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Corrosion behaviour of construction materials for high temperature steam electrolysers

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ABSTRACT

Different types of commercially available stainless steels, Ni-based alloys as well as titanium and tantalum were evaluated as possible metallic bipolar plates and construction materials. The corrosion resistance was measured under simulated conditions corresponding to the conditions in high temperature proton exchange membrane (PEM) steam electrolysers. Steady-state voltammetry was used in combination with scanning electron microscopy and energy-dispersive X-ray spectroscopy to evaluate the stability of the mentioned materials. It was found that stainless steels were the least resistant to corrosion under strong anodic polarisation. Among alloys, Ni-based showed the highest corrosion resistance in the simulated PEM electrolyser medium. In particular, Inconel® 625 was the most promising among the tested corrosion-resistant alloys for the anodic compartment in high temperature steam electrolysis. Tantalum showed outstanding resistance to corrosion in selected media. On the contrary, passivation of titanium was weak, and the highest rate of corrosion among all tested materials was observed for titanium at 120 °C.

1. Introduction

Most of long term visions about the use of hydrogen as an energy carrier include electrolysis. Unfortunately, the efficiency of water splitting by electrolysis is rather low for conventional electrolysers and there is hence a large potential for improvement.

Decentralized production of hydrogen by means of water electrolysis is favourable in several ways. When renewable energy sources (hydropower, windmills, solar cells, etc.) are considered, electrolysis is a practical way of converting the surplus electrical energy into chemical energy to be used when the power is needed [1]. One way of doing this is by using high temperature water steam electrolysis (above 100 °C).

PEM water electrolysis technology is frequently presented in the literature as a potentially very effective alternative to more conventional alkaline water electrolysis [2–4].

PEM water electrolysis systems offer several advantages over traditional technologies, including higher energy efficiency, higher production rates, and more compact design [5]. This method of hydrogen production is envisioned in a future society where hydrogen as the energy carrier is incorporated in an idealized "energy cycle". In this cycle, electricity from renewable energy sources is used to electrochemically split water into hydrogen and oxygen [6].

This technology is environmentally friendly and usually has a considerably smaller mass–volume characteristic and power cost. Besides the high purity of produced gases, there is

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Table 1 – Alloy chemical composition.

Alloy type	Chemical composition of alloys (elements, weight%)											
	Ni	Co	Cr	Mo	W	Fe	Si	Mn	C	Al	Ti	Other	Nb+Ta
AISI 347	9.0–13.0	–	17-19	–	–	Bal.	1.0	2.0	0.08	–	–	–	0.8
AISI 321	9.0–12.0	–	17-19	–	–	Bal.	1.0	2.0	0.08	–	0.4-0.7	–	–
AISI 316L	10.0–13.0	–	16.5–18.5	2.0-2.5	–	Bal.	1.0	2.0	0.03	–	–	N Less 0.11	–
Hastelloy® C-276	57	2.5	15.5	16.0	3.75	5.5	0.08	1.0	0.02	–	– –	V 0.35	–
Inconel® 625	62	1.0	21.5	9.0	–	5.0	0.5	0.5	0.1	0.4	0.4	–	3.5
Incoloy® 825	44	–	21.5	3.0	–	27	0.3	1.0	0.05	0.1	1.0	Cu 2.0	–

an opportunity of obtaining compressed gases directly in the installation [7].

At temperatures above the boiling point of water, the energy efficiency of water splitting can be significantly improved because of decreased thermodynamic energy requirements, enhanced electrode kinetics and possible integration of the heat recovery. Other operating features, such as control of steam flow rate, cell temperature and cooling are easier for steam-based systems [8]. However, this increases the demands to all materials used with respect to corrosion stability and thermal stability [3,9].

At the anodic compartment of an electrolyser, strong corrosive conditions will generally exist due to high anodic polarisation in combination with the presence of oxygen. This will be even more severe when the temperature is elevated. It is therefore an important task to choose materials which besides their catalytic properties also possess sufficient corrosion resistance. This demands further development of all materials from which electrolyser cells are built.

