

# CORROSION BEHAVIOR OF HIGHLY AUSTENITIC STAINLESS STEELS AND Ni-BASED ALLOYS AT ELEVATED TEMPERATURES IN CONCENTRATED PHOSPHORIC ACID SOLUTIONS

**Petrushina I.M., Nikiforov A.V., Bjerrum N.J.\***

Technical University of Denmark, Department of Chemistry,  
Kemitorvet, 207, Lyngby, 2800 Denmark

\*Fax: +45 45 88 3136

E-mail: [njb@kemi.dtu.dk](mailto:njb@kemi.dtu.dk)

## Introduction

Most of the long term visions about the use of hydrogen as an energy carrier include electrolysis. However, the efficiency of water splitting by electrolysis is at present rather low for now, which means that there is a large potential for improvement.

In a long-term vision, decentralized production of hydrogen by water electrolysis is favourable in several ways. When renewable energy sources based on electricity (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. One way of doing this is to use high temperature water steam electrolysis (above 100 °C).

In this way the energy efficiency can be significantly improved because of the decreased thermodynamic energy requirements, enhanced electrode kinetics, and the possible integration of the heat recovery. However, this increases the demands to all the used materials used with respect to corrosion stability and thermal stability [1].

At the anode compartment of the electrolyser, strong corrosive conditions will generally exist due to the anodic polarization in combination with the presence of oxygen, especially, under elevated temperatures. It is, therefore, important to develop materials which possess sufficient corrosion resistance. This demands further development of all the materials of which the electrolyser cells are built.

The bipolar plates are multifunctional and usually the most expensive components in the high temperature water electrolysis stacks, as they collect and conduct the current from cell to cell, they separate the gases, and the flowchannels in the plates allow the product gases to escape.

In a typical PEM electrolysis stack, the bipolar plates comprise the most part of the mass, and almost all of the volume. In the absence of dedicated special plates, the bipolar plates also facilitate heat management. The most widely used bipolar plate material is titanium, which is ideal in terms of corrosion resistance and conductivity [2- 4].

But the corrosion resistance decreases in acidic media at the temperatures above 80 °C.

A possible alternative for titanium bipolar plates at high temperatures can be the use of iron or nickel based alloys. It has been proposed recently, that nickel and stainless steel alloys can be used as the construction material in PEM water electrolyser up to 100°C [6].

The Energy and Materials Science Group at Department of Chemistry has been involved in PEM fuel cells activity (operated at elevated temperatures of up to 200 °C) for a number of years. The most successful membrane system so far has been polybenzimidazole (PBI) doped with phosphoric acid [5]. That is why 85% solution of phosphoric acid was used as an electrolyte in our experiments to simulate the PEM water electrolyser anode compartment.

In this paper, the corrosion resistance of a number of metal alloys was evaluated, namely common stainless steels (AISI 316L, AISI 321, AISI 347) and Ni-based alloys (Hastelloy® C-276, Inconel® 625, Incoloy® Alloy 825).

## Experimental part

The specimens of austenitic stainless steels SS316L, AISI321 and AISI347 (annealed type of temper) were provided by Good Fellow Cambridge Limited Company (England) and Hastelloy® C-276, Inconel® 685, Incoloy® Alloy 825 were provided by T.GRAAE SpecialMetaller Aps Company (Denmark).

The specimens were cut into round plates of about 15 mm in diameter. The surfaces of all the samples were manually ground prior to test. SiC abrasive paper was used, following polishing with polycrystalline diamond powder, and degreased with acetone.

The experimental set consists of a specially designed corrosion cell (Fig 1.), which is a typical three-electrode electrochemical cell by itself. The main body material is PTFE and it consists of a platinum curl, used as a counter electrode to ensure good polarization distribution and a saturated calomel electrode, which was used as a reference electrode in the system. Pyrex® Allihn condenser

was used to keep the concentration of the electrolyte continuous over the whole experiment. Tests were performed at 30 °C, 80 °C and 120 °C degrees at the ambient atmosphere.

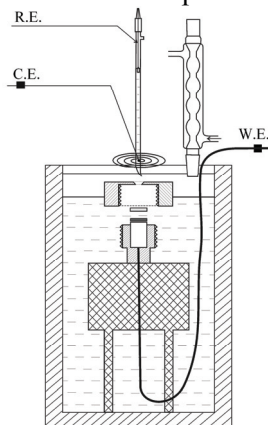


Fig. 1. The electrochemical cell. W.E. - working electrode, C.E. - counter electrode, R.E. - reference electrode.

## Results and Discussion

The results are shown on the Fig. 2 and in the Table 1.

