

Supporting Information for:

Magnetic field-oriented ferroferric oxide/poly(2,6-dimethyl-1,4-phenylene oxide) hybrid membrane for anion exchange membrane applications

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Characterization of Membrane

Nuclear Magnetic Resonance (NMR) Characterization

A Bruker AV 400 NMR spectrometer (400 MHz) was used to analyze the structure of triple-ammonium precursor and TA-PPO polyelectrolyte. Typically, DMSO-d₆/D₂O was chosen as the mixed solvent to better analyze the chemical structure of TA-PPO polyelectrolyte, on account of this solvent system can eliminate the negative effect of H₂O (3.34 ppm) on ammonium groups in ¹HNMR spectra.

Morphology and Crystal structure Analysis

X-ray diffraction (XRD) patterns of the Fe₃O₄ and QA-Fe₃O₄ were recorded on a Japan Shimadzu XD-3A diffractometer with a Cu K α radiation ($\lambda = 1.54 \text{ \AA}$). Scanning electron microscopy (SEM, Zeiss Supra 55) with EDX-linear scanning analysis was used to observe the morphology of the aligned QA-Fe₃O₄/TA-PPO hybrid membrane, and SEM analysis was operated at 15 kV. Besides, the micro-phase structure of the TA-PPO membrane in Br⁻ form was further revealed by atomic force microscopy (AFM, DI

Multimode V, Bruker Co.) and transmission electron microscope (TEM, Hitachi HT7700).

Thermal stability and mechanical properties

The thermal decomposition of membrane samples was evaluated by thermogravimetric analysis (TGA) on a TG209C thermogravimetric analyzer with operating temperature from 30 to 800 °C under a N₂ atmosphere at a heating rate of 10 °C min⁻¹. Mechanical properties of membrane samples were performed on an Instron Model 1185 instrument at 70% humidity. A membrane sample was cut into a dumbbell shape, and the length and width of effective sample domains are 20 mm and 4 mm, respectively) and the measurement is performed at a crosshead speed of 10 mm·min⁻¹ at 25 °C.

Physical properties

Ion exchange capacity (IEC): The back titration method is used to determine the IEC of membrane samples. In detail, a dried membrane (OH⁻ form) was soaked in standard HCl solution (0.01 M) for 24 h. Subsequently, a standard NaOH solution (0.01 M) was used to titrate the HCl solution with a phenolphthalein indicator. The IEC value is determined as follows:

$$IEC = \frac{C_1V_1 - C_2V_2}{m_{dry}} \quad (1)$$

m_{dry} is dry weight of a membrane sample, which is obtained after drying the membrane (Cl⁻ form) to constant weight. C_1 and V_1 are the concentration and volume of HCl solution, and C_2 and V_2 represent the concentration and volume of NaOH solution, respectively.

Water uptake (Wu) and swelling ratio (Sr): The variation of membrane weight was used to determine the Wu and Sr. Typically, a membrane sample in OH⁻ form was soaked in deionized water for 24 h, and the weight (W_1) and length (D_1) of the membrane were immediately measured after wiping excessive water on the membrane. Then, the membrane sample was dried in a vacuum oven to a constant weight and recorded the

weight (W_2) and length (D_2). The W_u and S_r of the membrane sample can be determined by follow equations.

$$W_u (\%) = \frac{M_1 - M_2}{M_2} \times 100\% \quad (2)$$

$$S_r (\%) = \frac{D_1 - D_2}{D_2} \times 100\% \quad (3)$$

Membrane conductivity

A two-electrode AC impedance method was used to test the longitudinal ion conductivity of membrane samples on a Zahner Ennium electrochemical workstation with AC frequency ranges from 1 Hz to 100 kHz. The membrane sample (OH^- form) was soaked in degassed and deionized water exceeding 24 h to remove excess salt on the membrane. The effective contact area (S) of the membrane and thickness (d) of membrane samples were recorded. The high frequency impedance was used to calculate the ion conductivity as follows:

$$\sigma = \frac{d}{RS} \quad (4)$$

R (Ω) represents the membrane resistance.

