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Performance analysis of direct Black Sea hydrogen sulphide (in artificial sea water)/hydrogen peroxide fuel cells

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ABSTRACT

This study aims to analyse fuel cells constructed with the artificial Black Sea water containing hydrogen sulphide (H_2S) as fuel. A parametric analysis of the performance of the direct H_2S/H_2O_2 fuel cells is conducted to investigate the effect of certain parameters on the cell's operation. The effects of the concentration of anolyte and catholyte and the pH of the anolyte are investigated. Increasing the solution pH leads to increased HS^- concentration of the anolyte, resulting in higher cell power. The concentration of H_2O_2 has a greater impact on the cell's power density than the other parameters investigated. In the present study, the fuel cell can yield a power density of 23 mW cm^{-2} at a cell voltage of 300 mV and current density of 75 mA cm^{-2}.

Introduction

Hydrogen sulphide (H_2S) is an inorganic pollutant due to its corrosive, extremely toxic and highly reactive nature. H_2S is observed in anaerobic sea waters and industrial wastewaters. Gas containing hydrogen sulphide is produced in heavy oil industries and during coal gasification as an undesirable by-product. H_2S is also produced by sulphur-reducing bacteria in anaerobic sea waters, such as those in the Black Sea, the Cariaco Basin and the Framvaren Fjord. The Black Sea is anaerobic and is the largest anoxic basin in the world, with an area of 423,000 km^2 [1].

Petrov et al. investigated the hydrogen production of Black Sea water. This process was evaluated in terms of the design of the process and the plant, energy requirement, capital investment, plant efficiency and product cost. It is not feasible because of the high cost of the installed equipment [2].

Hydrogen sulphide is an electron donor, due to its S^{2-} moiety and hydrogen-carrying tendencies. It is ionised in basic electrolytes to form disulphide ions according to the following reaction:

$$2H_2S \rightarrow 2HS^- + 2H^+ \quad (1)$$

The disulphide ions are oxidised to free sulphur and electricity as follows:

$$2HS^- \rightarrow S^0 + H_2S + 2e^- \quad (2)$$

The electrochemical oxidation of H_2S in the liquid phase via a fuel cell is another approach. For example, Microbial Fuel

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Cells (MFCs) might be able to produce electricity directly from many degrading liquid organic and inorganic compounds in wastewater, particularly sulphides. The sulphides are converted into elemental sulphur, generating electricity when the MFCs oxidise the sulphides [3,4]. Moreover, Solid Oxide Fuel Cells (SOFC), in which gas-phase H_2S is oxidised as a fuel, have been developed. In principle, H_2S can be converted to electrical energy with only sulphur and water as by-products in a fuel cell constructed with an ion-exchange membrane at 850 °C [5–8].

Electric power can be produced from hydrogen sulphide by anodic oxidation via electrochemical cells. Fuel cells are electrochemical devices that convert chemical energy into electricity using hydrogen or chemicals containing hydrogen, such as methanol, ethanol, and borohydrides. H_2S can also be used as an energy carrier in fuel cells [6]. Consequently, a galvanic cell having the anode/membrane/cathode in contact with an electrolyte, which contains hydrogen sulphide, could be a source of electric power.

Furthermore, in our previous studies, the H_2S Black Sea water fuel cell was revealed as a novel fuel cell. In this type of fuel cell, the H_2S was electro-oxidised in basic artificial sea water using a suitable anode material [9–11]. We investigated the electrochemical behaviour of a nickel electrode in the ASW + Na_2S solution and demonstrated the catalytic activity of Ni electrodes for oxidising HS^-. In the present study a fuel cell target was constructed with basic artificial Black Sea water using a nickel anode material, and the effects of the parametric variables, such as the pH, concentration, anolyte and catholyte, on the performance of the H_2S/H_2O_2 fuel cell were determined.

Experimental

Preparation of the artificial sea water

Artificial sea water (ASW) was prepared by dissolving salts (23.985 g NaCl, 5.029 g $MgCl_2$, 4.011 g Na_2SO_4, 1.1409 G $CaCl_2$, 0.6986 g KCl, 0.1722 g $NaHCO_3$, 0.1 g KBr, 0.0143 g $SrCl_2$ and 0.0254 g H_3BO_3) in 1 L of distilled water (ASTM D 1141-90). Sodium sulphide stock solutions were prepared by dissolving reagent grade $Na_2S{\bullet}6H_2O$ in the ASW. The Na_2S stock solution's concentration was determined with a standard titration method using excess iodine solution. The pH was adjusted dropwise with NaOH. It was kept at 14 with 1 M NaOH solution and at >14 with 6 M NaOH solution. Under the present electrolyte conditions, HS^- ions are expected to be predominant.

