MORFAI JOURNAL Multidiciplinary Output Research For Actual and International Issue

Multidisciplinary Output Research For Actual and International Issue (MORFAI Journal) ISSN (e): 2808-6635
Volumes 5 No. 4 (2025)

UTILIZATION OF ACTIVATED CARBON FROM ELEPHANT GRASS (PENNISETUM PURPEREUM) AND MANGANESE DIOXIDE AS SUPERCAPACITOR ELECTRODES

Erna Frida[1], Syahrul Humaidi[2], and Fathi Marzuqi[3]
[1,2,3]Universitas Sumatera Utara
*Corresponding Author:fthmarzuqi@gmail.com

Received	: 21 April 2025	Published	: 12 June 2025
Revised	: 30 April 2025	DOI	: https://doi.org/10.54443/morfai.v5i4.3146
Accepted	: 16 May 2025	Link Publish	: https://radjapublika.com/index.php/MORFAI/article/view/3146

Abstract

The growing need for sustainable and eco-friendly energy storage solutions has led to advancements in high-performance supercapacitors with extended cycle life. This research explores the fabrication of composite electrodes using activated carbon derived from elephant grass (*Pennisetum purpureum*) combined with manganese dioxide (MnO_2). The carbon material was produced through chemical activation with potassium hydroxide (KOH) and subsequent physical activation using carbon dioxide (CO_2). MnO_2 was incorporated into the activated carbon at various weight ratios (10:0, 7:3, 5:5, 3:7, and 0:10). Morphological and elemental analyses were performed using SEM-EDS, Meanwhile, the electrochemical performance was evaluated using galvanostatic charge-discharge (GCD) tests and electrochemical impedance spectroscopy (EIS). Of all the samples evaluated, the composite containing a 3:7 ratio of carbon to MnO_2 exhibited the highest specific capacitance, reaching 198.51 F/g, highlighting the beneficial interaction between double-layer capacitance and pseudocapacitance. These findings suggest that elephant grass-derived carbon, when effectively combined with MnO_2, presents a cost-effective and environmentally friendly option for next-generation supercapacitor electrodes.

Keywords: ***Activated Carbon, Electrochemical Performance, Elephant Grass, Manganese Dioxide, Supercapacitor***

1. Introduction

With the rising global need for sustainable and eco-friendly energy solutions, the advancement of high-performance energy storage systems has become more essential than ever. Among these technologies, supercapacitors have gained considerable attention due to their superior characteristics, such as rapid charge-discharge capability, long cycle life, and high power density [1]. The performance of supercapacitors is largely determined by the properties of their electrode materials, with activated carbon being widely utilized owing to its large surface area, excellent chemical stability, and decent electrical conductivity[2]. One promising and underutilized source of carbon is elephant grass (*Pennisetum purpureum*), a fast-growing biomass with high lignocellulosic content. This makes it an ideal candidate for conversion into activated carbon through pyrolysis followed by chemical and/or physical activation. Utilizing elephant grass not only provides a renewable raw material for energy applications but also contributes to biomass waste valorization and environmental sustainability.

In addition to carbon-based materials, transition metal oxides—particularly manganese dioxide (MnO_2) have shown great potential in enhancing the electrochemical performance of supercapacitor electrodes. MnO_2 is considered a promising material because of its pseudocapacitive nature, which enables high specific capacitance. Additionally, its low cost, natural abundance, and eco-friendly properties make it even more appealing for energy storage applications. However, its intrinsic low electrical conductivity poses a limitation when used as a standalone electrode material. To address this issue, hybrid electrodes combining activated carbon with MnO_2 have been explored to take advantage of both electric double-layer capacitance (from carbon) and pseudocapacitance (from MnO_2). This synergistic approach is expected to enhance specific capacitance, charge-discharge efficiency, and overall electrode performance. This study focuses on the synthesis and characterization of composite electrodes made from activated carbon derived from elephant grass and MnO_2 in various mass ratios. The materials were evaluated using morphological analysis (SEM-EDS) and electrochemical tests including GCD and EIS. The goal is to assess the potential of this green composite material as an efficient, low-cost, and sustainable electrode candidate for supercapacitor applications.

