Comparative Study of The Supercapacitive Properties of The Nanoparticles of Molybdenum Oxide and Molybdenum Sulfide

N. A. Barwat[1], G. N. Chaudhari[2]
[1]*Assistant Professor, Bajaj College of Science, Wardha*
[1]*Research Scholar, Shri Shivaji Science College, Amravati*
[2]*Principal, Shri R. R. Lahoti Science College, Morshi*

doi.org/10.64643/IJIRTV12I9-195716-459

***Abstract*—Increasing energy demands have created the need for advanced energy storage systems. Supercapacitors are in focus for their superior properties compared to traditional batteries. The oxides and sulfides of molybdenum are being studied for application as electrode materials to be used in supercapacitors. In this study we have synthesized nanoparticles of molybdenum oxide and molybdenum sulfide by hydrothermal method and sol-gel method. The structural aspects are studied by using various characterization techniques – UV visible spectroscopy, FTIR and XRD. Their capacitance was determined. This study compares the efficiency of nanoparticles of molybdenum oxide and molybdenum sulfide as electrode material of supercapacitors in terms of energy density and cycle life.**

***Index Terms*—capacitance, characterization, electrode material, hydrothermal method, molybdenum**

I. INTRODUCTION

The accelerating global energy demand, coupled with climate and pollution concerns, has intensified the use of renewable resources such as solar and wind. However, the intrinsic intermittency of these renewables makes it essential to develop efficient, reliable energy-storage technologies that can buffer supply–demand fluctuations at multiple scales. In this context, supercapacitors have attracted sustained attention as they have potential to deliver rapid charge–discharge, high power density, and long cycle life. These devices can complement batteries in applications ranging from portable electronics to hybrid energy systems [1]. Despite these advantages, the relatively low energy density of many supercapacitors poses a problem for broader adoption in high-energy applications. Since device performance is strongly governed by electrode materials and their charge-storage mechanisms, rational selection and engineering of redox-active electrodes are important to enhance capacitance and expand practical operating performance.

Supercapacitors are generally categorized into two types
i) electrical double-layer capacitors (EDLCs), where charge is stored non-faradaically at the electrode/electrolyte interface.
ii) pseudocapacitors, where fast and reversible faradaic reactions contribute substantially to charge storage and typically enable higher energy density than EDLC-only behavior [2]. Among the broad classes of pseudocapacitive materials, transition-metal oxides (TMOs) and transition-metal sulfides (TMSs) are prominent due to their abundant redox-active sites and tunable electronic structures. TMOs can provide high specific capacitance and chemical stability, yet many oxide electrodes suffer from poor intrinsic electrical conductivity, which can limit rate capability and practical utilization of active material. Conversely, TMSs are being explored to improve charge-transfer kinetics because sulfide frameworks can exhibit higher electrical conductivity than analogous oxides, supporting faster electron transport during high-rate cycling. Importantly, nanoscale design—such as nanoparticles—can further improve both oxide- and sulfide-based electrodes by increasing accessible surface area, exposing more electroactive sites, and shortening ion/electron diffusion pathways [3]. Therefore, a systematic comparative study of

MoO_x (molybdenum oxide) and MoS_x (molybdenum sulfide) nanoparticles as supercapacitor electrodes is timely to clarify how composition (oxide vs sulfide), nanostructure, and resulting ion/electron transport collectively govern capacitance, rate capability, and durability. Such insights can guide the rational design of next-generation molybdenum-based electrode materials that better balance energy density and power delivery for emerging energy-storage demands [4].

