CHAPTER 6

Conclusion and future prospects

6.1 Conclusion

This chapter presents the key conclusions derived from the thesis. Electrochemical capacitors based on the Earth abundant elements have the potential to complement in the current range of energy storage technologies. In this regard, aluminum can play an important role in the energy conversion systems as it is the third most abundant element in the Earth's crust. It has also other advantages such as eco-friendly, ability to transfer three redox electrons per cation, higher volumetric capacity than Li, K, Na, Mg, Zn and Ca. Electrolytes can greatly influence the stability of the devices and storage performances. Aqueous and gel electrolytes are safer in environment compared to the other flammable non aqueous electrolytes. The significant results and focus points of the thesis are concisely summarized chapter wise as provided below.

Chapter 2: Gel electrolyte assisted Al^{3+} ion capacitor with electrospun MoO_3

This study highlights the significant improvement in electrochemical performance achieved by integrating reduced graphene oxide (rGO) with electrospun MoO_3 for Al^{3+} ion capacitors, particularly in gel electrolytes. When compared to earlier works that focused solely on MoO_3 or similar materials in aqueous electrolytes [1-5], the results here demonstrate a marked enhancement in both energy density and power density. Specifically, while MoO_3 alone delivered a modest energy density of 8 Wh kg^{-1} and power density of 7.5×10^3 W kg^{-1} at a current density of 10 Ag^{-1}, the incorporation of rGO into MoO_3 boosted these values to 43 Wh kg^{-1} and 104 W kg^{-1}, respectively. Moreover, electrolyte type played a crucial role in improving the electrochemical performances, long-term cycling stability and self-discharge voltage. For example, in gel electrolytes, the rGO/MoO_3 cell retained 38 % of its charge potential after 21 hours, which is a substantial improvement over the MoO_3 only cell in aqueous electrolyte, which only retained 5 % after 12 hours. This demonstrates that gel electrolytes, combined with rGO enhanced MoO_3 offer superior performance, addressing the common issue of low stability seen in aqueous electrolyte systems. Overall, this work underscores the importance of material design and electrolyte selection in enhancing the energy storage capabilities of Al^{3+} ion capacitors and positions rGO/MoO_3 composites in gel electrolytes as a promising candidate for next-generation energy storage devices.

Chapter 3: Al^{3+} ion capacitor with vanadium oxy-acetylacetonate and polyaniline

This study explores the electrochemical properties of Polyaniline (PANI) and Vanadium-oxy acetylacetonate (VOA) as electrode materials in Al^{3+} ion capacitors. It was found that PANI can interact Al^{3+} ion in the positive potential region where as VOA is in negative potential region. The measured specific capacitance values 182 Fg^{-1} for VOA and 282 Fg^{-1} for PANI at a current density of 1 Ag^{-1}, highlights the favorable electrochemical behavior of both materials. Interestingly, VOA exhibited pseudocapacitance, while PANI provided surface charge storage, suggesting different mechanisms contributing to their overall performance. For the first time, PANI and VOA combined in an asymmetric cell configuration, which demonstrates an excellent electrochemical stability and significantly enhanced performance within the potential range of 0 to 2 V. The cell delivered an energy density of 15 Wh kg^{-1} at a power density of 750 W kg^{-1}, indicating its potential for high performance applications. Compared to other studies [6-9], the results suggest that combining materials with distinct charge storage mechanisms, like pseudocapacitance and surface charge storage, can lead to improved electrochemical performance. The cell’s good stability and efficiency in a practical voltage range make it a promising candidate for advanced energy storage systems.

Chapter 4: Illustration of monovalent and polyvalent ion storage in vanadyl acetate

This study investigates the ion storage capabilities of Vanadyl acetate (VA), in both aqueous and gel electrolytes. For the first time, electrochemical insertion of Na^{+}, Mg^{2+}, and Al^{3+} ions with VA was explored. It was found that VA demonstrated the best cycling stability for Na^{+} ion storage in comparison to other ions. When employed in a symmetric supercapacitor configuration with gel electrolyte of composition 0.5 M Na_2SO_3/silica, it exhibited impressive electrochemical performance. The cell delivered a high energy density of 48 Wh kg^{-1} and a power density of 1800 W kg^{-1}, alongside excellent cycle stability, maintaining 60 Fg^{-1} over 2000 cycles at a current density of 2 Ag^{-1}. This performance, especially in gel electrolytes, underscores the potential of VA as an effective electrode material for energy storage devices. Compared to other electrode materials and electrolytes [10-14], VA’s remarkable performance with Na^+ ions, particularly in gel electrolytes, positions it as a promising material for energy storage applications.

Chapter 5: A study on Al^{3+} ion storage in hydrated vanadate and aluminium doped hydrated vanadate

This study illustrates the Al^{3+} ion storage capabilities of hydrated vanadate (VOH) in both aqueous and gel electrolytes for the first time. The findings reveal that VOH exhibits impressive electrochemical performance for Al^{3+} ion storage. For example, in a 1 M $AlCl_3$ aqueous electrolyte, VOH demonstrated a specific capacitance of 434 Fg^{-1} and maintained a stable capacitance of 208 Fg^{-1} over 100 cycles at a current density of 1 Ag^{-1}. When tested with gel electrolyte, VOH's performance was significantly improved, achieving a specific capacitance of 772 Fg^{-1} and a stable capacitance of 236 Fg^{-1} over the same 100 cycles at the same current density, highlighting the advantage of gel electrolytes in enhancing performance. Furthermore, the electrochemical study of aluminum-doped VOH did not result in any performance improvements compared to pure VOH, suggesting that aluminum doping does not enhance the capacitive behavior of VOH. In summary, compared with previous studies [15-16], VOH with gel electrolytes shows great potential as a high performance material for Al^{3+} ion storage, offering both high capacitance and excellent cycling stability.

6.2 Future Prospects

This thesis focused on different electrode materials for the application of electrochemical capacitors. Some of the future outlooks of this thesis are as follows:

1. Different types of metal oxides, conducting polymers and vanadium based materials may be investigated for electrochemical capacitors using the Earth abundant metal ions.
2. Storage performances can be improved by making different composites materials.
3. Cycling stability can be enhanced using various gel electrolytes.

6.3 References

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