2. Methodology

This research utilized elephant grass (*Pennisetum purpureum*) as the main precursor for activated carbon, collected from local plantations in Sei Mencirim, Deli Serdang. Additional materials included manganese dioxide (MnO_2) powder with 99.9% purity, potassium hydroxide (KOH) as the chemical activating agent, distilled water for neutralization, polyvinylidene fluoride (PVDF) as a binder, and N-Methyl-2-pyrrolidone (NMP) as a solvent.

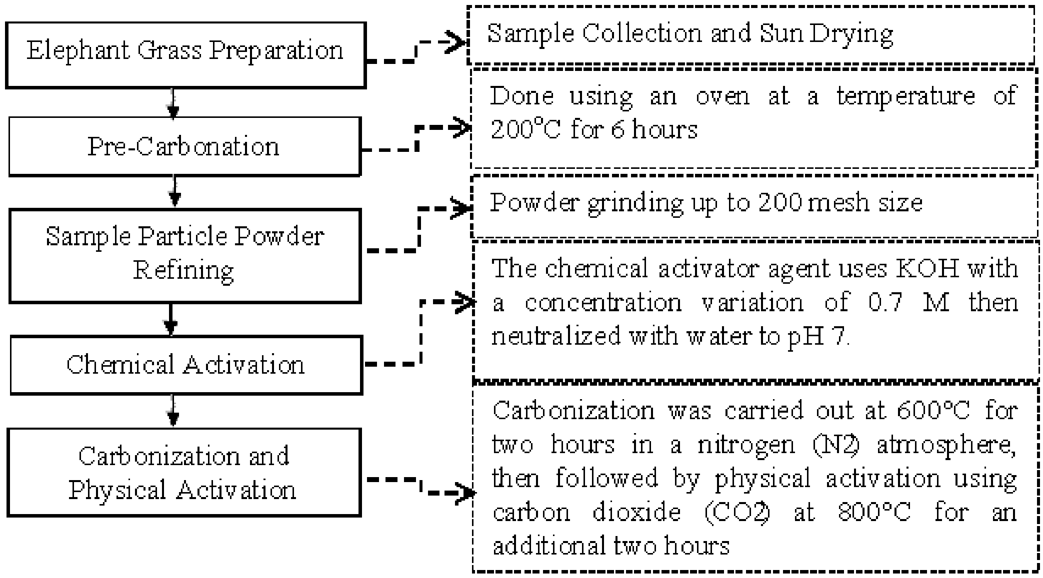


Figure 2.1. Flowchart of activated carbon production from elephant grass

The preparation of activated carbon began with washing and sun-drying the elephant grass, followed by a pre-carbonization process at 200 °C for six hours. The pre-treated biomass was ground and sieved to a particle size of 200 mesh. Chemical activation was performed by soaking the powdered material in 0.7 M KOH solution, which was then rinsed with distilled water until the pH reached neutral. The sample underwent carbonization at 600 °C for two hours in a nitrogen atmosphere to eliminate volatile compounds and strengthen the carbon framework. This process was followed by physical activation with carbon dioxide (CO_2) at 800 °C for two hours to further enhance its surface area and porosity.

