Interfacial Redox Phenomena for Enhanced Aqueous Supercapacitors

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Electrochemical with its fundamental and applied branches gives an excellent feedback for a dramatic increase of energy demand and offers several solutions for various energy conversion and storage systems. At the interface between electrode and electrolyte, several mechanisms of energy conversion and storage might be exploited in batteries, fuel cells and electrochemical capacitors. Electrochemical capacitors (quite often named as supercapacitors, ultracapacitors, etc.) are excellent devices for power demand but they suffer from moderate energy density. This feature greatly distinguishes them from batteries which store energy in a faradaic manner and provide high energy but moderate power. Therefore, their application and final target is different. Moreover, one should conclude that the competition between supercapacitors and batteries is pointless and it is more reasonable to consider them rather as complementary to each other. On the other hand, a remarkable interest of the scientific community is observed in the development of novel materials based on transition metal oxides and conducting polymers providing good capacitive behavior but involving slow faradaic processes in order to enhance the performance and introducing pseudocapacitance.

Another trend in recent research in supercapacitor development is to exploit redox processes originating from electrolyte solution. Contrary to redox active electrode materials, such a concept offers fast charge transfer reactions on the electrode surface, limited either by diffusion of a redox specimen from the electrolyte bulk to the interface or specific adsorption of ions within the pores of the electrode. To date, redox active electrolytes are based on iodide/iodine, bromide/bromine or hydroquinone/quinone redox couples. A variety of halide oxidation states allows reaching a remarkable contribution of pseudocapacitance; however, only iodide- and bromide-based electrolytic solutions seem to be promising for supercapacitor application. Fluorine and chlorine have too high formal oxidation potentials (i.e., above oxygen evolution potential) to be successfully and reversibly reached in aqueous solutions. Additionally, the reversibility of the redox reaction strongly depends on the pressure (tightness) in the system. Moreover, both of them are dangerous, corrosive and recognized as environmentally unfriendly. In the case of iodide and bromide species, their oxidation potential is below the oxygen evolution potential and they can be reversibly oxidized/reduced with excellent efficiency and it was accepted that these species have no negative impact on the system.

Pseudocapacitance originating from a quinone/hydroquinone redox couple has been reported by many authors; however, primary research concerned rather oxygen-based functional groups on carbon electrodes. Recently hydroquinone has been demonstrated as a redox active electrolyte additive enhancing capacitance values especially in acidic and alkaline media.

The properties of electrode surface (availability, conductivity) play a crucial role in the optimal exploitation of redox phenomena from an electrolytic solution. Typically activated carbons are considered as excellent materials preserving high capacitance values, good charge propagation and a cycle life of several thousand charging/discharging cycles because of their well-developed surface area, suitable and controllable porosity and acceptable chemical and electrochemical stability. Moreover, the carbon electrode/electrolyte interface is a unique locus for several electrochemical processes and both components of interface determine the final electrochemical capacitor performance. For aqueous electrolytes the main bottleneck is the decomposition voltage of water at 1.23 V with oxygen and hydrogen evolution. However, by applying electrolytes with neutral pH or by balancing the mass of the electrodes, one can benefit from a high effective voltage in symmetric carbon/carbon systems. It is worth noting that water-based electrolytes usually offer high conductivity values and ions with excellent mobility preserving good charge propulsion and power performance as well as easy manipulation during assembling. Hence, continuous efforts are undertaken in order to improve the operational voltage of water-based systems and to approach the energy profile typical of organic electrolytes accompanied by excellent power characteristics for aqueous electrolytes.

This research is devoted to enhancing voltage and capacitance values of water-based supercapacitor using a selected redox active electrolyte and suitable carbon. In our concept both electrodes operate in different electrolytic solutions (various pH). For the positive electrode, the main obstacle to overcome is oxygen evolution, causing electrolyte decomposition and electrode oxidation. Hence, we applied iodide/iodine redox shuttle (neutral medium) in order to slightly shift the potential of oxygen evolution and to extend the potential window of the electrode. To preserve the charge balance in the system, on the negative electrode we electrosorbed hydrogen in alkaline solution, exceeding the hydrogen evolution potential and extending the potential range of the electrode. Electrochemical characterization of the capacitor with combined electrolytes will be presented in two- and three-electrode configurations showing an enhancement of supercapacitor performance in the term of capacitance, energy and cycling.