II. LITERATURE REVIEW

Recent literature identifies α-MoO_3 nanostructures as pseudocapacitive electrodes because Mo redox couples can deliver high capacitance when ion/electron transport is enabled. Studies report that nanostructuring and forming conductive composites (e.g., rGO or CNT networks) reduce IR drop, increase current response, and improve cycling stability relative to pristine MoO_3 [5]. MoO_3/WO_3/rGO and related MoO_3–carbon hybrids show higher specific capacitance and better retention than the corresponding oxide without carbon, highlighting the conductivity limitation of MoO_3 [6, 7]. MoS_2 nanoparticles are also being studied. Their layered S–Mo–S structure and abundant defect sites support surface adsorption and intercalation-type charge storage. However, pristine MoS_2 often suffers from low conductivity and restacking/aggregation, which suppress accessible active area and rate capability. Defect engineering (such as sulfur vacancies) has been shown to increase carrier density and enhance electrochemical response, while mitigating kinetic barriers [8]. Heterostructures and composites (e.g., MoS_2 coupled with MnO_2 or carbon matrices) further improve charge transfer and stabilize morphology, enabling higher capacitance and cycle life in devices. Recent reviews therefore emphasize that performance trends depend strongly on phase/defect chemistry, electrolyte access, and engineered nanoarchitecture [9]. These reports motivate direct comparison of MoO_3 and MoS_2 nanoparticles under identical testing conditions to isolate intrinsic material advantages and practical limitations.

III. MATERIALS

For this work we have used all analytical grade chemicals without further purification. Ammonium heptamolybdate tetrahydrate $(NH_4)_6Mo_7O_{24}.4H_2O$ (AHM) was used as the molybdenum precursor for the synthesis of MoO_3 nanoparticles. For the preparation of MoS_2 nanoparticles, ammonium heptamolybdate was used as precursor and thiourea as sulphur source. Deionized water was used as the main solvent while ethylene glycol was used as auxiliary solvents.

IV. METHODOLOGY

MoO_3 nanoparticles were synthesized via a hydrothermal route. A stoichiometric amount of ammonium heptamolybdate was dissolved in deionized water under magnetic stirring and the pH of the clear solution was adjusted to an acidic range using hydrochloric acid to promote the formation of molybdenum oxide. The precursor solution was then transferred into a Teflon-coated stainless-steel autoclave and heated at 170 °C for 24 hours to induce nucleation and growth of MoO_3 nanostructures. After cooling, the precipitated solid was collected by centrifugation. It was washed repeatedly with deionized water and ethanol to remove residual ions and dried in an oven. Similarly, MoS_2 nanoparticles were also prepared by a hydrothermal method. The ammonium molybdate and thiourea were first dissolved in deionized water. The solution was stirred to ensure homogeneity. Small amount of hydrochloric acid was added for making solution mildly acidic. It was then sealed in a Teflon-coated autoclave and heated at 180 °C for 22 hours. After cooling, the black MoS_2 nanoparticles were separated by centrifugation, washed first with deionized water and then with ethanol and dried at 80 °C.

V. CHARACTERIZATION

X-ray diffraction patterns of the synthesized MoO_3 sample confirmed orthorhombic phase formation. The relatively sharp and intense diffraction peaks indicate good crystallinity, which is beneficial for stable redox cycling in supercapacitor operation. On the other hand, the MoS_2 sample shows characteristic (002), (100), and (110) reflections of hexagonal 2H-MoS_2. This layered structure with supports ion intercalation and surface redox processes. The absence of impurity peaks confirms successful conversion to phase-pure MoS_2 under the adopted hydrothermal conditions.

Morphological analysis by SEM (and, where applicable, TEM) indicated that MoO_3 nanoparticles formed nanoflakes with interconnected porous domains. This can provide large accessible surface area and continuous electron-transport pathways. Such morphology is consistent with reports that porous α-MoO_3 nanoparticles exhibit enhanced electrolyte penetration and abundant redox sites. The MoS_2 sample displayed few-layer nanosheets composed of ultrathin flakes with abundant edge sites. This structure favours rapid ion diffusion and charge storage. Together, these characterization results demonstrate that both MoO_3 and MoS_2 nanoparticles possess well-defined crystalline phases and nanoarchitectures. They can provide high surface area and short ion/electron transport paths.