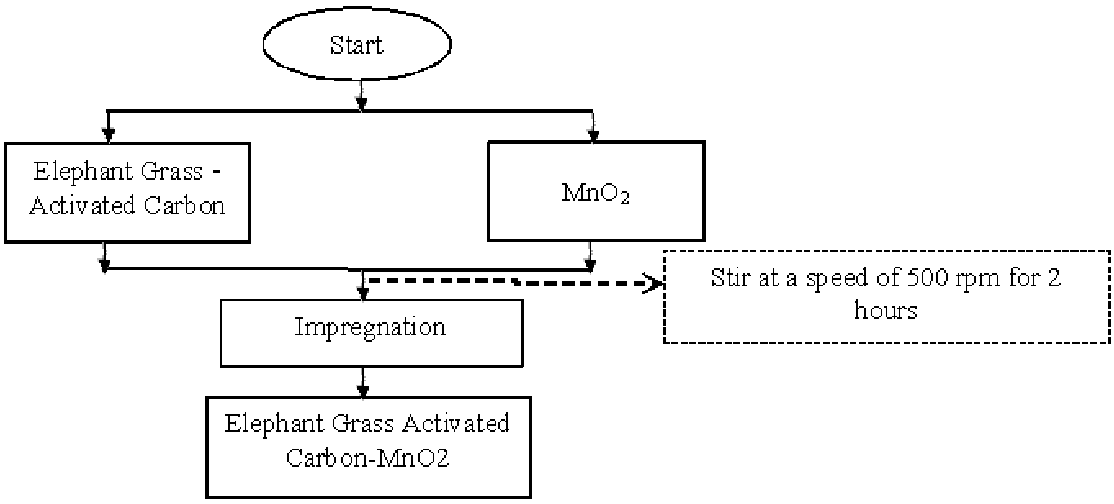


Figure 2.1. Flowchart of activated carbon and manganese dioxide composite fabrication

For the synthesis of the composite electrode material, the activated carbon was blended with MnO_2 powder at varying mass ratios (10:0, 07:03, 05:05, 03:07, and 0:10). The mixtures were stirred magnetically at a temperature range of 60–70 °C and a speed of 200 rpm for one hour to ensure even dispersion. The resulting composites were then dried and stored prior to electrode fabrication.

