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Effect of Configuration on Mass Transfer in a Filter-press Type Electrochemical Cell*

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Abstract Effect of configuration (structure of electrode, interelectrode gap, positions of inlet and outlet, volume of the cell and additional nets) on mass transfer characteristic of a filter-press type electrochemical cell has been studied. The mass transfer coefficients on the electrodes were obtained by using the well-known technique based on the determination of limiting diffusion current. It is found that mass transfer coefficients with mesh electrode are greater than that of with plate electrode. Mass transfer coefficient is decreased with interelectrode gap. While interelectrode gap achieved a certain value (7 mm), mass transfer coefficient is steady, no more declining. Mass transfer characteristic for different positions of inlet and outlet are different and dimensionless number groups correlated equations are obtained by experiment. Mass transfer characteristic is the best when inlet located on the top and outlet on the bottom of the cell respectively. While magnified the volume of the cell to eight times, mass transfer characteristic changes little. Mass transfer characteristic without nets is lower than that of with additional nets in the exit region, but higher than that of with additional nets in the entry region.
Keywords mass transfer characteristic, mass transfer coefficient, filter-press type electrochemical cell, limiting current

1 INTRODUCTION

Traditional treatment technique is not of content with higher and higher requires of environmental protection for organic wastewater [1], which has abundant source, many sorts, low biodegradation and high toxicity. Studying and developing efficient technology for organic wastewater treatment have become the hotspots of research in both industry and academe [2].

Recently, electrochemical oxidation method is becoming a new alternative for wastewater treatment and replacing the traditional processes in view of electro-generated hydroxy radical and other strong oxidant, which may degrade or even mineralize toxic and non-biodegradable organic pollutant efficiently. Many researchers have paid a great attention to electrochemical oxidation. But so far, electrochemical oxidation technology has not been commercialized because of low current efficiency, high-energy consumption and large operating costs. Consequently, how to enhance mass transfer characteristic and current efficiency, develop efficient electrochemical cell for organic wastewater treatment is still a very urgent problem [3].

With the development of expanding anode [4] and porous electrode [5], mass transfer characteristics of a filter-press type electrochemical cell will be improved. In view of their uniformity of potential distribution, strong reliability, simple structure, flexible modularity, adaptability to monopolar or multipolar, low maintaining costs, facility of adding solid electrode, promoter and baffles, easy expelling of gas, control of temperature and flow, the traditional filter-press type electrochemical cell applied to organic wastewater treatment has attracted much attention [6, 7].

Two different mechanisms can be distinguished for electrochemical oxidation of organic pollutant: (1) Direct anode oxidation, electrochemical combustion $[R + M\ (OH\cdot) \rightarrow mCO_2 + nH_2O + M]$ and electrochemical conversion $(R + MO \rightarrow M + RO)$ which took place on electrodes. Electrode reaction is the controlling step, and oxidation process followed with evolution of gas, which not only make current efficiency decline, but also lessen the actual surface of electrode. Since the electrode surface is covered with bubbles, which preventing electrode reaction happening, and then resulting in electrode potential enhancing [8]. The component, form and structure of the electrode have effect on direct anode oxidation. (2) Indirect anode oxidation occurs via mediators, which are continuously generated on anode. For indirect anode oxidation, mass transfer is the controlling-step, stirring and circulation of solution are in favor of the process. Hydrodynamics on the surface of electrode, mass transport characteristics, stirring rule and effect of electro-generated gas in bulk solution are primary problems.

For the real organic wastewater, because of its low concentration and low conductivity, mass transfer takes on the important role. Thus it can be seen, study of mass transfer is the basic problem for process optimizing and reactor optimizing in the course of organic pollution electrochemical oxidation degradation to industry.

According to literatures, research on mass transfer characteristic of electrochemical cell has three aspects: (1) determination of basic parameters (surface area per unit cell volume, mass transfer coefficient, *etc.*) [9–11]; (2) research on the influence of the inner structure and establishment, such as positions of inlet and

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outlet, electrolyte channels, turbulence promoter and baffles on mass transfer characteristic [12–19]; (3) set-up theory model [20]. These works are significant to understand objective property and design of electrochemical cell, but practical circumstances and interaction between electrochemical reaction process and transport process are not reflected completely, due to the particularity of electrochemical reaction kinetic for a given system. By now, there are few reports on the study of correlated parameter, mass transfer rule and model of filter-press type electrochemical cell with electrochemical oxidation degradation mechanism, characters of non-biodegradable organic pollution, and general rule of mass transport.