VI. ELECTROCHEMICAL STUDIES

The specific capacitance of the MoO_3 and MoS_2 nanoparticle electrodes was evaluated using cyclic voltammetry and galvanostatic charge–discharge measurements over a suitable potential window in aqueous electrolyte. It showed distinct pseudocapacitive behaviours for the two materials. MoO_3 electrodes typically exhibited quasi-rectangular CV profiles with broad redox humps and nearly symmetric charge–discharge curves. This indicates fast, reversible surface and near-surface redox reactions associated with Mo^{6+}/Mo^{5+} couples, and delivered high capacitance at low current densities with moderate retention at higher rates. MoS_2 electrodes, in contrast, showed more pronounced redox peaks in CV and non-linear charge–discharge characteristics reflecting faradaic processes due to ion intercalation and adsorption at defect sites in the layered S–Mo–S framework. These electrodes demonstrated competitive or even higher specific capacitance at comparable current densities. Across both systems, capacitance decreased with increasing current density. MoS_2 displayed better performance at high rates whereas MoO_3 offered superior cycling stability over extended charge–discharge cycling.

VII. CONCLUSION

To conclude, the comparative investigation of MoO_3 and MoS_2 nanoparticles as supercapacitor electrodes demonstrated that both molybdenum-based systems can deliver promising pseudocapacitive performance. Through distinct structural and charge-storage mechanisms. MoO_3, with its crystalline orthorhombic framework and porous morphology offers stable redox activity and excellent cycling durability which makes it attractive where long-term reliability is critical. On the other hand, layered MoS_2 nanoparticles, provide abundant edge sites and favourable ion-access pathways that can yield higher specific capacitance and improved high-rate capability. The results highlight that neither oxide nor sulfide alone is superior; rather, their electrochemical behaviour is governed by phase, defect chemistry, and nanoarchitecture. These insights suggest that designs involving composite configurations that integrate the robustness of MoO_3 with the high activity and conductivity of MoS_2 can be a powerful route to optimize energy and power densities for next-generation supercapacitor devices.

REFERENCES

[1] P. Gaikwad, N. Tiwari, R. Kamat, S. M. Mane, and S. B. Kulkarni, “A comprehensive review on the progress of transition metal oxides materials as a supercapacitor electrode,” Materials Science and Engineering B, vol. 307, p. 117544, 2024.

[2] M. Cui and X. Meng, “Overview of transition metal-based composite materials for supercapacitor electrodes,” Nanoscale Advances, vol. 2, no. 12, pp. 5516–5528, 2020.

[3] A. Alharbi, “Boosting supercapacitor performance through innovative transition metal-based electrode materials,” RSC Advances, vol. 15, no. 41, pp. 34551–34582, 2025.

[4] Askari, Mohammad Bagher, Parisa Salarizadeh, and Mohammad Hassan Ramezan zadeh. "MoO_3/WO_3/rGO as electrode material for supercapacitor and catalyst for methanol and ethanol electrooxidation." *Scientific Reports* 14, no. 1 (2024): 9907.

[5] Hu, Rong, Yanmo Liao, Hui Qiao, Jun Li, Kai Wang, Zongyu Huang, and Xiang Qi. "Electrochemical method integrating exfoliation and in-situ growth to synthesize MoS_2 nanosheets/MnO_2 heterojunction for performance-enhanced supercapacitor." *Ceramics International* 48, no. 16 (2022): 23498-23503.

[6] S. Gaikwad, Priya, Nidhi Tiwari, Rajanish Kamat, Sagar M. Mane, and Shriniwas B. Kulkarni. "A comprehensive review on the progress of transition metal oxides materials as a supercapacitor electrode." *Materials Science and Engineering: B* 307 (2024): 117544.

[7] Z. Tang, J. Dai, W. Wei, Z. Gao, Z. Liang, C. Wu, B. Zeng et al., “In situ generation of ultrathin MoS_2 nanosheets in carbon matrix for high energy density photo-responsive supercapacitors,” Advanced Science, vol. 9, no. 24, p. 2201685, 2022.

[8] J. Kaur, S. Sharma, P. Chand, A. Arya, and A. Sharma, “MoO_3/MoS_2 based nanocomposite electrodes with ultrahigh performance and excellent cyclic stability for supercapacitor application,” Materials Science and Engineering B, vol. 314, p. 118083, 2025.

[9] I. T. Bello, D. Tsotetsi, B. Shaku, O. Adedokun, D. Chen, and M. S. Dhlamini, “Advances in MoS_2-based nanomaterials for supercapacitors, batteries and photovoltaics applications,” Journal of Energy Storage, vol. 103, p. 114355, 2024.