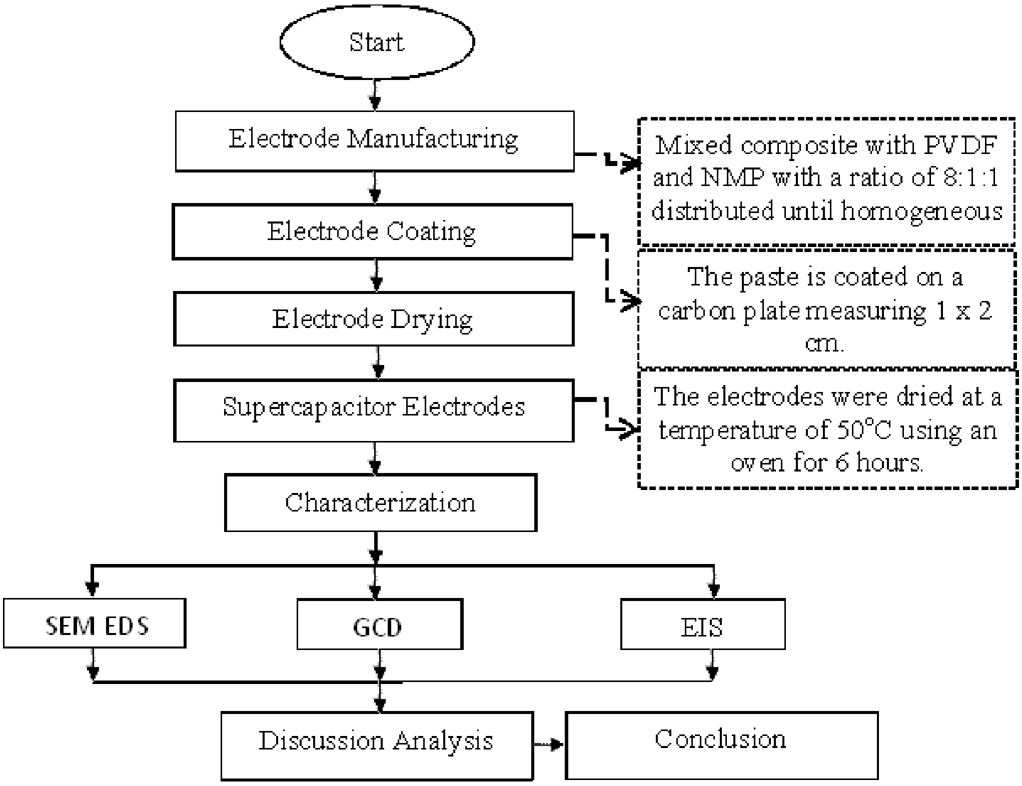


Figure 2.1. Flowchart of supercapacitor electrode fabrication

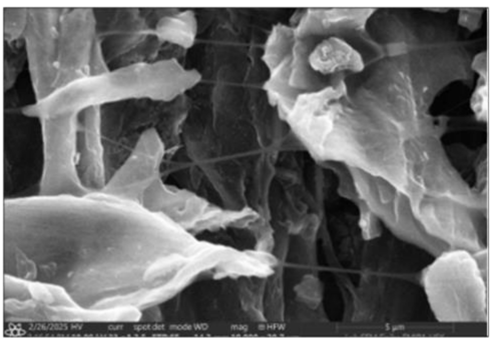
Electrode preparation involved mixing the composite powder with PVDF and NMP in a weight ratio of 8:1:1 to produce a uniform slurry. This slurry was applied to carbon plates with dimensions of 1 × 2 cm, which acted as current collectors. The coated plates were then oven-dried at 50 °C for six hours to complete the electrode formation process.

Characterization of the materials was conducted using SEM-EDS to analyze surface morphology and elemental composition. The electrochemical performance of the electrodes was evaluated through GCD testing to determine specific capacitance, coulombic efficiency, and cycling stability. EIS was also conducted to assess the conductivity and resistance behavior of the electrode materials under different compositional variations.

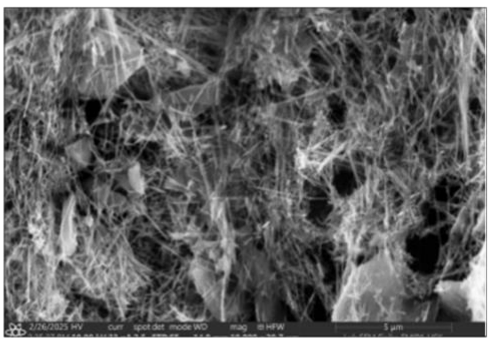
3. Results and Discussion

3.1 Morphological and Elemental Characterization (SEM-EDS)

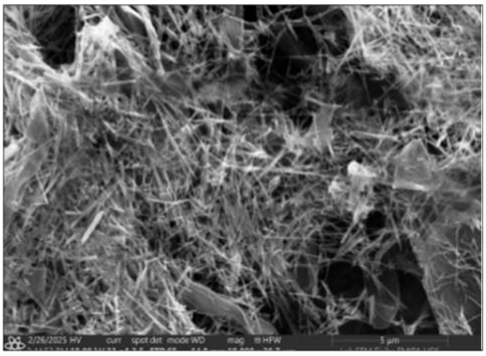
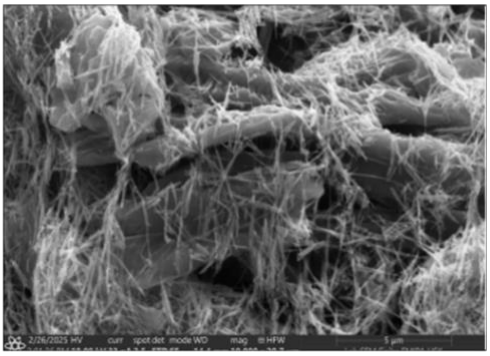
SEM is used with a magnification of 10,000 times for microstructural analysis of the material in order to determine the shape and size of the constituent particles.



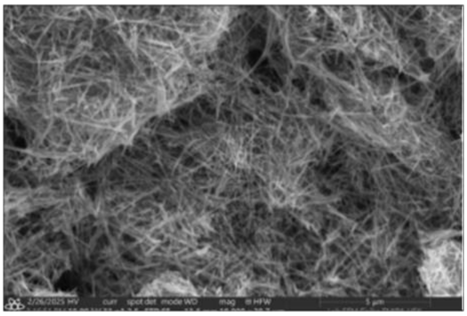
(Ratio 10:0)



(Ratio 07:03)

(Ratio 05:05) (Ratio 03:07)



(Ratio 0:10)

Figure 3.1 SEM results of activated carbon and MnO^2 as supercapacitor electrodes

EDS testing is used to determine the composition and distribution of elements. With the following test results.

