Agro-waste-derived functional materials for dye removal: Cocoa nib shell–functionalized gum ghatti grafted poly (acrylamide-co-acrylic acid)

K. Okyere [1], J. E Oduro-Sakyi [2,]

Department of Chemistry, PMB University Post Office, KNUST, Kumasi, Ghana

Kennethokyere23@gmail.com

The sustainability of Africa's aquatic ecosystem relies on the protection of marine and coastal environments, yet pollutants such as dyes from textile, printing, and leather industries pose significant risks to water quality and aquatic habitat [1]. This study addresses this challenge through the development of eco-friendly bio-adsorbents derived from Cocoa Nib Shell (CNS), functionalized Gum Ghatti (Gg), and grafted with acrylamide (AM) and acrylic acid (AA) for Methylene Blue (MB) removal from simulated wastewater.

Bio-adsorbents were synthesized via a microwave-assisted method and structurally characterized using Fourier Transform Infrared Spectroscopy (FTIR), Proton Nuclear Magnetic Resonance (^{1}H NMR), and Zeta potential analysis. Among different filler compositions (3–20% CNS), the 5% CNS formulation exhibited the highest dye removal efficiency of 93.7%. Kinetic and thermodynamic studies identified optimal conditions at 0.3 g dosage, 90 minutes contact time, and pH 9. Adsorption followed the Langmuir isotherm (R^2 = 0.9964) and pseudo-second-order kinetics (R^2 = 0.9998), confirming a monolayer, chemisorption-driven process. Thermodynamic parameters ($\Delta G°$ = -2.71 to -2.78 kJ/mol; $\Delta H°$ = -1.35 kJ/mol) indicated spontaneous and exothermic adsorption.

Spectroscopic evidence revealed functional groups (–COOH, –OH, –$CONH_2$) central to hydrogen bonding and electrostatic interactions with cationic dye molecules. Grafting acrylamide and acrylic acid onto the Gum Ghatti backbone introduced amide (–$CONH_2$) and carboxyl (–COOH) groups, increasing hydrophilicity, surface polarity, and the density of active binding sites, resulting in enhanced adsorption heterogeneity and stronger affinity for methylene blue dye [2]. Zeta potential analysis confirmed a more negative surface charge (-4.09 mV) and nanoscale particle size (646.2 nm), both favouring strong electrostatic attraction under alkaline conditions.

These findings demonstrate the contribution of functional materials and structural science to the design of sustainable, agro-waste-based functional materials for dye removal. The study provides a low-cost pathway to mitigate dye pollution, supporting Africa's broader societal goals of environmental protection and sustainable development.

References:

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