes was achieved for the first time in the USA [9]. In spite of these successes at this time, electrocoagulation could not equalize other processes known because of its elevated cost [10]. However, some electrocoagulation processes have been developed since

1987 for the treatment of excessive fluoride in water sources [11,12] and for the treatment of industrial wastewaters [13].

The weak use of the electrocoagulation on an industrial scale contrasts with the number of laboratory experiments. Indeed, electrocoagulation has been carried out in the treatment of various aqueous wastes and its interest has been presented in recent reviews [14–22]. In electrocoagulation experiments, a convenient current is imposed on soluble anodes also called sacrificial anodes. Generally, aluminum or iron electrodes are used in an electrochemical cell acting as the reactor. The electrolysis results in the anodic dissolution leading to metal ions ( $\text{Fe}^{2+}$ ,  $\text{Fe}^{3+}$  or  $\text{Al}^{3+}$ ) which are active coagulant precursors involved in the neutralization of the negative charges on the colloids of the effluent. These metal ions also react with the hydroxyl ions generated at the cathode leading to metal hydroxides which favor the formation of flocks which are easily separated by decantation or filtration, depending upon their density [18,23].

They are many reviews dealing with electrocoagulation, but recent papers showed that this electrochemical process is still under development as for instance the use of horizontal-flow continuous

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electrocoagulation [24], a free radical-assisted electrocoagulation [25], the use of an oscillating anode [26], the research of a low sludge settling time [27] and a coupled process for seawater pretreatment [28]. All these recent interests in electrocoagulation induce the need of an increase of treatment capacity using reactor with efficient bipolar electrodes.

Although the principle of the treatment of an effluent is identical for both electrocoagulation and chemical coagulation, the formation of the cationic species involved in the coalescence of colloidal particles is specific in each of these processes. As a matter of fact, during electrocoagulation, the coagulants are obtained *in situ* by the dissolution of the anode, which is not the case for chemical coagulation in which the coagulants are obtained by dissolution of aluminum or iron salts [3].

In its simplest form an electrocoagulation reactor is an electrolytic cell which contains only one anode and one cathode. This easy kind of experiment explains the great number of waste treatments which are rarely developed on a larger scale. In order to increase the treatment capacity of an electrocoagulation process, the electrode surface must be increased. One way is the use of more electrodes in the reactor. Many papers give schemes of these reactors using monopolar or bipolar electrodes [20,29–36]. The bipolar electrodes do not need electrical connections and this is a main advantage *versus* monopolar electrodes where an electrochemical reactor needs to use several electrodes. Various electrocoagulation reactors patented are described, but they are rarely marketed [37–46]. They generally include channels of entry and exit of the effluents, several monopolar and/or bipolar electrodes disposed vertically and connected to an outside source of current [30–36]. In spite of their use, these reactors present various disadvantages: (i) voluminous electrodes, (ii) bad circulation of the effluents, (iii) energy consumption not optimized or a non-homogeneous wear of the electrodes.

New improvements in electrocoagulation cells and electrode configurations were recently published like the use of a combined Al-Fe electrode [47,48], or a rotated anode [49], the coupling of ultrasound irradiation with electrocoagulation [50], a new flow column reactor [51] and the coupling of a magnetic field with iron electrode [52].

The reactor investigated in this paper was conceived to be a scalable pilot with a constant minimization of energy and an increase of the electroflotation phenomena. In the conception, this reactor contains several electrodes with a constant gap between them thanks to the gravity. This reactor is different from a recent one which has been recently published [53]. So in this case, bipolar electrodes were disposed horizontally so that the flows of current and effluent assure uniform consumption of the soluble anodes without deforming these [54]. The reactor was also conceived in order to palliate the shortcomings of the other reactors, by reducing the energy consumption during electrolysis. For reaching this objective, the electric performances of the reactor were studied.