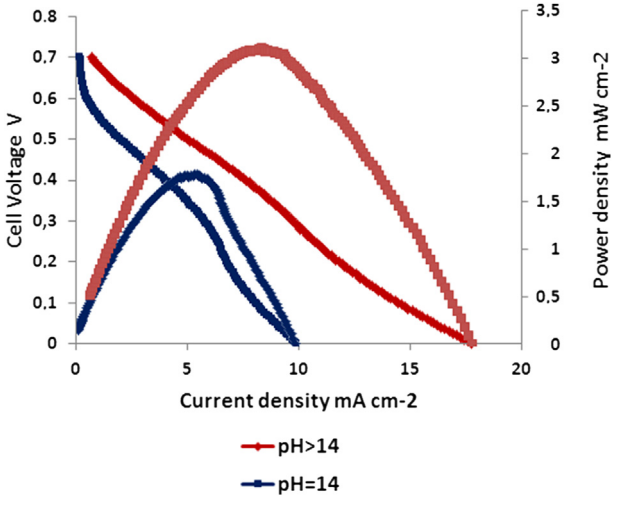

Fig. 1 – Effect of anolyte pH (anolyte: 1 mmol Na_2S, catholyte: 3 M H_2O_2 at 25 °C).

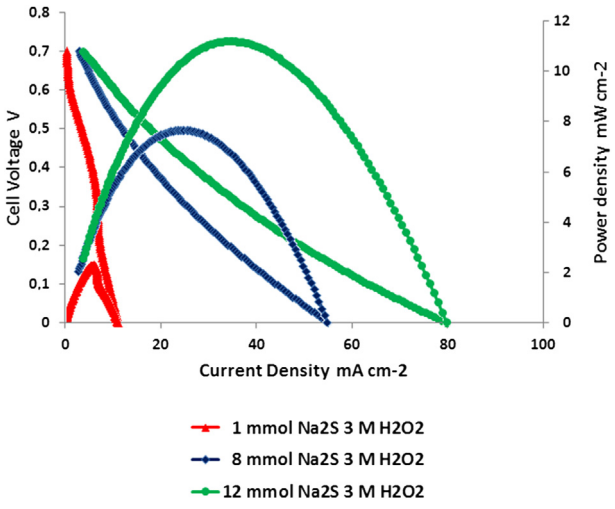

Fig. 2 – Effect of the Na_2S concentration on the cell performance (catholyte: 3 M H_2O_2, at 25 °C).

Construction of the fuel cell

The single passive cell used in this study was made of plexiglass material [9]. The cell consisted of two plates without any specific flow field for liquid diffusion. Reservoirs of 6 ml for liquid fuel/oxidant were constructed. The geometric area each electrode (anode: Ni gauze 100 mesh (from Alfa Aesar) and cathode: Pt plate from Aldrich) was 4 cm^2. The fuel and

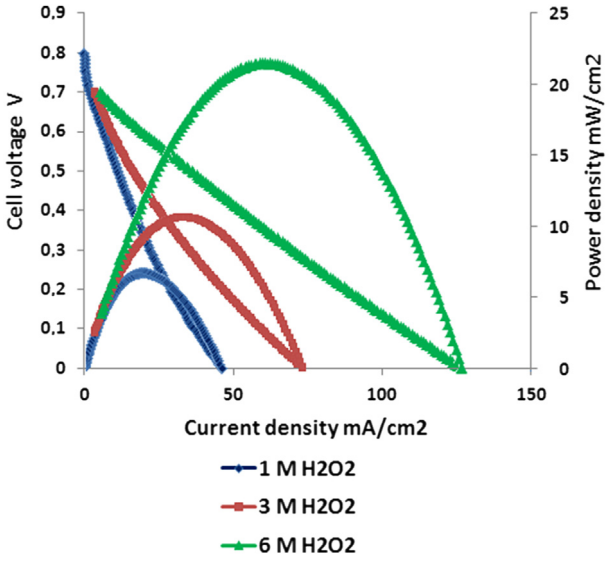

Fig. 3 – Effect of H_2O_2 concentration on the cell performance (anolyte: 12 mmol Na_2S, at 25 °C).