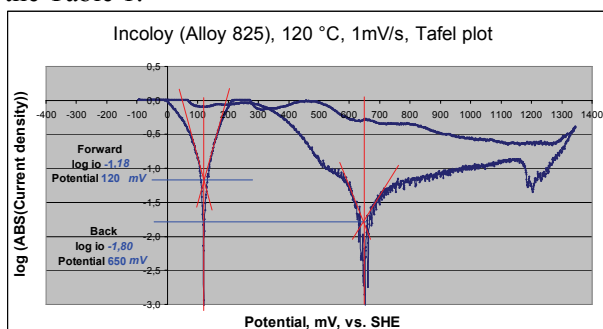


Fig. 2. Anodic polarization diagram for Incoloy® Alloy 825 at T=120°C, presented in the Tafel coordinates (scan rate 1 mV/s).

Table 1. The comparison table for the corrosion rates of different alloys at T=80°C, 120°C.

	T=80 °C	T=120 °C
	$i_{cor}$ , mA/cm <sup>2</sup>	
Stainless steel AISI 316L	$6.166 \cdot 10^{-2}$	$1.778 \cdot 10^{-1}$
Stainless steel AISI 321	$5.623 \cdot 10^{-2}$	$1.122 \cdot 10^{-1}$
Stainless steel AISI 347	$1.778 \cdot 10^{-1}$	$3.981 \cdot 10^{-1}$
Inconel® (Alloy 625)	$1.778 \cdot 10^{-2}$	$1.122 \cdot 10^{-1}$
Incoloy® (Alloy 825)	$1.259 \cdot 10^{-2}$	$6.607 \cdot 10^{-2}$
Hastelloy® (Alloy C276)	$1.122 \cdot 10^{-3}$	$5.623 \cdot 10^{-2}$

As it can be seen from the comparison of the data in Table 1, the nickel based alloys generally show the better corrosion stability, then the iron-based alloys.

Also it should be noticed, that the pitting type of corrosion apparently took place in this media. It can be explained by the following fact. In alloy AISI 347, which is usually exposed to

intergranular corrosion [7], small additions of niobium and tantalum, such as 0,8 wt.% are usually present to protect it from the corrosion at the intergranular boundaries. Nevertheless, this material did not show outstanding stability in comparison with ordinary AISI 316 and AISI 321 in our experiments.

Corrosion resistance at T=120 °C increases in the following sequence:

AISI 347<AISI 316L<AISI 321<Inconel® Alloy 625<Incoloy® Alloy 825<Hastelloy® Alloy C276.

It can be also noticed, that the corrosion stability grows with increasing content of molybdenum in this media, as shown in Table 2.

Table 2. The content of Mo, in wt.% for the tested alloys.

Alloy	AISI 347	AISI 316L	AISI 321	Inconel® Alloy 625	Incoloy® Alloy 825	Hastelloy® Alloy C276
Mo content, wt.%	-	2,0-2,5	-	9,0	3,0	16,0

The high content of Mo in the used alloys can be explained by the well-known fact, that molybdenum is more soluble in nickel, than in austenitic stainless steels. It follows, that the higher levels of alloying are possible with a higher content of nickel.

It has been established that as bipolar plate materials in high temperature water steam electrolyzers can be more reasonable to use AISI 316L or AISI 321 stainless steels, than other alloys. It can be as well justified by the price and availability of the materials.

## References

- Dutta S. Technology assessment of advanced electrolytic hydrogen production. Int. J. of Hydrogen Energy. 1990; 15(6): 379–386.
- Di Blasi A., D'Urso C., Baglio V., Antonucci V., Arico' A. S., Ornelas R., Matteucci F., et.al. J. of Applied Electrochemistry. 2008; 39(2): 191–196.
- Labou D., Slavcheva E., Schnakenberg U., Neophytides S. J. of Power Sources. 2008; 185(2): 1073–1078.
- Song Shidong, Zhang Huamin, Ma Xiaoping, Shao Zhi-Gang, Zhang Yining, Yi Baolian, Electrochemistry Communications. 2006; 8(3): 399–405.
- Jensen J.O., Li Q., Pan C., Vestbo A.P. et.al. Recent progress in high temperature PEMFC and the possible utilization of excess heat for fuel processing. Int. J. of Hydrogen Energy. 2007; 32(10-11): 1567–1571.
- International patent application, 03.01.2008, WO 2008/002150 A1, PCT/NO2007/000235.
- Cappeln F., Bjerrum N.J., Petrushina I.M. Materials and Corrosion. 1997; 58(8): 588–593.