## 2. Materials and methods

### 2.1. Materials

The reactor presented in this paper has a parallelepipedic shape. The material used to achieve the electrocoagulation reactor was expanded polyvinyl chloride (PVC). It is able to resist temperatures until 50 °C, and is stable in acidic and basic media. The thickness of the PVC plates (1 cm) permits to support the pressure of the electrodes and effluents. The different parts of the reactor were assembled with technical glue (Saniplas R). The grids of synthetic polymers which were separators between electrodes were made of polyamide or polytetrafluoroethylene of approximately 0.2 cm of thickness. Fig. 1 shows on a scheme the dimensions of main parts of the reactor.

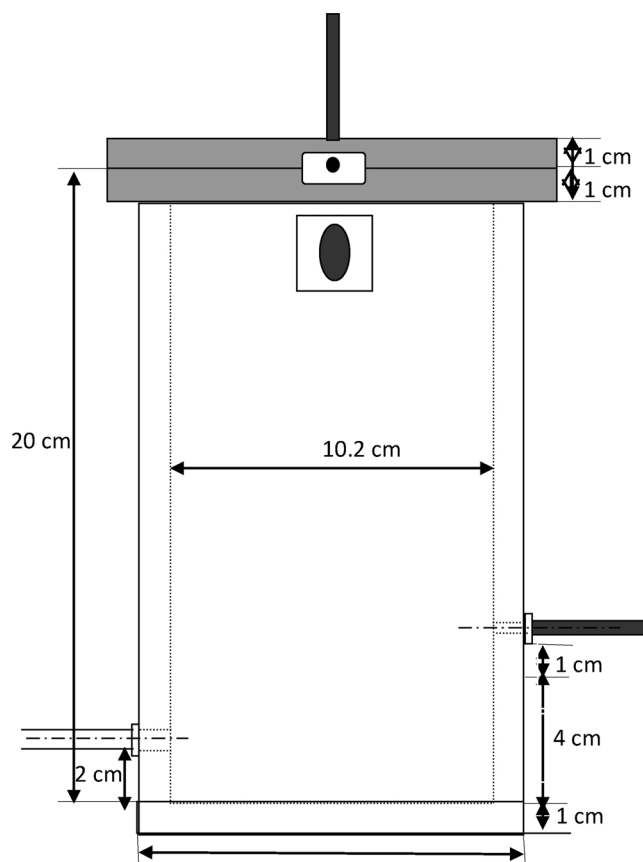


Fig. 1. Main dimensions of the body of the reactor.

### 2.2. Electrodes

Schematic presentations of electrodes are given in Fig. 2. The bipolar electrodes were made of iron of dimensions 10 cm × 10 cm × 1 cm or 10 cm × 10 cm × 0.5 cm. These electrodes are bored holes to allow the passage of the effluent in the reactor. The diameters of these holes were dependent upon the thickness of the electrodes. The electrodes of 1 cm thickness had 2 holes of 1 cm in diameter, while those of 0.5 cm thickness had 8 holes of 0.5 cm in diameter (Fig. 2a and b). Whatever the electrodes, the surface of the holes was 1.59% of the electrode surface. The terminal electrodes which were connected to the current generator were made of graphite (Fig. 2c).

### 2.3. Reactor and electrocoagulation experiments

The current was provided by a regulated Micronics System DC power supply (1 A/300 V). A schematic presentation of the reactor is given in Fig. 3. Ten iron electrodes, as described previously, were piled up horizontally in the reactor in order to achieve a bipolar configuration of the intermediate electrodes. In this system, the electrical contacts were created on the graphite plate (16) and the sliding metallic stem (9), directly connected to the generator. The two terminal monopolar electrodes (2) of the stacking were used as anode and cathode thanks to their connection to the stem (9) and the graphite plate (16). The intermediate electrodes (11) between terminal electrodes were bipolar electrodes. This assembly is simple and facilitates the maintenance of the device, because it is easy to modify the number of bipolar electrodes in the reactor.

The installation of the electrodes was made as follows: the electrodes were laid on a graphite plate (16) with dimensions 10 cm × 10 cm × 1 cm, also pierced of holes (whose diameter is 1 cm),

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