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Experimental

Activated carbon material in the form of tissue (purchased from Kynol GmbH) was used. Specific surface area and pore size distribution of that material was estimated from nitrogen sorption isotherm at 77 K, performed on ASAP 2020 (Micromeritics, USA). Oxygen content was estimated from thermoprogrammed desorption coupled with mass spectrometry (heating rate 20 K min⁻¹, He flow: 50 mL min⁻¹) using Iris F1 (TGA) and Aeolos (MS) instruments (Netzsch, Germany). Raman spectra were recorded on dispersive Raman microscope DXR (ThermoFischer, USA) with the 532 nm laser, 120 s sampling time within the wave numbers of 50–3500 cm⁻¹, if not stated otherwise. The laser power was 5 mW. In-situ experiments were performed in a three-electrode quartz crystal electrochemical cell with platinum wire as the counter electrode (with a surface area of 1.5 cm²) and the calomel electrode for reference. The working electrode (with a geometric surface area of 0.283 cm²) was placed on a gold current and the calomel electrode for reference. The working electrode (with a geometric surface area of 5 cm²) was used in order to separate the electrodes.

Electrochemical investigations were performed on multipotentiotstat/galvanostat VMP3 and SP-200 (BioLogic, France) equipped with low current board. Three different techniques, i.e., cyclic voltammetry at various scan rates, galvanostatic charging/discharging (25 mA g⁻¹–6 A g⁻¹ current load) and electrochemical impedance spectroscopy (100 kHz–1 mHz frequency range) were applied. In three-electrode configuration the activated carbon disk was a working electrode (geometric surface area of 0.785 cm²) and the same active carbon served as a counter one (geometric surface area of 5 cm²). The calomel electrode was used as a reference one. All potential values are referred to as NHE.

In the case of the capacitor with combined electrolytes, electrochemical characterization was performed in Swagelok cell. 1 mol L⁻¹ KI was used as an electrolyte for the positive electrode, while 6 mol L⁻¹ KOH served as an electrolyte for the negative one. It is worth noting that before assembling both electrodes were immersed in an appropriate electrolyte and kept for 1 h. It was crucial to provide a sufficient amount of electrolyte for only wetting the bulk of each electrode without any excess (in the case of electrolyte excess they easily mix each other). Additionally, in order to avoid mixing the aforementioned electrolytes and to preserve more stable conditions, electrodes were separated by two glassy fibre separators (Whatman, GF/A) which were firstly soaked in neutral solution, i.e. 1 mol L⁻¹ Na₂SO₄. For three electrode configuration the glassy carbon rod was a reference electrode.

Results and Discussion

Electrode material characterization.— In order to determine the specific surface area and pore size distribution of the carbon electrodes, nitrogen adsorption isotherms (77 K) were recorded (Fig. 1). The specific surface area of ACC 507-25 Kynol tissue was 2350 m² g⁻¹ and demonstrated a strictly microporous character. Pore size distribution (PSD, calculated by NLDFT method with heterogeneous surface model using SAIEUS Program, ver. 1.02 by Jacek Jagiello) confirmed unimodal PSD profile with the highest contribution of micropores at ca. 1 nm (micropore volume ~0.92 cm³ g⁻¹). Thermo-gravimetric analysis confirmed a moderate oxygen content ~6.5 wt.%. Raman spectra of carbon tissue demonstrated typical D and G bands at ca. 1340 cm⁻¹ and 1600 cm⁻¹ with secondary-type reflections at 2910 cm⁻¹. No remarkable shift of band was observed whatever the excitation line was (532, 633 and 780 nm).

Figure 1. Nitrogen adsorption isotherm (77 K) for ACC 507-25 activated carbon electrodes and its pore size distribution.

