Abstract

Global energy demands are expanding day by day due to rapid industrialization and highly increasing population. Therefore, supply of fossil fuels is about to deplete. To overturn this problem, the use of sustainable energy sources and advanced technologies to store energy is indispensable. Supercapacitors have been considered as contemporary storage devices with numerous boons including high power density, energy density, high capacitance, good retention, and excellent cycling stability. Supercapacitor consists of various components having their own significance but the focus of the research in field of supercapacitor is its electrode material. Electrode material has great influence on performance of supercapacitor.Simultaneously, industrial development has led to a significant increase in the discharge of industrial wastewater into natural water bodies, causing great concern for both human health and aquatic life. In response, researchers are actively exploring sustainable solutions to address this serious issue. Photocatalysis is an efficient, cost-effective, and straightforward technique that utilizes $\cdot OH$ and $\cdot O^{2-}$ radicals under light irradiation to convert pollutants and toxic organic dyes present in water into non-toxic CO_2 and H_2O. Photocatalytic materials are major requirement of the photocatalytic process. Researchers are finding the multipurpose materials that can be used as both supercapacitor electrode material and photocatalytic material. Metal hexacyanoferrates have attracted intense interest as an electrode material for supercapacitor applications and as photocatalysts. Due to their unique structure, high porosity, large surface area, redox yielding nature, multiple valence states, ionic conductivity, redox mediating nature and water insolubility, these materials are considered as beneficial commercial materials as supercapacitor electrode materials and photocatalytic materials. Incorporation of various metallic oxides, carbon-based materials, and metal ions can be done in metal hexacyanoferrate to further enhance its supercapacitive and photocatalytic features. In the present research, we synthesized Copper Hexacyanoferrate based composites for both supercapacitor and photocatalytic applications. Brief details are given as follows, including the methods used and main findings of the work:In first experiment, facile, and cost-effective chemical route is used for the synthesis of Nickel Oxide-Copper Hexacyanoferrate Binary Hybrid Nanocomposite (NiO_2-CuHCF). As-synthesized NiO_2-CuHCF delivers superior specific capacitance of 908 Fg^{-1} at a current density of 2 Ag^{-1} and retains excellent rate capabilities, and outstanding cycling stability (86.5% capacity retention at 4 Ag^{-1} after 1600 cycles) highlighting its potential use for the practical electrochemical energy storage applications. The enhanced electrochemical behavior of NiO_2-CuHCF is attributed to incorporation of nickel oxide which assisted in enhancement of the surface area, active sites and fast charge transfer rate. Furthermore, the redox couples (Ni^{3+}/ Ni^{2+}, Fe^{3+}/ Fe^{2+}, Cu^{2+}/ Cu^{+}) as confirmed by XPS are also responsible for improvement in the electrochemical properties.

In second experiment, Nickel Oxide Coupled Copper Hexacyanoferrate Nanocomposites (NiO_2–CuHCF) are synthesized by employing facile co-precipitation route. 97% degradation of Methyl blue (MB) is observed in just 110 min by NiO_2–CuHCF nanocomposite when exposed to natural sunlight. Moreover, it also retains 92% photocatalytic efficiency over 6 cycles which shows its excellent stability and reusability. The improved photocatalytic performance of NiO_2–CuHCF nanocomposite is attributed to their sheet resembling morphologies which may provide adequate active sites responsible to transport more charge carriers and also reduce charge recombination. In general, this research may open new avenue to use CuHCF with the addition of NiO_2 in future as an efficient degradation agent at industrial level.

In third experiment, we focus on incorporating Cobalt Oxide (Co_3O_4) into Copper Hexacyanoferrate to improve its electrochemical behavior. Remarkably, the study reveals that the specific capacitance of the resulting Co_3O_4-CuHCF composite is as high as 1456 Fg^{-1} at a current density of 2 Ag^{-1}, which is significantly higher than that of pure CuHCF (264 Fg^{-1} at 2 Ag^{-1}). Co_3O_4 sheets coated with CuHCF nanoparticles provide various electroactive surface sites that are responsible for the enhancement of electrochemical behavior of prepared composite when employed as supercapacitor electrode material. The redox couples (Co^{3+}/Co^{2+}, Fe^{3+}/Fe^{2+}, Cu^{2+}/Cu^{+}) as confirmed by XPS also enhance the electrochemical properties. Additionally, the composite material retains 85% of its original value even after 2500 cycles, further demonstrating its exceptional durability and stability. These findings suggest that the Co_3O_4-CuHCF composite has significant potential for use in high-performance energy storage applications.

In fourth experiment, we emphasis on enhancing the photocatalytic degradation capabilities of copper hexacyanoferrate (CuHCF) by adding cobalt oxide (Co_3O_4). The Co_3O_4-CuHCF composite has demonstrated significantly improved photocatalytic behavior 97% MB dye degradation in just 90 minutes. The interconnection between CuHCF nanoparticles and Co_3O_4 sheets promotes the transfer of photogenerated electrons, which lead to improved charge separation and, consequently, enhanced photocatalytic efficiency. Furthermore, the Co_3O_4-CuHCF photocatalyst retains its efficiency for up to six cycles, indicating its potential as a stable solution for treating polluted water resources.

In fifth experiment, we selected Copper Hexacyanoferrate (CuHCF) to achieve more enhanced properties and improve overall performance of the material by incorporating mixed metal oxide Nickel Cobaltite ($NiCo_2O_4$) in CuHCF. The $NiCo_2O_4$-CuHCF composite exhibit the specific capacitance 1980 Fg^{-1} at current density 2 Ag^{-1} and degraded the organic dye upto 97% in just 60 minutes. It is suggested that multi-dimensional composite $NiCo_2O_4$-CuHCF is promising material for its utilization as supercapacitor electrode and an efficient photocatalyst.