

## Optimization of Flowable Electrode for Electrochemical Flow Capacitors

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Renewable energy sources (solar, wind etc.) can provide a substantial amount of energy, their intermittent nature requires low cost, safe and highly efficient electrochemical energy storage systems (EESs). Tremendous efforts to improve EESs like batteries and supercapacitors have been reported but they mainly address small scale storage (e. g. portable electronics) and grid-scale energy storage still remains a challenging field[1][2][3].

To address this challenge, recently, a novel concept to store grid-scale electrical energy called the electrochemical flow capacitor (EFC) has been reported by our group[4]. The EFC has the advantages of both flow batteries (high power density) and supercapacitors (long cycle life & fast charge/discharge). The charge storage mechanism in the EFC is similar to the supercapacitors; the flowable electrode stores charge electrostatically. The composition of flowable electrode is a low cost carbon material, electrolyte (mainly aqueous, organic or ionic liquid) and a conductive agent[5].

The fundamental goal of this work is to optimize the electrochemical performance of the flowable electrode. Here, we addressed two different approaches to optimize the electrode; activation of active material (carbon spheres) and the nature of electrolyte (aqueous, non-aqueous etc.). We performed series of physical activations on carbon spheres having diameters between 250-350  $\mu\text{m}$  using  $\text{CO}_2$  as an activation agent at four different temperatures 800, 900, 950 and 1000  $^\circ\text{C}$  for duration of 1hour. The resultant activated carbons were characterized using  $\text{N}_2$  adsorption, scanning electron microscope (SEM), cyclic voltammetry, galvanostatic charge/discharge cycling and impedance spectroscopy. Changes in the surface area and pore distribution were observed at different activation temperatures. Between 950 and 1000  $^\circ\text{C}$  the pore distribution appeared to become more uniform (Fig. 1a). Electrochemical characterizations of the flow electrode were done in 2M KOH aqueous solution at different scan rates.

In general, the higher the activation temperature the greater was the capacitance across all rates studied (Fig. 1b). The capacitance nearly doubled from 70  $\text{Fg}^{-1}$  (unactivated) to 145  $\text{Fg}^{-1}$  (activated at 1000  $^\circ\text{C}$ ) in aqueous electrolyte and this increase is attributed to enhancement of the porosity of the carbon spheres after  $\text{CO}_2$  activation. As the voltage window in aqueous electrolytes is limited by the electrolyte decomposition at higher potentials ( $>1$  V), we further report the electrochemical performance of activated carbon spheres

in different organic electrolytes and ionic liquids with increased voltage window which essentially enhances the energy density of the flowable electrode.

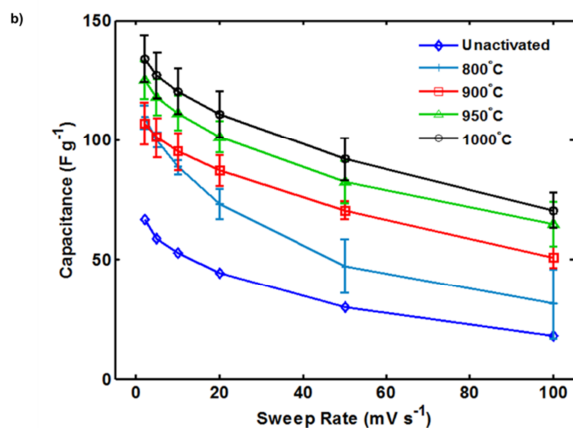
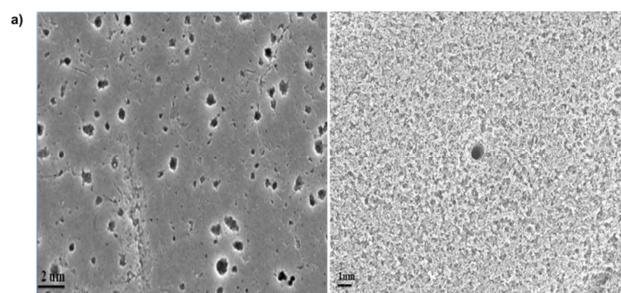


Figure 1: (a) SEM images of carbon spheres activated at 950  $^\circ\text{C}/1\text{h CO}_2$  (top left) and 1000  $^\circ\text{C}/1\text{h CO}_2$  (top right). (b) Capacitance vs. charging rate for EFC electrode made of carbons activated at different temperatures.

## References

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