Electrochemical characterization of carbon electrode.— To select a redox active electrolyte and to estimate a practical operating range of potential in this electrolyte, some preliminary experiments were performed using single electrolytic solutions, while extension of capacitor voltage was realized with a combination of various electrolytes. Firstly, hydrogen electro sorption on activated tissue was realized by cyclic voltammetry investigation in 6 mol L⁻¹ KOH solution using typical three electrode configuration. The electrode was screened with a potential sweep rate of 5 mV s⁻¹ toward cathodic potential values, in order to investigate electrical double layer (EDL) capacitance, as well as hydrogen storage kinetics (Fig. 2). The capacitance of the electrode was ca. 165 F g⁻¹ within EDL charging/discharging region. A significant increase of current indicates cathodic decomposition of water and hydrogen storage in a carbon electrode. A detailed mechanism of this phenomenon might be found elsewhere. Briefly, decomposition of water on activated carbon electrode results in hydrogen production (either H or H₂ specimen) and its storage in stätu nascenti, i.e. inside the micropores as a monoatomic molecule, H₂. The amount of hydrogen stored was determined by galvanostatic charging/discharging at 1 A g⁻¹ cathodic current for storage and 50 mA g⁻¹ of anodic current for desorption. Because reduction of water occurs as charge transfer...
In order to confirm that hydrogen is electrochemically stored in carbon material, in-situ Raman spectroscopy investigation was performed (Fig. 4). The electrode was polarized by cyclic voltammetry at 0.1 mV s$^{-1}$ scan rate within the potential range from 0 to $-1.8$ V vs. NHE and simultaneously Raman spectra were collected.

The in-situ spectra confirmed that hydrogen is stored reversibly in carbon material with charge transfer process. A significant increase of Raman intensity in D and G band region (1350 cm$^{-1}$ and 1585 cm$^{-1}$, respectively), as well as in secondary reflections area (above 2500 cm$^{-1}$ Raman shift) might suggest that C–H bond is created. Particularly, an increase of Raman intensity at ca. 1180 and 1540 cm$^{-1}$ can be assigned to hydrogen storage. As found by other authors, these bands should be attributed to C=C=H and C=C stretching vibrations in amorphous carbons.

Additionally, quantitative investigation of hydrogen storage in alkaline medium by galvanostatic polarization of the electrode (not shown here) demonstrated 372 mAh g$^{-1}$ of charge attributed to hydrogen load giving 1.37%wt of hydrogen stored in the material. Electrooxidation of hydrogen is affected by current load and discharging profile does not show plateau but significant overpotential $>0.36$ V. It suggests that the electrode has an extra capacitance which might enhance final capacitance of the system, as well as extend an operational voltage of capacitor on the negative electrode side.

Thus, it was proved that carbon electrode operating in alkaline solution (6 mol L$^{-1}$ KOH) is an ideal negative electrode for a capacitor with 1.1 V potential window.

Subsequent electrochemical investigations were performed in order to find an optimal positive electrode with the highest oxygen evolution potential. In principle, oxygen evolution potential should be the highest in acidic medium ($+1.23$ V vs. NHE in 1 mol L$^{-1}$ H$_2$SO$_4$ solution). Hence, electrochemical behavior of ACC 507-25 activated carbon electrode was examined in the same way as in alkaline electrolyte (Fig. 5). Specific capacitance of the electrode measured by cyclic voltammetry at 5 mV s$^{-1}$ scan rate approached 300 F g$^{-1}$ but a significant contribution from quinone/hydroquinone pseudocapacitance has to be pointed out. This result confirmed the physicochemical investigation by TPD method demonstrating –C=O type functional groups on the electrode surface, able to undergo a reversible redox reaction. Unfortunately, such pseudocapacitance is rather unstable and disappears with charging/discharging cycles.

As might be expected, in acidic electrolyte effective HEP was shifted toward more positive values (ca. $-0.26$ V vs. NHE). However, a slight extension of the electrode potential over HEP value caused a significant increase of cathodic current with no hysteresis loop when polarization was reversed. It might be expected that hydrogen in acidic electrolyte is bonded weakly and recombination reactions are in favor prior to storage in carbon structure. Similar results were obtained by GITT method and the results are presented in Fig. 6.

Although the hysteresis loop between charging/discharging steps is higher than for alkaline medium (1.19 V vs. 1.075 V), the oxidation profile does not indicate any remarkable proof of hydrogen bonding. The overpotential upon relaxation time is significantly lower, i.e., ca. 0.19 V vs. 0.38 V for alkaline medium. Hence, it seems that in acidic solution hydrogen desorption is rather negligible and galvanostatic estimation of hydrogen loading (not shown here) confirmed this assumption, reflecting only 186 mAh g$^{-1}$ of charge attributed to hydrogen oxidation, i.e. 0.86% wt of hydrogen stored in the material. Moreover, Raman spectra recorded in the same manner as in the case of alkaline solution did not demonstrate any significant change of intensity upon polarization.

