INTERNATIONAL JOURNAL OF HYDROGEN ENERGY XXX (2017) 1–12

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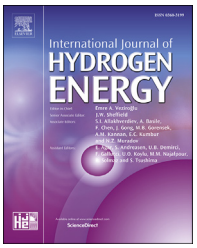

In-operando optical observations of alkaline fuel cell electrode surfaces during harsh cycling tests

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ARTICLE INFO

Article history:
Received 13 March 2017
Accepted 3 July 2017
Available online xxx

Keywords:
Alkaline
Fuel cell
Durability
In-operando
Cycling
Degradation

ABSTRACT

The durability of low-cost fuel cells is one of the last technical challenges to be overcome before the widespread adoption of fuel cells can become a reality. Most research concentrates on polymer electrolyte membrane or solid oxide fuel cells in this topic with little published regarding the durability of recirculating liquid electrolyte alkaline fuel cells. In this paper we present an investigation into the durability of this fuel cell variant under harsh load cycling, air starvation and fuel starvation conditions. In the study, making use of the high ionic conductivity of the electrolyte, a novel rig design was utilised, which allowed the surfaces of the electrodes to be constantly monitored optically during the experiments. This demonstrated the good physical durability of the anode during the test protocols whilst highlighted the instability of the manganese-cobalt spinel cathode, used in this study, during the air starvation protocols. The load cycling stability of the alkaline fuel cells used was found to be good with the standard configuration giving only around a 2.7% voltage degradation at 100 mA cm^{-2} operating point over 8000 load cycles.

Introduction

Hydrogen fuel cells are efficient clean energy conversion devices poised for widespread implementation, however, when applied to most real world applications where cycling conditions are experienced high lifecycle costs remains a major obstacle to commercialisation. Alkaline fuel cells (AFC) are attractive for their greater electrical efficiencies, up to 60% in moderate conditions [1] compared to other fuel cell types. This is largely the result of excellent oxygen reduction kinetics in alkaline media compared with acidic conditions such as those in polymer electrolyte membrane fuel cells (PEMFC) [2]. Secondly, a significant advantage of AFCs is the wide range of electrocatalysts (including low cost, non-noble metal based materials) which can be used for both electrode reactions, although stability and activation issues exist [3,4]. Another attractive feature is that concentrated alkaline electrolytes are highly ionically conductive compared to the electrolyte in other fuel cells where ultra-thin electrolytes must be used to achieve similarly low electrolyte resistive losses [5]. Despite this, alkaline fuel cells have never been produced in commercial quantities. During the latter part of the 20th century, research in alkaline fuel cells waned as interest in other types of fuel cells increased [6]; however, with recent advances in materials and processes in the intervening period, opportunities for producing commercial alkaline fuel cell systems

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http://dx.doi.org/10.1016/j.ijhydene.2017.07.018
0360-3199/

have become apparent. This can be seen by the success of UK based alkaline fuel cell developer, AFC Energy Plc, who demonstrated their 240 kW 'KORE' system at the Air Products Stade site in Germany during early 2016.

There are two primary variants of alkaline fuel cell systems; immobilised electrolyte and re-circulating liquid electrolyte. Immobilised alkaline cells can be easier to manage due to their system simplicity; however, this variant requires very careful CO_2 management as carbonates formed by reaction of the hydroxide with carbon dioxide in the air cannot be easily removed. Carbonates act to degrade the performance of the cell through reducing the conductivity of the electrolyte [7]. The second type of alkaline fuel cell, the re-circulating liquid electrolyte cell, is able to resolve this issue by transporting the carbonate outside the cell and processing it externally. Other key benefits of recirculating AFCs are their ability to manage heat and water removal from the fuel cell reliably and accurately, as the electrolyte provides an efficient transfer medium.