Alkaline stability

The QA- Fe_3O_4 /TA-PPO membrane sample was exposed in 1 M NaOH at 80 °C under N_2 protection for various times. The variation of membrane conductivity was used to assess the alkaline stability of the membrane sample. Besides, for better investigating TA-PPO membrane stability, ^1H NMR spectroscopy was further used to detect the structure variation of the membrane in DMSO- d_6 solution. 6%-10% of trifluoroacetic acid (TFA) was chosen as co-solvent to dissolve the TA-PPO polyelectrolyte after alkaline treatment. The NaOH solution was updated every 3 days.

Single cell performance

The TA-PPO (IEC=2.31 mmolg^{-1} , 75 ± 3 μm) and aligned 6%-QA- Fe_3O_4 /TA-PPO (IEC=2.32 mmolg^{-1} , 75 ± 3 μm) membranes were used to evaluate the single cell

performance. The membrane samples are assembled into membrane electrode assemblies (MEAs) with catalyst-loaded gas diffusion layer (GDL) (40%, Pt/C catalyst, Johnson Matthey Co.). The fuel cell performance of the MEAs is performed in a HephassMini-L100 fuel cell system at 80 °C. The both humidity temperatures of anode and cathode are carried out at 85 °C with at a backpressure of 0.1 MPa. The Pt loadings at both anode and cathode are 0.4 mg Pt cm⁻², and the area of electrode is 5 cm². The humidified gas was controlled at 300 mL/min for both H₂ and O₂.

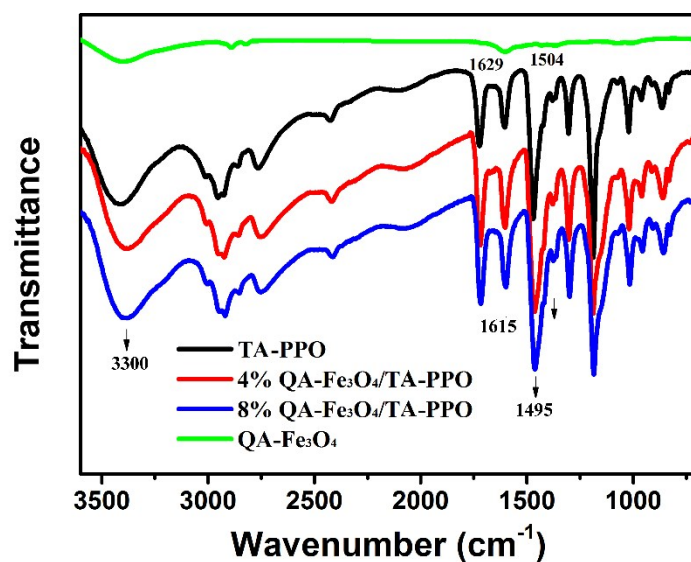


Fig. S1 FTIR spectra of QA-Fe₃O₄, TA-PPO, and QA-Fe₃O₄/ TA-PPO.

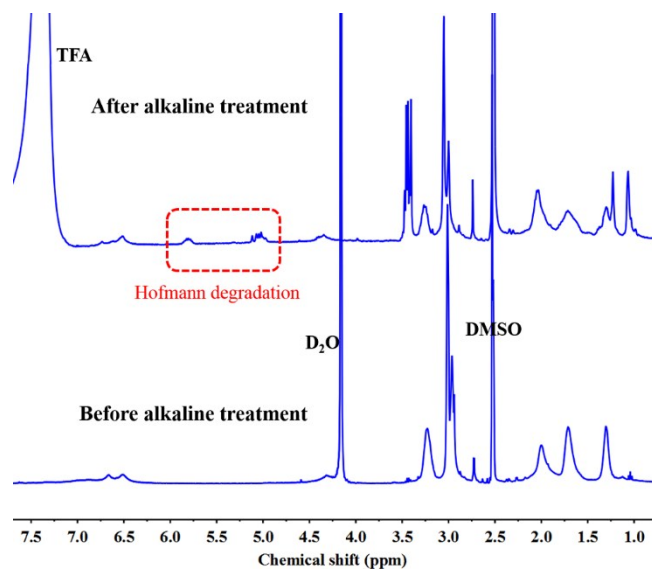


Fig. S2 ^1H NMR spectra of TA-PPO polyelectrolyte after alkaline treatment in 1 M NaOH at 80 °C for 500 h.