Table 3.1 Percentage content of activated carbon and MnO2 elements in a ratio of 10:0

Element	Atom (%)	Mass (%)
C	86.6	79.6
F	5.8	8.4
O	5.7	7.0
Ca	1.0	3.1
Si	0.5	1.1
Mg	0.4	0.7

Table 3.2 Percentage content of activated carbon and MnO2 elements in a ratio of 07:03

Element	Atom (%)	Mass (%)
C	62.0	42.2
O	18.9	27.1
Mn	8.7	17.1
F	7.8	8.4
K	1.2	2.6
Ca	0.6	1.4
Si	0.3	0.5

Mg	0.3	0.4
S	0.2	0.4

Table 3.3 Percentage content of activated carbon and MnO2 elements in a ratio of 05:05

Element	Atom (%)	Mass (%)
C	42.5	40.8
O	31.7	23.9
Mn	15.9	23.8
F	6.9	6.1
K	2.1	3.9
S	0.4	0.6
Ca	0.3	0.5
Si	0.2	0.3

Table 3.4 Percentage content of activated carbon and MnO2 elements in a ratio of 03:07

Element	Atom (%)	Mass (%)
O	38.2	44.5
C	34.0	26.9
Mn	18.4	18.0
F	6.2	5.2
K	2.9	4.9
S	0.4	0.6

Table 3.5 Percentage content of activated carbon and MnO2 elements in a ratio of 0:10

Element	Atom (%)	Mass (%)
Mn	49.8	54.1
O	27.0	29.1
F	9.4	6.5
K	9.3	5.6
C	4.0	4.1

Scanning Electron Microscopy (SEM) was utilized to observe the surface morphology of the electrode materialswhile elemental composition was identified through Energy Dispersive X-ray Spectroscopy (EDS). The SEM images of the pure activated carbon (ratio 10:0) revealed a well-developed porous structure, which is ideal for charge storage through electric double-layer capacitance (EDLC) [3]. However, since no MnO_2 was present at this stage, there was no contribution from pseudocapacitance.

As MnO_2 was gradually introduced, starting at a 7:3 ratio, the particles appeared evenly distributed on the carbon surface. This combination promoted dual-charge storage behavior, incorporating both EDLC from the activated carbon and faradaic reactions from MnO_2 [4]. At a 3:7 ratio, the optimal balance was observed—MnO_2 contributed significantly to charge storage, while activated carbon maintained sufficient conductivity to facilitate electron transport. The SEM images showed a well-connected network of MnO_2 and carbon, suggesting efficient ion and electron pathways. However, at a 0:10 ratio (100% MnO_2), the electrode surface became densely packed, with reduced porosity. This restricted electrolyte ion diffusion, limiting active surface access and thus reducing charge storage efficiency. Furthermore, excessive MnO_2 promoted particle agglomeration, which increased internal resistance and hindered performance [5].

3.2 Galvanostatic Charge-Discharge (GCD) Performance

The Galvanostatic Charge-Discharge (GCD) test serves to evaluate how effectively an electrode can store and release electrical energy. By applying a constant current during both charging and discharging cycles, this method helps determine the electrode's specific capacitance and charge-discharge efficiency. It is a crucial step in assessing the overall performance of supercapacitor electrodes.

Table 3.6 Electrical conductivity of supercapacitor electrodes from activated carbon and MnO^2

Ratio	Spesific Capacitance (F/g)	Specific energy (J/g)	Spesifik Power (W/g)
10:0	130,79	1,675	10,46
07:03	142,53	2,059	12,11
05:05	150,32	2,172	12,77
03:07	198,52	2,868	16,87
0:10	149,33	2,157	12,69