The degradation rates of fuel cells in real world applications is currently the most significant direct technical barrier to the adoption of fuel cells as power sources for wide spread application. Degradation studies, materials and design innovations to improve degradation rates in two of the most studied fuel cell classes, PEMFC and SOFC, are favoured topics as can be witnessed by the amount of research published in this field but, the degradation of liquid electrolyte alkaline fuel cells is not a well-researched topic. Most existing data is fairly limited, such as a series of post-mortem studies conducted on classical electrode designs [8,9] or specific studies on the effect for carbonates [7]. Karl Kordesch, a prolific researcher in the field of AFC device development, published and presented many papers on the subject from the 1970s to the early 2000s. He showed that many of the degradation modes experienced by PEMFC such as electrocatalyst agglomeration, carbon corrosion and current collector corrosion could be experienced by AFCs, but some particular degradation mechanisms, such as loss of hydrophobicity by de-fluorination of PTFE and layer cracking due to high hydroxide concentrations, were also evident [10–12]. Kordesch showed reasonable cycling performance of the AFC systems being developed at University of Graz as a continuation of the Union Carbide designs [13] and authors including Tomantschger and Kordesch have shown that Pt on carbon catalysts show greater Pt agglomeration during cycles than in acid media in *ex situ* experiments [11,14]. Again these were all based on post-mortem analysis which can be problematic. Post-mortem analysis by its very nature requires samples be extensively dried and prepared which essentially removes a significant body of the evidence – the electrolyte. Hence the research presented here aimed to

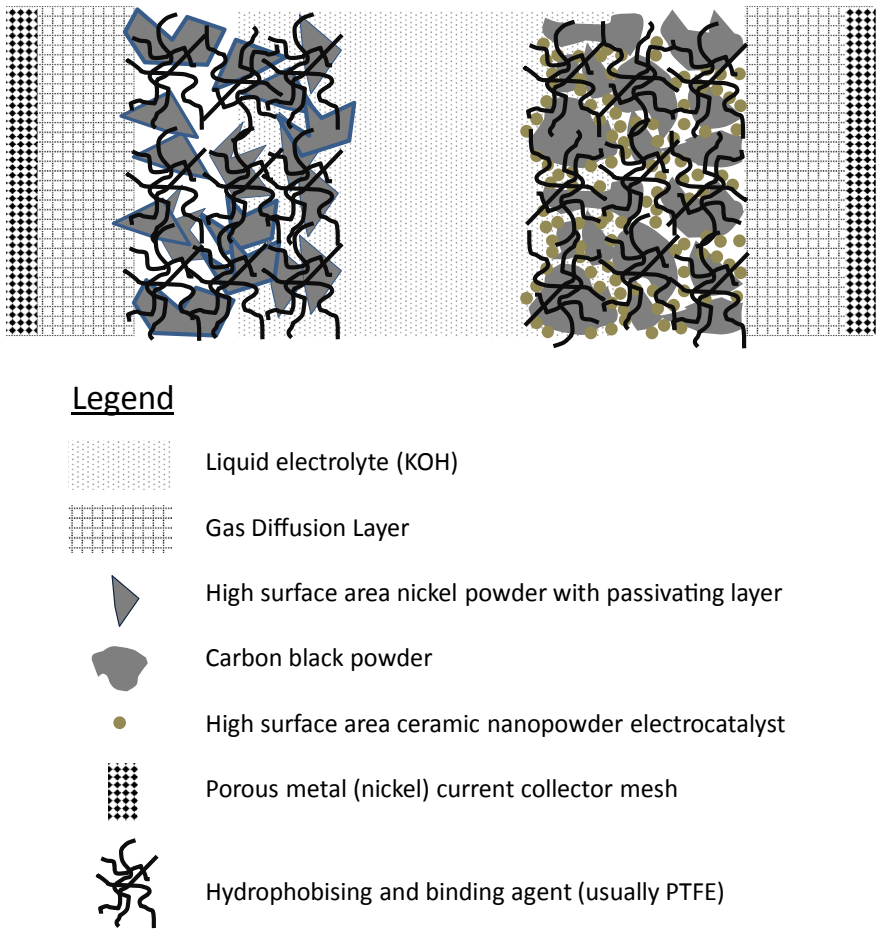

Fig. 1 – Standard structure of alkaline fuel cells with liquid electrolyte. Diagram shows PTFE bound layers on a gas diffusion layer with a conductive porous metallic backing.

Please cite this article in press as: Dawson R, et al., In-operando optical observations of alkaline fuel cell electrode surfaces during harsh cycling tests, International Journal of Hydrogen Energy (2017), http://dx.doi.org/10.1016/j.ijhydene.2017.07.018