Such an observation allows concluding that acidic electrolyte is inappropriate for the supercapacitor negative electrode. On the other hand, OEP was shifted for more than 0.8 V toward positive values and high capacitance values were observed. This might suggest that acidic solution could serve as electrolyte for the positive electrode in the supercapacitor system, with a high oxidation potential limit and excellent capacitance values. Theoretically, one might benefit from an extremely low reduction potential on the negative side and a
reasonably high oxidation potential on the positive one by combining electrolytes with various pH for each electrode. However, taking into account corrosive properties of acidic medium we focused our attention to neutral electrolytes.

Electrolytes with neutral pH were recognized as promising solutions for water-based supercapacitors operating with extended voltage. In this study we abandoned previously characterized sulfate and nitrate based solutions and 1 mol L$^{-1}$ Na$_2$S$_2$O$_3$ and 1 mol

Figure 4. Raman spectra profiles for ACC 507-25 activated carbon electrode operating in 6 mol L$^{-1}$ KOH electrolytic solution; scan rate 0.1 mV s$^{-1}$, laser wavelength 532 nm, laser power 5 mW.

Figure 5. Cyclic voltammograms for ACC 507-25 activated carbon electrode operating in 1 mol L$^{-1}$ H$_2$SO$_4$ electrolytic solution; scan rate 5 mV s$^{-1}$.

Figure 6. Galvanostatic Intermittent Titration Technique profile for ACC 507-25 activated carbon electrode operating in 1 mol L$^{-1}$ H$_2$SO$_4$ electrolytic solution; current load $\pm 25$ mA g$^{-1}$.
L⁻¹ KI solutions were investigated (Figs. 7, 8). One of the reasons for selecting such electrolytes was the fact that both of them might give additional pseudocapacitance from electrolyte solution, being necessary to balance the redox charge on the negative electrode storing hydrogen.

In the case of 1 mol L⁻¹ Na₂S₂O₃ solution a significant contribution from quinone-hydroquinone as well as from various oxidation states of sulfur might be observed and the capacitance value was determined as 320 F g⁻¹ (Fig. 7). Remarkable hysteresis loop observed when HEP is exceeded suggests good hydrogen storage ability. Moreover, oxidation limit was identified as +0.95 V vs. NHE. Hence, this solution could be considered as electrolyte for the positive electrode in supercapacitor application. Unfortunately, further research demonstrated that redox activity of sulfur-based species is very sensitive to pH changes (reversible oxidation to SO₄²⁻ specimen) and its combination with alkaline solution on the negative side resulted in a capacitance fade and voltage range decrease.

Much more interesting results were obtained with 1 mol L⁻¹ KI aqueous solution (Fig. 8). The activated carbon electrode operating in typical EDL range did not reflect any intriguing behavior and capacitance of ca. 200 F g⁻¹ was achieved. Exceeding HEP, a typical increase of cathodic current was observed and assigned to hydrogen storage. One might notice that efficiency of electrosorption in this case is quite high (although investigated by voltammetry method), i.e. 93%. Hydrogen desorption peak is well-defined and indicates good sorption/desorption performance. Potential limits were determined as −1.5 V vs. NHE for the negative side and −0.1 V vs NHE for the positive side, giving in total ca. 1.4 V of effective operational voltage. Such a result is in good accordance with the results obtained previously for symmetric supercapacitors operating in 1 mol L⁻¹ KI solution. However, three electrode investigations conducted in our previous studies demonstrated a different mechanism of charge storage process, involving redox activity of I⁻/I₂ couple. In Fig. 8 such activity is not observed because potential of electrode is not high enough to reach reduct response of this couple. Therefore operating potential of the electrode was extended into positive direction. The results are presented in Fig. 9. Extension of the potential window toward more positive values demonstrated excellent redox activity of iodide/iodine/iodate redox couple with a great variety of its oxidation states. A detailed mechanism of this pseudocapacitive phenomenon may already be found in.¹³,¹⁹ However, this study confirms that redox activity of iodide/iodine remarkably aggravates hydrogen storage process, if the same electrolyte is used for both electrodes. Therefore, one cannot expect a significant voltage extension in iodide-based systems. We assume that the presence of iodine/iodates in the solution blocks the active sites for hydrogen adsorption and inhibits its storage process.
Negligible current assigned to hydrogen storage/desorption might confirm such an assumption. As a result, symmetric iodide/iodine system is limited rather on the negative side by irreversible hydrogen evolution.