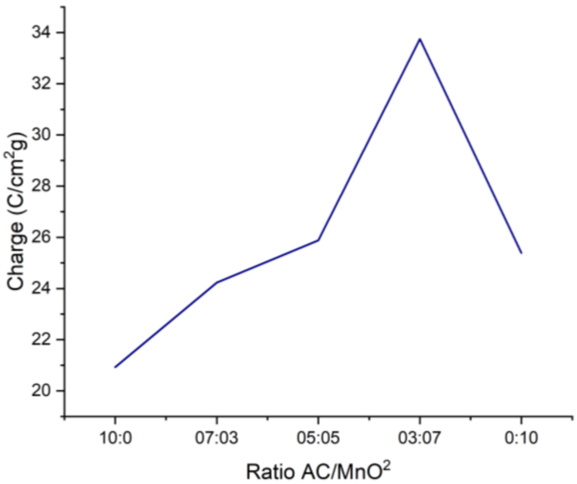


Figure 3.2 Graph of specific charge against the ratio of activated carbon and manganese dioxide

GCD measurements were performed to evaluate the specific capacitance of each electrode composition. At the 10:0 ratio, The electrode demonstrated a specific capacitance of 130.79 F/g, primarily driven by the physical adsorption of ions through EDLC mechanisms. As MnO_2 was added, the capacitance increased due to additional pseudocapacitive contributions. The highest specific capacitance was recorded at the 3:7 carbon-to-MnO_2 ratio, reaching 198.51 F/g. These findings highlight the synergistic interaction between the large surface area of activated carbon and the redox properties of MnO_2. The GCD curve for this composition showed a quasi-triangular shape with good symmetry between the charge and discharge phases, indicating stable and efficient energy storage behavior. Conversely, the 0:10 composition (pure MnO_2) delivered a lower specific capacitance of 149.33 F/g. Although this value was still notable, it came with reduced efficiency due to high internal resistance and the absence of conductive carbon. These findings highlight the importance of activated carbon in improving both electron mobility and surface accessibility for electrolyte ions [6].

3.3 Electrochemical Impedance Spectroscopy (EIS)

EIS was employed to examine the performance of supercapacitor electrodes composed of varying ratios of activated carbon (from elephant grass) and manganese dioxide (MnO_2). Essential electrochemical parameters, including series resistance (Rs), charge transfer resistance (Rct), and ion diffusion characteristics, were analyzed through Nyquist plots, impedance modulus, and phase angle curves.

