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The effect of internal impellers on mixing in an electrochemical reactor with rotating rings electrodes

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ABSTRACT

An electrochemical reactor with rotating electrodes has been used to to remove pollutants from aqueous media. Poor mixing and passivation of electrodes surface have been identified as the major drawbacks for the operation of this type of reactors because they adversely affect the critical reactions that take place in the liquid bulk. In this work, three different reactor configurations are proposed and their performance on reactor mixing time and process costs is evaluated. CFD simulations, based on previously validated models, were used to observe mixing inside the electrochemical reactors. Three different arrays were used for the rotating rings electrodes: (a) without impellers, (b) with four internal vertical fins and (c) with a pitched blade central impeller. Power consumption, torque, and parameters such as turbulent intensity, mixing time, among others, were evaluated for all configurations. The reactor with no impellers showed two separated zones of recirculation, reducing the reactor mixing and performance. The reactor with pitched blade impeller, showed no significant improvement due to its low central impeller pumping capacity at low rotational speeds (150 rpm). The array with 4 vertical fins operated at 130 rpm presented the highest flow/power ratio, and the lowest mixing time.

1. Introduction

The hexavalent chromium (Cr(VI)) contained in the electroplating and galvanizing wastewaters is a major source of environmental contamination [1,2]. If not properly treated, wastewaters from these industrial processes can contaminate groundwater and cause serious health problems due to Cr(VI) high toxicity. Several methods have been used to remove Cr(VI) from wastewaters, namely, the use of bisulfite, evaporation, ion exchange, and ferrous sulfate, among others. As an alternative to these treatments, the electrochemical treatment has proved to be an effective method for Cr(VI) reduction from wastewaters. By using this technique, very low levels of concentration can be reached [3]. During the electrochemical treatment, Fe(II) is released from the anode reducing Cr(VI) into Cr(III) in the bulk liquid as shown in Eqs. (A)–(C) [4].

(a) Cr(VI) reduction through formation of ferrous ions Fe(II) as a result of oxidation at the steel anodes (solution):

$$6Fe^{2+}{}_{(aq)} + Cr_2O_7{}^{2-}{}_{(aq)} + 14H^{+}{}_{(aq)} \leftrightarrow 6Fe^{3+}{}_{(aq)} + 2Cr^{3+}{}_{(aq)} + 7H_2O_{(l)} \text{ (A (I)}$$

(b) Cr(VI) reduction at the cathode:

$$Cr_2O_7{}^{2-}{}_{(aq)} + 7H_2O_{(l)} + 6e^- \leftrightarrow 2Cr^{3+}{}_{(aq)} + 14OH^-{}_{(aq)} \text{ (B} \quad (I)$$

(c) Fe(III) reduction to Fe(II) at the cathode:

$$Fe^{3+}{}_{(aq)} + e^- \leftrightarrow Fe^{2+}{}_{(aq)} \quad (C)$$

Due to the Cr(VI) electrochemical reduction to Cr(III) is mainly carried out in the solution, mixing is a very important factor in the process.

At the same time oxide film can be formed on the surface of the electrodes (passivation effect). Therefore, to increase the reaction

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rate in the bulk liquid and mitigate the electrode passivation, efficient mixing must be maintained in the reactor. To this purpose, an electrochemical reactor with rotating ring-shaped electrodes, as shown in Fig. 1(a), was designed and studied in previous works [5]. The Cr(VI) was removed from 500 mg/L to concentrations less than 0.5 mg/L, this means that there is a the reduction Cr(VI) in to Cr(III) efficiency higher than 99.9%. The operation conditions were: voltage of 2.75 V, current density of 190 A/m^2 and pH of 1.5. The agitation generated by the rotational movement of the electrodes in the reactor, enhanced mixing and reduced the passivation oxide film on the electrode, thus decreasing the processing time. The effect of the rotating speed was evaluated, and it was found that as the rotational speed increased, the treatment time was reduced. However, at higher rotational speeds (i.e., 150 rpm and 230 rpm) there were no important differences in the processing times because the fluid behavior in the central region of the electrodes rings was barely affected by the rpm increment [6,7]. In order to enhance the agitation of the liquid and ensure optimal conditions for the electrochemical process, the electrochemical reactor presented in this work was modified to include impellers inside the central region of the rotating rings electrode. The intention was to generate greater and more homogeneous mixing and turbulence throughout the reactor specifically intended to create a mixing flow field circulating downwards inside the rotating rings and upwards in the outer vicinity of the electrodes. For that purpose, two types of impellers were added to the electrodes array; one with a 45° pitched blade impeller mounted on the electrodes shaft (Fig. 1(c)) and a set of four internal fins symmetrically disposed directly on the inner side of the rings (Fig. 1(b)). However, both solutions demand an additional input of energy and therefore, their performances were compared against the original arrangement of rotating rings, based on a constant power consumption constraint. Power consumption, axial velocity, vorticity magnitude, turbulent intensity, mixing time, power number, pumping and circulation number were evaluated for each case.