GITT technique confirms poor hydrogen storage capacity in 1 mol L\(^{-1}\) KI solution with the presence of iodine/iodate species (Fig. 10). Cathodic limit in such a case is at ~0.310 V vs NHE and the anodic limit was determined to be at +0.5 V vs NHE, with a typical redox-dependent profile and no remarkable potential drop during relaxation periods. Such an electrochemical system is an excellent candidate as the positive electrode in supercapacitor application.

Taking into account the above results obtained from three electrode configuration, one might expect ca. 1.55 V of the effective capacitor voltage. Therefore, we decided to combine two electrolytes with the most promising electrochemical characteristics in one two-electrode electrochemical capacitor (Swagelok cell). 6 mol L\(^{-1}\) KOH solution served as electrolyte for the negative electrode storing hydrogen and 1 mol L\(^{-1}\) KI served as electrolyte for the positive one, exploiting pseudocapacitance from redox activity of iodide-based redox couples. As mentioned in the experimental technique there was no excess of electrolytes with different pH and both electrodes were previously soaked in KI and KOH respectively and then additionally separated by two layers of a separator with neutral electrolyte. It is assumed and lately widely proved experimentally and by modeling\(^{26-30}\) that during capacitor charging/discharging the ions do not need to move from the bulk of electrolyte to electrode pores. The ions already occupy pores and their movement in pores is quite limited, thus, separation of positive and negative ions occurs inside the pores. Therefore, our selected anolyte and catholyte maintain during capacitor operation in the porous carbon structure.

Galvanostatic charging/discharging cycling performed in two electrode Swagelok cells with the additional carbon reference electrode connected through Luggin capillary indicated good efficiency (ca. 98%) of the supercapacitor operating at 1.5 V voltage (Fig. 11). However, the profile of the electrode potentials demonstrated a different charge mechanism on the electrodes. In the case of the negative electrode operating in 6 mol L\(^{-1}\) KOH solution, typical charging/discharging of EDL might be observed with contribution of hydrogen storage below ~1.0 V vs NHE. It seems that this electrode is responsible for voltage response. Indeed, the positive electrode potential window is much narrower and almost all capacitance is accumulated by iodide/iodine/iodate redox couple reaching 476 F g\(^{-1}\) from cyclic voltammetry (Fig. 12). This CV characteristic at 5 mV s\(^{-1}\) correlates well with the results from constant current load method. The negative electrode demonstrated a typical EDL charging/discharging profile, with hydrogen storage at deep cathodic conditions. The positive electrode has a very narrow EDL charging region and the majority of the capacity is accumulated by iodide-based redox shuttle. Unfortunately, the capacitances of the electrodes are quite different (476 F g\(^{-1}\) for the positive electrode and 145 F g\(^{-1}\) for the negative one) and final capacitor capacitance will be limited by the negative electrode giving the specific capacitance of 56 F g\(^{-1}\) (calculated for active mass of both electrodes and excluding casing). Nevertheless, the capacitor voltage was extended to 1.5 V.

In order to determine the ohmic contribution to final operating voltage and energy loss during capacitor operation several methods can be applied. For the purpose of this study real capacitor voltage (excl. ohmic drop) was determined by IR compensation method (at 80%) using interrupted current steps. Namely, the supercapacitor was subjected to 30 impulses of 1 A g\(^{-1}\) discharging current with 2.5 s of relaxation period while the voltage drop was recorded. Ohmic contribution was determined as the ratio between the voltage measured and the current applied in the step (1 A g\(^{-1}\)). It seems that effective capacitor voltage has to be determined as 1.45 V, i.e., the ohmic drop is only 0.05 V. This value is in good accordance with electrochemical impedance spectroscopy measurement at high frequencies, reflecting low ESR value (see Fig. 13). In order to study the charge propagation in the system, electrochemical impedance

Figure 10. Galvanostatic Intermittent Titration Technique profile for ACC 507-25 activated carbon electrode operating in 1 mol L\(^{-1}\) KI solution; current load ±25 mA g\(^{-1}\).

Figure 11. Galvanostatic charge/discharge profile for supercapacitor with ACC 507-25 activated carbon electrodes operating in 1 mol L\(^{-1}\) KI (+) and 6 mol L\(^{-1}\) KOH (−) electrolytic solution; current load ±1 A g\(^{-1}\).

