REACTIVE CONDUCTING POLYMERS AS ACTUATING SENSORS. SENSING MUSCLES

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An oversimplified way to write the electrochemical reaction for the oxidation/reduction of any prevailing anion (A^-) interchange-conducting polymer (CP), according with the relaxation model [1] is:

$$[CP^{a+}(A^-)]_s + n(A-)_{aq} + mH_2O \leftrightarrow [(CP^{(n+a)+})(A^-)_{n+a}(H_2O)m]_{gel} + (n\ e-)_{metal}$$

This reaction indicates the great difficulties to attain a totally reduced material due to shrinking and closing processes during reduction, and includes all electrochemical properties and electrochemical applications of those non-stoichiometric [2] and reactive materials. The change of volume between $[CP^{a+}(A^-)]_s$ and $[(pPy^{n+})_s(Cl-)_n\ (H_2O)_m]_{gel}$ originates artificial muscles. According with the chemical equilibrium the muscle potential during actuation, working under constant current, must be influenced by any chemical or physical variable acting on the chemical reaction. As expected the evolution for any device (bilayer, triple layer or complex design), the muscle potential changes if we modify: the electrolyte concentrations, the temperature, the weight of objects attached to the bottom of the muscle, or the current flowing through the device. Lineal evolutions are obtained for the electrical energy consumed by the artificial muscle to cross over a constant angle as a function of the studied experimental variable. Both signals, the actuating current and the muscle potential response, are included by the same two connecting wires, opening a new paradigm for electrochemical devices. Those results underline the simultaneous sensing and actuating capabilities of the device. If a muscle moves freely meeting, touching, and pushing an obstacle the muscle potential steps, proportionally to the mechanical resistance of the obstacle, at the touching moment. So we have a muscle with tactile sense: quite simple response analysis software can transform the ensemble (computer, potentiostat and device) into a very primitive conscious system. The system indicates when a muscle, or the mechanical tool driven by the muscle, touches an obstacle. Also indicates how much mechanical resistance the obstacle opposes, or if the muscle is unable to move the obstacle. The current allows a perfect control of the movement rate and movement sense. All that actuating and sensing information is supported by only two connecting wires.

The tactile muscle mimics natural muscles: it is constituted by a reactive material including organic polymers and water, and involves electric currents, chemical reactions, conformational movements in chains, ionic and aqueous interchanges. The driven electrochemical reaction includes, simultaneously, actuating and sensing properties.

Any property based on the electrochemical reaction, so on the reversible change, under control, of the counterion composition has biomimicking possibilities and simultaneous actuating and sensing devices can be developed based on those properties: electromechanical, electrochromic, electroporosity, charge storage, chemicals storage, electron-ion and ion-electron transduction.

So, soft, wet and reactive conducting polymers generate expectancies for a new world of sensing actuators.

[1]TF Otero et Al. *J. Electroanal. Chem.* **394**, 211-216 (1995); *J. Phys. Chem.*, **101**, 3688-3697 (1997); Conducting polymers, electrochemistry and biomimicking processes. In *Modern Aspects of Electrochemistry*, **Vol. 33**, edited by Bockris, J. O'm. White, R.E. and Conway, B.E. New York , Pg. 307-434 (1999). *Handbook of Conducting Polymers (3rd Edition)*. Ed by Elsenbaumer. R.L. and Reynolds, J.R. CRC Press. Boca Raton 591-624 **(**2007).
[2] TF Otero and I, Boyado *ChemPhysChem*, *4* (2003) 868. *Electrochim. Acta*, *49* (2004) 3719.