2. Materials and methods

Fig. 1 shows the three types of arrays tested: with no impellers (a), with four fins (b) and with a central 45° pitched blade impeller (c). The electrochemical reactor capacity was 18 L; the reactor consists of a cylindrical tank with four baffles arranged symmetrically and a set of 14 iron steel rings allocated in a sequence of one cathode followed by one anode. The electromechanical connection of the anode rings was made with a pair of external bar allocated 180° apart from each other. A similar array of bars was disposed 90° apart from them to connect the cathode components. Both arrays produce mixing outside the ring electrode. Such bars produce

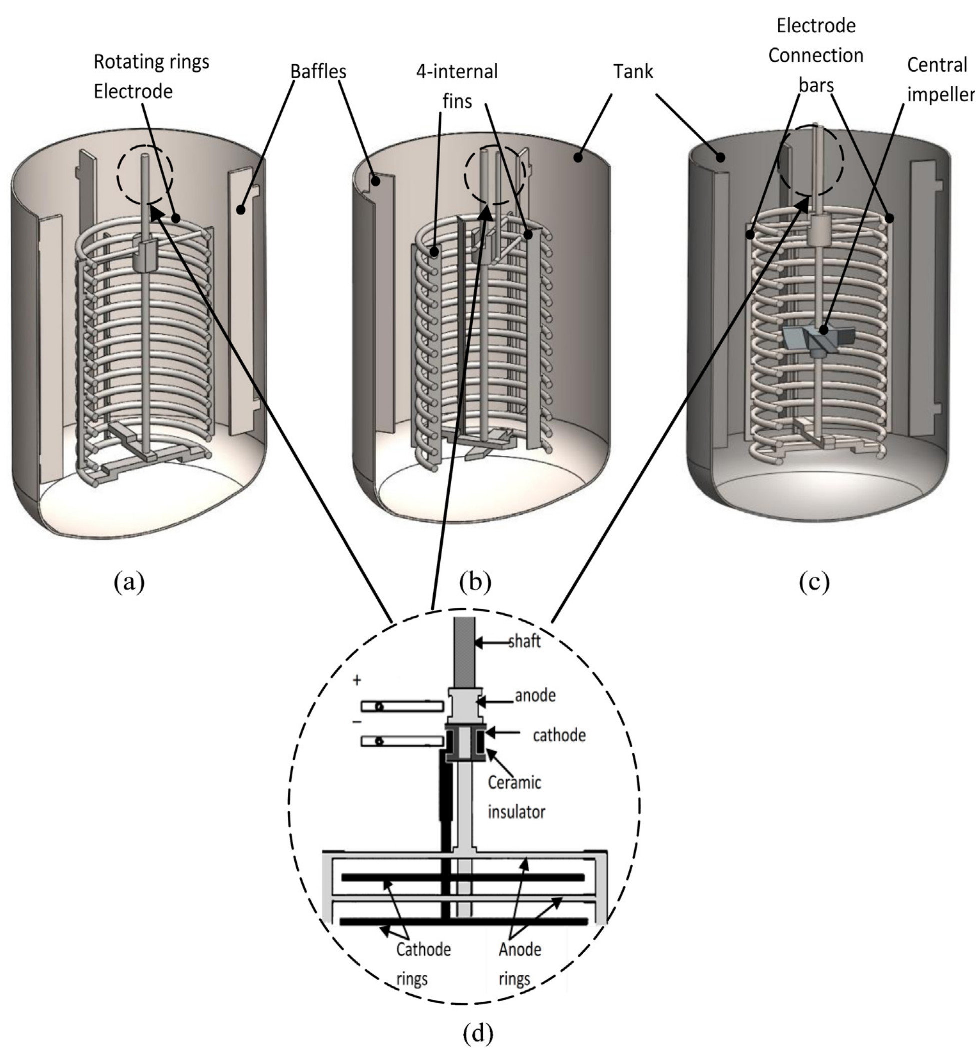

Fig. 1. Electrochemical reactor (a) with no impellers, (b) with four internal fins, (c) with a central 45 pitched blade impeller and (d) detailed electrodes connection.