




Cite this: *RSC Adv.*, 2021, 11, 6764

DOI: 10.1039/d1ra90053f

rsc.li/rsc-advances

## Correction: Nafion film transport properties in a low-Pt PEM fuel cell: impedance spectroscopy study

Tatyana Reshetenko <sup>a</sup> and Andrei Kulikovskiy <sup>\*b</sup>

Correction for 'Nafion film transport properties in a low-Pt PEM fuel cell: impedance spectroscopy study' by Tatyana Reshetenko *et al.*, *RSC Adv.*, 2019, 9, 38797–38806, DOI: 10.1039/C9RA07794D.

The authors would like to propose a modified version of the model presented in their article, which is consistent with the idea of the 1d + 1d approach reported in ref. 1. This adjustment makes the model more sensitive to the Nafion film parameters.

In this Correction article, equation numbers and notations referred to in the text are those used in the original article. On the right side of eqn (3) and its dimensionless version, eqn (12), the oxygen flux is calculated at the metal surface. A more accurate approximation is to use the flux  $N_{N,p}$  at the open pore radius  $R_p$  instead of  $N_{N,m}$ , *i.e.*,

$$N_{N,p} = D_N \frac{\partial c_N}{\partial r} \Big|_{r=R_p} \quad (1)$$

and its dimensionless variant should be substituted into eqn (3) and (12), respectively. It follows that in eqn (23) the perturbed flux  $\tilde{N}_{N,m}^1$  should be replaced by  $\tilde{N}_{N,p}^1$  and eqn (23) takes the form

$$\varepsilon^2 \tilde{D}_p \frac{\partial^2 \tilde{c}^1}{\partial \tilde{x}^2} = -\varepsilon \varepsilon^2 \tilde{N}_{N,p}^1 + i \tilde{\omega} \mu^2 \tilde{c}^1 \quad (2)$$

The flux  $\tilde{N}_{N,p}^1 = \tilde{D}_N \partial \tilde{c}_N^1 / \partial \tilde{r} \Big|_{\tilde{r}=\tilde{R}_p}$  is obtained from solving eqn (24), resulting in

$$\tilde{N}_{N,p}^1 = \frac{A_\eta \tilde{\eta}^1}{B} + \frac{A_c \tilde{c}^1}{B} \quad (3)$$

where

$$B = \sqrt{2\tilde{\omega}\varepsilon\varepsilon^2\mu\tilde{D}_N} \left( (1+i)K_1(-iq\tilde{R}_m)J_0(q\tilde{R}_p) + (1-i)J_1(q\tilde{R}_m)K_0(-iq\tilde{R}_p) \right) - 2\varepsilon\sqrt{\tilde{D}_N} \exp(\tilde{\eta}^0) \left( J_0(q\tilde{R}_m)K_0(-iq\tilde{R}_p) - J_0(q\tilde{R}_p)K_0(-iq\tilde{R}_m) \right) \quad (4)$$

$$A_\eta = \sqrt{2\tilde{\omega}} \exp(\tilde{\eta}^0) \tilde{D}_N \mu \tilde{c}_{N,p}^0 \left( (1+i)K_1(-iq\tilde{R}_p)J_0(q\tilde{R}_p) + (1-i)J_1(q\tilde{R}_p)K_0(-iq\tilde{R}_p) \right) \quad (5)$$

$$A_c = -K\tilde{D}_N\mu \left\{ \sqrt{2\tilde{\omega}} \exp(\tilde{\eta}^0) \left( (1-i)K_0(-iq\tilde{R}_m)J_1(q\tilde{R}_p) + (1+i)J_0(q\tilde{R}_m)K_1(-iq\tilde{R}_p) \right) - 2\tilde{\omega}\varepsilon\varepsilon^2\mu\sqrt{\tilde{D}_N} \left( J_1(q\tilde{R}_m)K_1(-iq\tilde{R}_p) - J_1(q\tilde{R}_p)K_1(-iq\tilde{R}_m) \right) \right\} \quad (6)$$

and

<sup>a</sup>Hawaii Natural Energy Institute, University of Hawaii, Honolulu, Hawaii 96822, USA. E-mail: tatyana@hawaii.edu

<sup>b</sup>Theory and Computation of Energy Materials (IEK-13), Forschungszentrum Jülich GmbH, Institute of Energy and Climate Research, D-52425 Jülich, Germany. E-mail: A. Kulikovskiy@fz-juelich.de



$$q = \sqrt{-\frac{i\tilde{\omega}\mu^2}{\varepsilon_*^2\tilde{D}_N}} \quad (7)$$

Here,  $J_0$ ,  $J_1$  are the Bessel functions of the first kind, and  $K_0$ ,  $K_1$  are the modified Bessel functions of the second kind. This modification leads to marginal changes in the calculation results reported in the original article. In the range of current densities 100 to 800 mA cm<sup>-2</sup>, the Nafion film thickness changes between 8.5 and 12 nm and the film resistivity decreases from 0.6 s cm<sup>-1</sup> down to 0.25 s cm<sup>-1</sup>, in agreement with the results in the original article.

Qualitatively, the pore radius is about an order of magnitude larger than the Nafion film thickness, meaning that the shape of the small film element is close to planar and hence the real part of the fluxes  $\tilde{N}_m^{-1}$  and  $\tilde{N}_p^{-1}$  are almost equal. Eqn (23) takes into account the phase shift due to transport of  $\tilde{c}^1$  perturbation through the film. However, replacing  $N_{N,m}$  by  $N_{N,p}$  in this equation increases the effect of the film on the phase shift. In general, this makes the model more sensitive to the film parameters.

The Royal Society of Chemistry apologises for these errors and any consequent inconvenience to authors and readers.

## References

- 1 A. A. Kulikovsky, *Analytical Modelling of Fuel Cells*, Elsevier, Amsterdam, 2nd edn, 2019.

