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Electrolytic Hydrogen Production with Coaxial Cylinder Electrolyzers: A CFD Study

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I. Introduction

The ongoing global energy crisis, marked by falling fossil fuel supplies, increased demand, and escalating greenhouse gas emissions, has intensified the need for sustainable, effective, and environmentally friendly energy alternatives. Hydrogen stands out for its versatility and environmental benefits as an energy carrier, offering the potential to decarbonize sectors such as transport, industry, and electricity generation. The widespread adoption of hydrogen depends on the development of production methods that are efficient, cost-effective, and environmentally benign. Traditional hydrogen production methods, like gasification and pyrolysis, are carbon-producing and not considered environmentally sustainable. Conversely, water electrolysis, represents a green approach to hydrogen production that aligns with environmental conservation goals. This paper examines the computational fluid dynamics (CFD) analysis of alkaline water electrolysis using coaxial cylinder electrolyzers. It seeks to assess the performance and feasibility of this innovative design, which holds several potential benefits over conventional planar electrolysis systems. The coaxial cylinder design can enhance the performance of AWEs due to its increased electrode surface area, improved mass transfer, uniform electric field distribution, scalability, effective thermal management, and reduced ohmic losses [1]. These features could contribute to greater efficiency and reduced production costs, bringing sustainable hydrogen production within closer reach and increasing its viability as an energy source alternative to fossil fuels. This paper presents CFD analyses of coaxial concentric cylinder AWEs to illustrate the potential benefits that this type of electrolyzer could offer.

II. Coaxial Cylinders AWE Model Description & Analysis

This analysis focuses on studying the operational and performance dynamics of a cylindrical-shaped AWE that is 100 mm in length. The model comprises five coaxial cylinders, two cathodes, two separators, and a single dual polarization anode. Table 1 shows the input parameters used in the model. The design configuration involves a vertical upward flow by positioning the alkaline solution inlet at the bottom and the outlet at the top. A 1 mm thick separator is inserted between the two chambers where the gases are produced. The electrolyzer's compact design is intended to optimize the distribution of electric current within the electrolysis cell. Figure 1 illustrates the proposed 3D structure of the AWE. The cathodes are highlighted in red and are positioned to maximize hydrogen production efficiency. The anode, highlighted in blue, is located in the center and acts as the anode for the cathodes on both the inner and outer sides of the coaxial cylindrical model. Separators, shown in yellow, are placed between the anode and each cathode to effectively partition the electrolytic space. The electrolyte volume is indicated in light grey. The model also incorporates an upward fluid flow along the z-axis, with the inlet at the bottom and the outlet at the top, ensuring a consistent and efficient path for the electrolyte flow through the system.

Table 1. Model Input Parameters

Parameter	Value
Inlet Velocity [m/s]	0.01
Bubble Diameter [m]	5 x 10-5
Operating Voltage [V]	2-32
Reference Pressure [Pa]	101,325
Inlet Temperature [Co]	25
KOH Concentration [mol/m3]	6000
Separator Porosity	0.5

In the study, three modules from COMSOL Multiphysics were employed to construct a detailed model of the system for electrolytic hydrogen production. The “Hydroxide Exchange Water Electrolysis” model was utilized to simulate the electrochemical reactions involved in hydrogen production from water electrolysis. This model aids in understanding the reaction mechanisms and shows the polarization curves for the AWE. The second is the “Euler-Euler Two Phase Fluid Flow” model was selected for its capability to simulate the two-phase flow of the liquid electrolyte and the evolved gas bubbles [2]. This is essential for analyzing the interactions between evolved gas bubbles and the surrounding liquid electrolyte, which greatly impact the AWE performance [3].

