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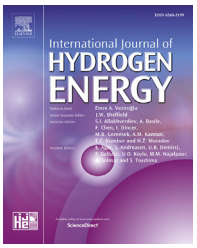

An experimental investigation of convective mass transfer characterization in two configurations of electrolysers

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ABSTRACT

This work is devoted to the study of hydrodynamics behavior and mass transfer performance in water electrolysis processes, two configurations of containers and electrodes are studied in laboratory experiments under different current densities, the platinum (0.2 mm in diameter) in an acidic environment (36% CH_3COOH) as electrode material, surrounds the sides of the container in horizontal mode. The system is studied using particle image velocimetry (PIV), microscope enhanced visualization. The experimental results show that the velocity distribution in most regions of electrolyser is dominated by two asymmetry bubble buoyancy induced flow patterns. The greater reaction rate of water electrolysis and better mass transfer arise in the smaller space of electrodes. By comparing hydrodynamic behavior in two containers with different current densities, hydrogen production, bubble-driven convection and convective mass transfer increase at higher current densities, however, this increase is not linear, the interaction mechanisms are analyzed on mass transfer, electrochemical reaction and bubble effect. Results facilitate the understanding and the design of the transport phenomena in electrolyser.

Introduction

Hydrogen, the clean energy carrier with the highest specific energy density, is considered as the best alternative to fossil fuel in order to ensure sustainability of energy [1]. This is a renewable and sustainable source, which can obtain high hydrogen purity via electrolysis. Hydrogen produced by water electrolysis has many advantages such as high purity, simple and green process.

On purpose to realize good efficiency of water electrolysis, many researches have been conducted so far, mainly focused on decrease of reversible potential and overvoltage by realizing water electrolysis under developing new electrode materials [2–4].

However, from the point of view of hydrodynamic and two-phase flow, during operation of gas-evolving electrodes, a fraction of the electrode surface is covered with adhering gas bubbles, which are known to exert substantial effect on mass and heat transfer, on overpotential, on limiting current density and on ohmic resistance. For this reason, many investigations were conducted experimentally and numerically.

Vogt [5] studied the relationship expressing the bubble coverage with the current density, it not only applies to small

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values of the bubble coverage but also takes into account the decay of the nominal current density at very large values.

Jianu et al. [6] pointed out that the increase of volume fraction of hydrogen or oxygen bubbles between electrodes, i.e. increase of void fraction, would increase electric resistance in aqueous solution, resulting in efficiency decrease of water electrolysis.

Haug et al. [7] investigated the influence of several alkaline water electrolysis process conditions, namely electrolyte flow rate, concentration, temperature and electrolyte management, on the resulting gas purity.

Schilling et al. [8] reported that a two-phase mixture model is used to simulate the bubbly flow resulting from typical water electrolysis process. A numerical mixture model is used in order to resolve the two dimensional bubble plumes evolving along the electrodes. Their results demonstrated that an additional forced flow significantly reduces the bubble plume thickness.

Hreiz et al. [9] carried out an experimental investigation of the hydrodynamics in a laboratory-scale Vertical Plane Electrode Reactors with Gas Electrogeneration reactor for three different current densities. The calculated velocity fields provide an overall picture of the flow behavior, and two-phase flow was simulated using the two-way momentum coupling Euler–Lagrange CFD approach.

Hydrodynamics characteristics of hydrogen evolution process through electrolysis has been simulated by Askary et al. [10] to predict the flow characteristics, gas release rate and void fraction distribution in electrochemical cells. The hydrogen production rate increases as the electrolyte flow velocity increases due to the consequent decrease in the residence time of bubbles on the electrode. The formulation of variable bubbles diameters of the hydrogen gas phase plays an important role in the simulation improvements.

Abdelouahed et al. [11] studied the hydrodynamics of electrogenerated oxygen bubbles for iron electrodeposition in alkaline solutions. Distributions of bubble velocities and void fractions in the anode-to-anode space were determined through experimental observations and CFD simulations to investigate the behavior of gas bubbles in the anode gap.

In addition, some bubbles remain attached to the surfaces of electrode or dispersed in the electrolyte during water electrolysis, which leads to large Ohmic voltage losses.

A possibility to increase the rate of hydrogen produced was mentioned by Wang et al. [1] that water electrolysis was carried out galvanostatic under a super gravity field.

The imposed magnetohydrodynamics (MHD) electrolyte flow around the evolving hydrogen bubble was studied by Dominik [12] to clarify the effect on the detachment of the bubble from the electrode and the mass transfer toward the electrode. The results demonstrated that the MHD flow imposes only a small stabilizing force on the bubble. However, the observed secondary flow enhances the mass transfer toward the electrode and may reduce the local supersaturation of dissolved hydrogen.

Dominik [13] confirmed by numerical and experimental investigation that a significant reduction of the bubble growth time and detachment diameter with increasing magnetic induction, which is known to improve the efficiency of water electrolysis.

Most of the studies presented above are focused on electrode materials, process intensification and new electrolytic cell, which is usually alkaline solution, fewer studies is devoted to electrolyte with acidic water electrolysis water electrolysis.

Previous investigations have experimentally looked at gas bubbles behavior in narrow channels between vertical electrodes, and in conditions corresponding to industrial processes, few experimental or numerical results in the literature discussing the hydrodynamic behavior on non-narrow reactors, since the electrochemical reactor's geometry has a strong impact on the flow field, in most papers, the influence of the reactor configuration on the hydrodynamics in the reactor is not recognized in the literature survey part, which often leads to systematic assessment errors and makes it difficult to extract general information on the flow characteristics [14].

Flow field of the electrolyte determines the mass (ionic) transfer, temperature distribution and bubble sizes, bubble detachment and rising velocity, and in turn influence the current and potential distributions in the electrolysis reactor, the subject is complicated and still not fully explained, further research is required.

In order to evaluate different electrolysis systems, it is necessary to relate a number of practical parameters to the performance of different electrolysers. The important parameters are reactor configurations and operating conditions. Therefore, studies dealing with the hydrodynamics in acidic water electrolysis water electrolysis containers have considered in this paper with different current densities and reactor configurations as illustrated in Table 1. The configuration is not encountered in industrial processes, but has often been addressed in order to characterize more precisely some fundamental aspects of the flow. To the best of our knowledge no such attempt has been made to date in the literature.

Meanwhile, this study also clarifies the mechanisms of both the bubble-driven and thermal-driven convection, which affect the growth and detachment of bubbles and the mass transfer near the electrode. To our knowledge, there is no report in literature that systematically quantifies the effect of bubble-driven and thermal-driven convection.

The present study aims to provide a discussion of the combined bubble driven convection, bubble blockage and Joule dissipation effect on the mass transfer, so as to understand the relationship between electrochemistry and hydrodynamics in reactor. The investigation will measure the global behavior of bubble driven motion of electrolyte fluid in the container, and bubble layer, through particle image velocimetry (PIV), CCD camera in the PIV system and microscope enhanced visualization.

Table 1 – Geometry of electrolysis containers and electrodes.

	Container (cm)			Horizontal electrodes (cm)		
	Height H	Width W	Depth D	Space W	Height h	Length L
A	10	20	40	20	4.5	30
B	15	12	30	12	8	24

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