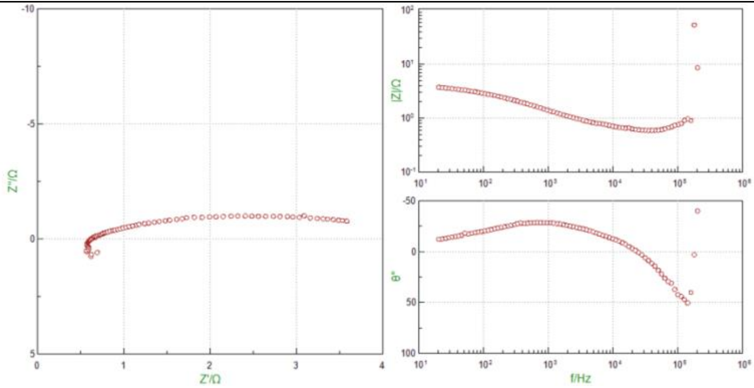


Figure 3.3 EIS Results of the Supercapacitor Electrode at a 10:0 Ratio

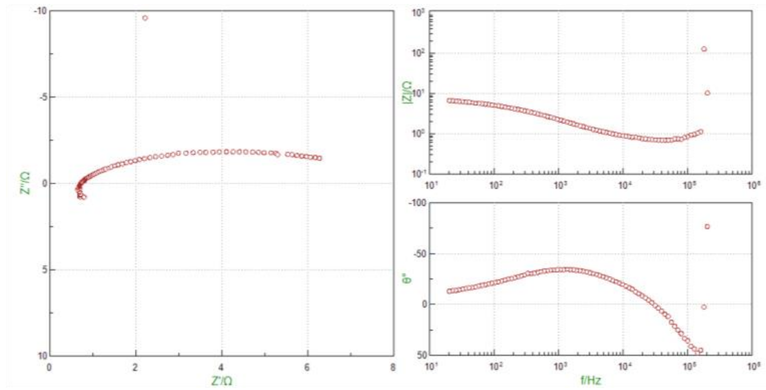


Figure 3.4 EIS Results of the Supercapacitor Electrode at a 07:03 Ratio

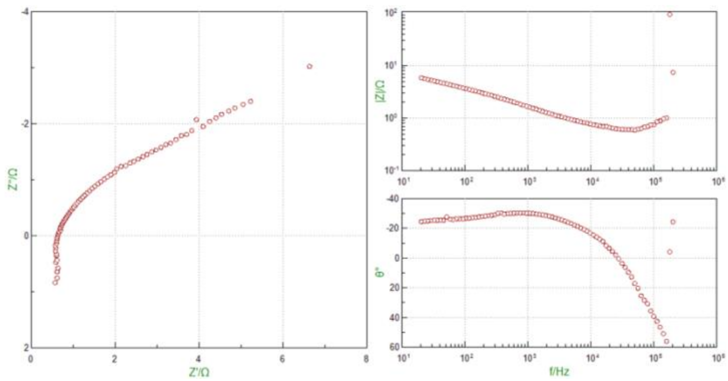


Figure 3.5 EIS Results of the Supercapacitor Electrode at a 05:05

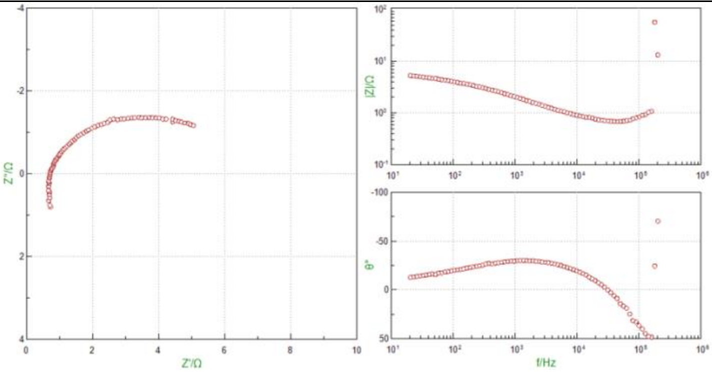


Figure 3.6 EIS Results of the Supercapacitor Electrode at a 07:03

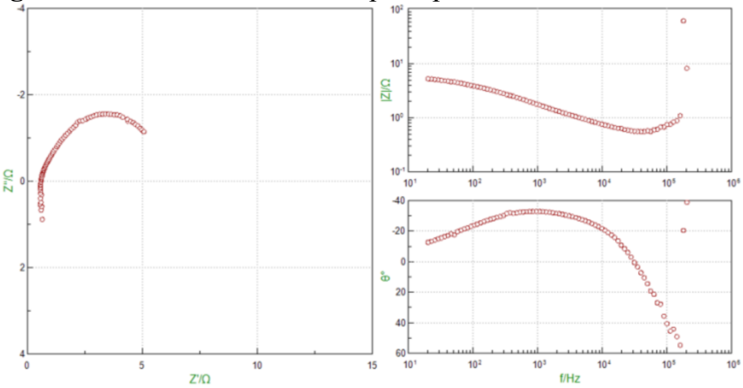


Figure 3.7 EIS Results of the Supercapacitor Electrode at a 0:10

At the 10:0 (pure activated carbon) ratio, the electrode demonstrated excellent capacitive behavior. A low Rs value and the absence of a semicircle in the Nyquist plot confirmed efficient charge transport and negligible Rct, indicating dominant electric double-layer capacitance (EDLC). Furthermore, the absence of a Warburg tail implied fast ion diffusion due to the highly porous carbon structure, making this composition ideal for high-power applications [7]. Introducing MnO_2 at a 7:3 ratio increased Rs and introduced a small semicircle in the Nyquist plot, indicating the onset of pseudocapacitive behavior via surface redox reactions. While this contributed to enhanced energy storage, it also raised internal resistance and slowed ion kinetics. A slight Warburg tail appeared, suggesting moderate ion diffusion constraints.