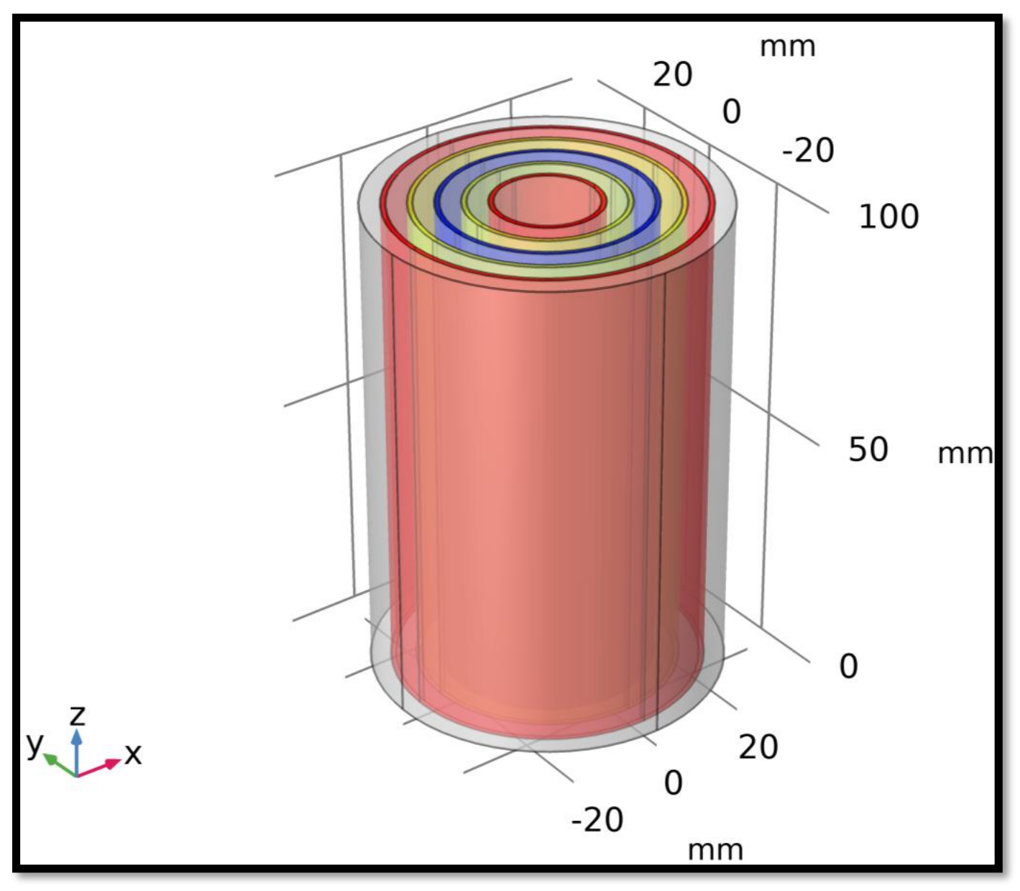

Figure 1. Simulation model

III. Results & Discussion

Figure 2 (a) displays the results for different gap sizes. Reducing the gap size tends to lower the electrolysis potential, indicating increased efficiency. However, there is a point at which further reducing the gap size does not improve efficiency due to the negative impact of increased gas bubbles. Figure 2 (b) displays the hydrogen volume fraction for a range of electrode current densities. It shows that hydrogen production increases with higher current densities. This increase aligns with electrochemical principles, which state that higher current densities speed up the reactions that produce hydrogen. However, increasing the current density not only boosts hydrogen production but also affects the AWE efficiency and operational costs. At higher current densities, electrodes dissipate more energy, leading to elevated temperatures. This can increase energy consumption and present heat management challenges. Thus, managing these aspects is crucial to optimizing hydrogen production and maintaining the efficiency of the system. The coaxial cylindrical shape of the AWE aids in managing these thermal challenges more effectively.

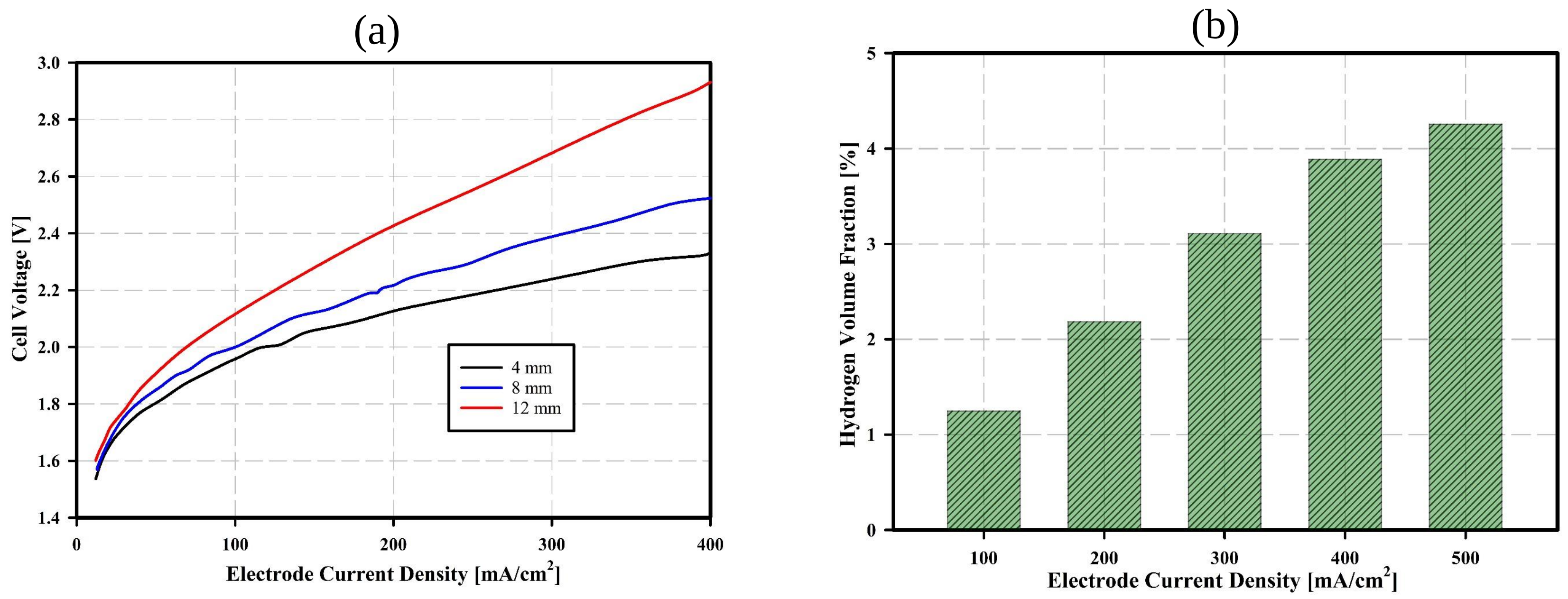

Figure 2. (a) Polarization curves, (b) Hydrogen volume fraction vs current density

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