Figure 12. Cyclic voltammograms for supercapacitor electrodes operating in 1 mol L\(^{-1}\) KI (+) and 6 mol L\(^{-1}\) KOH (−) electrolytic solution; scan rate 5 mV s\(^{-1}\).
spectroscopy method was applied within frequency range 100 kHz–1 mHz and voltage amplitude ±5 mV. A semicircle at high frequency region confirmed pseudocapacitance contribution in the charge storage mechanism. ESR was determined as 0.056 Ω whereas EDR was relatively high reaching the value of 8.2 Ω. However, for pseudocapacitive systems, one should expect that charge propagation will be affected by redox kinetics. In a moderate and low frequency region, the supercapacitor reflects typical capacitive behavior with a slope of diffusion contribution, aggravating fast transportation of ions to the electrode/electrolyte interface. The lifetime of the capacitor with combined electrolytes was determined by constant current load (±1 A g\(^{-1}\)). The 80% of initial capacitance was recorded after 16000 cycles within 1.5 V voltage range (Fig. 14). In order to obtain insightful information of the systems investigated and to show a benefit of our new concept, all considered electrolytes were subjected to constant current load (±1 A g\(^{-1}\)) investigation in two electrode Swagelok cells, within the voltage range determined by cyclic voltammetry and GITT methods. Capacitance values were calculated by taking into account the time of full discharge from the maximum voltage to 0.0 V using galvanostatic discharge characteristics. Such values were used to determine maximum specific energy. Capacitance as well as energy values were calculated per mass of the electrodes in a full device, i.e. for both electrodes (these data are shown in Table I). It is clearly seen that combination of two various electrolytes supplies beneficial capacitor parameters.

**Conclusions**

Activated carbon electrodes were investigated in several aqueous electrolytes with various pH and demonstrated different charge storage phenomena. In order to extend the supercapacitor voltage, hydrogen electrosorption process on negative electrode was examined and discussed. In the case of the positive electrode, several approaches were presented in order to avoid electrolyte decomposition and oxidation. The highest oxidation potential was recorded for 1 mol L\(^{-1}\) \(\text{H}_2\text{SO}_4\) solution, but fast aggravation of the electrode capacitance as well as corrosive properties of acidic medium excluded its further application in supercapacitor. To overcome this obstacle, pH-neutral electrolytes were selected and investigated. Finally, a combination of two electrolytes (alkaline for negative) and neutral (for positive electrode) was favorable to extend capacitor voltage. Therefore, the final conclusions are as follows:

1) Hydrogen electrosorption enhances the maximum limit potential of the negative electrode in alkaline medium.
2) In acidic medium hydrogen is stored weakly (recombination preferred), hence, no enhancement was observed
3) pH-neutral electrolytes based on iodide and thiosulfate demonstrated high capacitance values thanks to their redox activity
4) Activity of iodide/iodine redox couple aggravates hydrogen storage
5) 1.5 V of max. operational voltage of pH-combined electrolyte capacitor with KI and KOH solutions was achieved with good cycling over 16 000 cycles at 1 A g\(^{-1}\)
6) Energy stored in such systems was improved from 10 Wh kg\(^{-1}\) to 17 Wh kg\(^{-1}\) (per mass of two electrodes).

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Table I. Parameters of the symmetric AC/AC capacitors investigated in different electrolytes.

| Electrolyte                        | Specific capacitance of the device* (F/g) | Max. voltage (V) | Max. energy (Wh kg\(^{-1}\)) |
|------------------------------------|-------------------------------------------|------------------|-----------------------------|
| 1 mol L\(^{-1}\) \(\text{H}_2\text{SO}_4\) | 41                                        | 1.19             | 8.1                         |
| 1 mol L\(^{-1}\) \(\text{Na}_2\text{S}_2\text{O}_3\) | 51                                        | 0.98             | 6.8                         |
| 6 mol L\(^{-1}\) KOH               | 37                                        | 1.08             | 6.0                         |
| 1 mol L\(^{-1}\) KI                | 51                                        | 1.20             | 10.2                        |
| 6 mol L\(^{-1}\) KOH / 1 mol L\(^{-1}\) KI | 56                                        | 1.50             | 17.5                        |

*Specific capacitance from galvanostatic discharge based on the mass of two electrodes (without separator, electrolyte and casing)
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