At a 5:5 composition, the impedance response shifted further toward pseudocapacitive characteristics. Both Rs and Rct increased, with a larger semicircle and a more pronounced Warburg region. This suggests more significant redox activity and hindered ion transport due to MnO_2's denser structure and lower conductivity.

In the 3:7 configuration, MnO_2 became dominant, resulting in a larger Rct and limited EDLC contribution. The Warburg tail became more distinct, and the system showed longer relaxation times—signs of slower charge-discharge processes. While energy storage capacity improved, the electrode's power performance declined.

The 0:10 (pure MnO_2) electrode showed the highest Rct, poor ion diffusion, and sluggish electrochemical response. A large semicircle and vertical Warburg region reflected significant resistance and limited pore accessibility. Although MnO_2 provides high energy storage via redox reactions, its poor conductivity makes it unsuitable for high-power applications.

In summary, increasing MnO_2 content enhances energy storage through faradaic reactions but compromises power performance due to higher internal resistance and slower ion dynamics. The 10:0 composition offers the best balance for fast, high-power supercapacitor operation [8].

4. Conclusion

This study highlights the promising use of activated carbon derived from elephant grass combined with manganese dioxide (MnO_2) as a hybrid electrode material for supercapacitors. The elephant grass-based carbon provided a porous structure and favorable surface characteristics that supported electric double-layer capacitance, while the addition of MnO_2 introduced pseudocapacitive properties that enhanced the overall charge storage. Among the tested ratios, the 3:7 carbon to MnO_2 composition delivered the highest specific capacitance of 198.51 F/g, demonstrating a balanced synergy between the conductivity of carbon and the redox activity of MnO_2. Electrochemical impedance spectroscopy confirmed this performance with the lowest internal resistance, indicating efficient ion transport and charge transfer. These findings suggest that combining biomass-derived carbon with transition metal oxides offers a sustainable strategy for high-performance energy storage materials. Furthermore, using agricultural residues like elephant grass adds environmental and economic benefits, supporting the potential for scalable and eco-friendly electrode production. Future research may focus on long-term stability and integration into real-world energy storage devices to further assess practical viability.

Acknowledgments

The author sincerely thanks the Center of Excellence for Science and Technology at Universitas Sumatera Utara for their generous support and the resources made available during the course of this research. Special appreciation goes to the supervising lecturers and laboratory staff for their insightful guidance and technical help. Gratitude is also extended to fellow colleagues whose thoughtful input greatly contributed to the development of this manuscript. The successful completion of this study would not have been possible without the unwavering support, motivation, and prayers from family members and close friends.

REFERENCES

[1] Y. Zhao, X. Sun, and J. Wang, "Thermal and chemical stability of NMP as a solvent in polymer processing," Polymer Science Journal, vol. 45, no. 6, pp. 312–321, 2019.
[2] Y. Wang et al., "Effect of MnO_2 loading on supercapacitor performance," Materials Chemistry and Physics, vol. 220, pp. 78–89, 2021.
[3] X. Zhang et al., "Recent progress in carbon-based electrodes for supercapacitors," Energy Storage Materials, vol. 32, pp. 123–145, 2020.
[4] J. Lee and D. Kim, "Nanostructured carbon materials for adsorption," ACS Nano, vol. 15, no. 9, pp. 12345–12367, 2021.
[5] J. Zhou et al., "MnO_2 electrode performance in asymmetric supercapacitors," Journal of Materials Science, vol. 55, no. 12, pp. 4860–4872, 2020.
[6] Y. Wang et al., "Pseudocapacitive properties of MnO_2 composites for energy storage applications," Energy Storage Materials, vol. 14, no. 5, pp. 232–245, 2022.
[7] Y. Zhang, X. Liu, and Q. Wang, "Understanding impedance behavior in electrochemical energy storage devices," Journal of Electroanalytical Chemistry, vol. 860, p. 113884, 2020.
[8] Y. Li et al., "MnO_2/carbon composites as high-performance electrodes for supercapacitors," Journal of Power Sources, vol. 417, pp. 1–10, 2019.