The purpose of the present work is to study the effect of the configuration factors (structure of electrode, interelectrode gap, positions of inlet and outlet, volume of the cell and additional nets) on mass transfer characteristic.

2 THEORY

Mass transfer characteristics of filter-press type electrochemical cell can be considered using a model reaction, namely, the redox reaction between ferricyanide ion and ferrocyanide ion at Ru-Ti-Sn/Ti ternary oxide-coated anode (Ru-Ti-Sn/Ti) and Ti cathode, by measuring the limiting current over a range of flow rate of electrolyte. The reaction has been widely used to characterize mass transfer in electrochemical reactors [13–15]:

Cathode: $$Fe(CN)_6^{3-} + e^- \rightarrow Fe(CN)_6^{4-} \quad (1)$$

Anode: $$Fe(CN)_6^{4-} \rightarrow Fe(CN)_6^{3-} + e^- \quad (2)$$

Under full mass transfer control, that is, in the limiting current plateau region, the current is related to the global mass transfer coefficient k (m·s^{-1}):

$$k = \frac{I_{\mathrm{lim}}}{zFA_eC_b} \quad (3)$$

where I_{lim} is the limiting current (A), A_e is the electrode area (m^2), z is the number of electrons transferred, F is the Faraday constant (96482 C·mol^{-1}), and C_b is the concentration of the electroactive species (ferricyanide ion) in bulk of the electrolyte (mol·L^{-1}).

3 EXPERIMENTAL

The experimental apparatus consisted of a magnetic pump, an electrolyte reservoir, a constant temperature control water bath, a rotameter and longitudinal filter-press type electrochemical cell, as depicted in Fig. 1. After keeping at temperature for 20 min in electrolyte reservoir, electrolyte flowed through the rotameter, entered the cell, and then back to the electrolyte reservoir placed in constant temperature water bath. Magnetic pump and rotameter are used to modulate volume flux between 10–100 L·h^{-1}. Temperature of electrolyte was constant at 25°C.

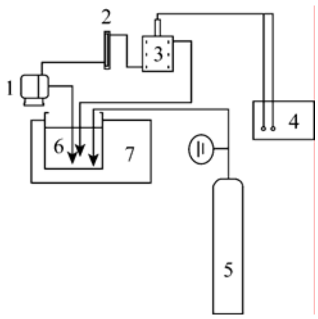

Figure 1 Experimental device and flow schematic diagram
1—magnetic pump; 2—rotameter; 3—electrochemical reactor; 4—DC power; 5—nitrogen cylinder; 6—electrolyte reservoir; 7—constant temperature water bath

There are two experimental filter-press type electrochemical cells made of colorless PMMA plates, whose size were shown in Table 1. Fig. 2 shows the schematic diagram of the experimental cell which has two inlets and four outlets. During the experiment, taking the example of the smaller one, inlet 1 pairs with outlet 1 or outlet 2; when inlet 2 with outlet 3 or outlet 4. The internal diameter of the inlet and outlet tubes is 5 mm.

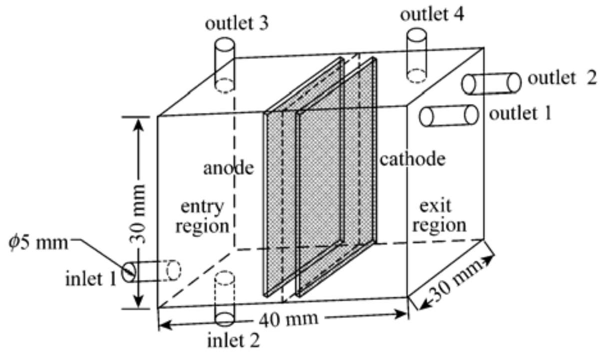

Figure 2 Schematic diagram of inlet and outlet in a filter-press type electrochemical cell

Table 1 Sizes of electrochemical cell and hydraulic diameter at different inlet-outlet system

Dimension of electrochemical cell	Inlet-outlet pairing	Cross section	Hydraulic diameter d_e/mm
30 mm×30 mm×40 mm	inlet 1 outlet 1 or oulet 2	30 mm×30 mm	30
	inlet 2 outlet 3 or oulet 4	30 mm×40 mm	34
60 mm×60 mm×80 mm	inlet 1 outlet 1 or oulet 2	60 mm×60 mm	68
	inlet 2 outlet 3 or oulet 4	60 mm×80 mm	68

Note: d_e=4A/P, A is the across section area of the duct (mm^2) perpendicular to the flow direction, P is the wetted perimeter (mm) of the duct.