Bipolar plates are a multifunctional and expensive part in high temperature steam electrolysis stacks, as they collect and conduct current from cell to cell, they separate gases, and the flow channels in these plates withdraw produced gases.

In a typical PEM electrolysis stack, bipolar plates comprises most of the mass, and almost all the volume. Usually they also facilitate heat management in the system.

The most crucial demands for bipolar plate materials are resistance to spalling and dimensional stability and resistance to corrosion in electrolyte media under anodic/cathodic polarisation. Numerous research projects have been devoted to bipolar plate materials in fuel cells [10–17]. However, the number of suitable materials for PEM electrolyser is still limited because of high requirements for corrosion resistance on oxygen electrode, where high overpotentials are combined with low pH media of electrolyte.

The most widely used bipolar plate material in Nafion® based systems is titanium, which is ideal in terms of corrosion resistance and conductivity [18–20]. The conductivity of Nafion® membranes decreases dramatically at temperatures above 100 °C. Thus, PBI membranes doped with phosphoric acid are typically used in fuel cells at elevated temperatures [21]. However titanium current collectors would considerably suffer from corrosion at temperatures above 80 °C in concentrated phosphoric acid environments [22].

Different types of stainless steels can be used as bipolar plates, and they have the advantages of being good heat and electricity conductors, can be machined easily (e.g. by stamping), are non-porous, and consequently very thin pieces are able to keep the reactant gases apart. The major disadvantage of these alloys is that they are prone to corrosion [13].

A possible alternative for stainless steel bipolar plates can be the use of nickel-based alloys [23]. Ni-based alloys are widely used in process industry and energy production in nuclear

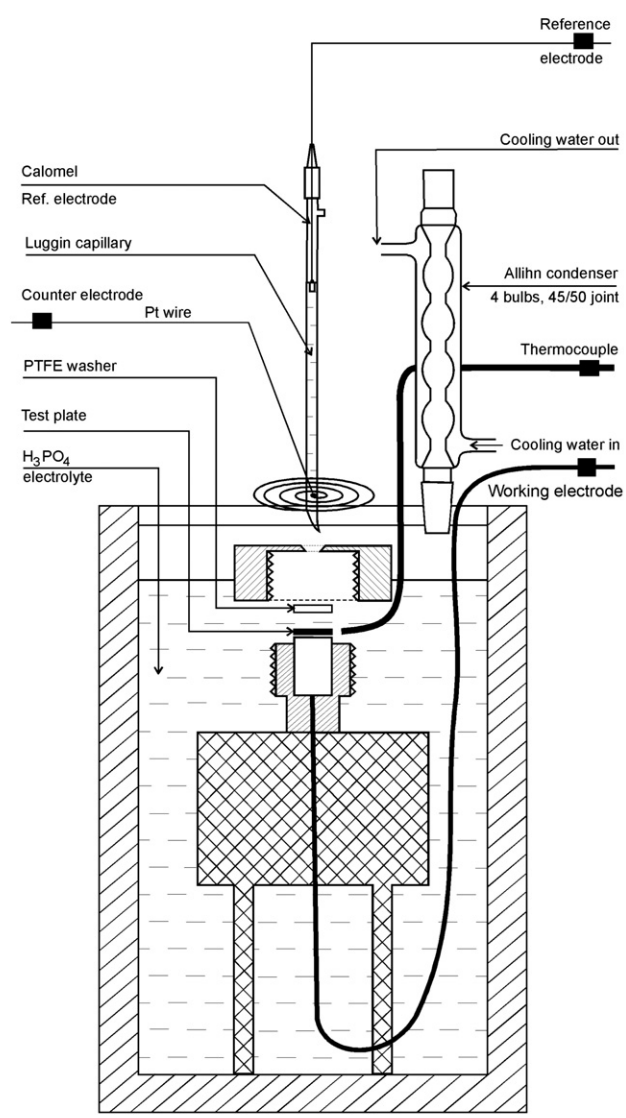

Fig. 1 – The electrochemical cell.