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Nanohybrid LDH/GCN photocatalysts immobilized in alginate beads for estrogens removal under dynamic flow conditions

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Steroidal estrogens such as estrone (E1) and 17α-ethinylestradiol (EE2) are persistent endocrine-disrupting compounds that pose significant environmental and health risks even at trace concentrations. Conventional wastewater treatment processes are often insufficient for their effective removal, motivating the development of advanced remediation strategies. In this study, a visible-light-active Ag-modified LDH/GCN nanohybrid heterostructure (AgH) was developed and evaluated for E1 and EE2 degradation [1,2], with particular emphasis on translating high photocatalytic activity from batch systems to dynamic flow conditions through alginate encapsulation.

Under static conditions, the powdered AgH heterostructure exhibited outstanding photocatalytic performance, achieving more than 99.5% removal of E1 and EE2 (initial concentration 1 ppm) within 40 min of visible-light irradiation (150 W LED lamp, 120 000 lx) at a material loading of 50 mg per 100 mL. To enable photocatalyst recovery and operation in continuous systems, the photocatalyst was immobilized in calcium-crosslinked alginate beads. The AgH content was systematically varied from 10 to 70 wt.% to optimize mass transfer, mechanical stability, and photocatalytic efficiency. Among the tested materials, the beads containing 40 wt.% AgH showed the best performance and structural integrity.

The optimized composite (Alg-AgH40) was subsequently tested in a packed-bed photoreactor operating under continuous flow in a closed system. In dynamic conditions, using 3.2 g of immobilized photocatalyst in 320 mL of solution, the system achieved over 95% removal of E1 and EE2 from an initial concentration of 1 ppm within 3 h of visible-light irradiation (30 W, 240 LED lamps, 115 000 lx). These results demonstrate that alginate encapsulation effectively preserves the high activity of the powdered photocatalyst while enabling its application in flow-through systems that better reflect real water treatment conditions.

The presented approach highlights alginate immobilization as a simple and scalable strategy for deploying highly active powdered photocatalysts in dynamic remediation systems, bridging the gap between laboratory batch studies and practical water treatment applications.

References:

[1] Jędras, Matusik, Dhanaraman, Fu & Cempura (2024), Langmuir 2024, 18163–18175.

[2] Jędras, Matusik, Kuncewicz, Sobańska (2025), Catalysis Science & Technology 2025, 6792–6804.

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