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Upcycling treated MSWI-FA for efficient phosphate removal

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The upcycling of purified Municipal Solid Waste Incineration Fly Ash (MSWI-FA) is a sustainable method for reducing eutrophication by effectively removing phosphate from effluent. In batch experiments, the highest phosphate removal efficiency (~70%) was found in finer MSWI-FA particles (-75 μm). This was due to the high calcium oxide (CaO) content and increased surface area, which facilitated both adsorption and chemical precipitation. The pH factor had a substantial impact on the removal efficiency, which reached its maximum at approximately 70% at pH 6. It was due to the optimal precipitation of insoluble calcium phosphate compounds. However, the removal efficiency decreased at extreme pH levels due to surface protonation from occurring (pH 2–4) and competition with hydroxide ions (pH >7). Contact time analysis showed that phosphate uptake was rapid in the first 8 hours, with a removal rate of 65%. Equilibrium occurred at 48 hours, with a removal rate of approximately 70%. The interaction mechanisms between MSWI-FA and phosphate ions were clarified by adsorption isotherm models, and structural modifications were confirmed by FTIR analysis post-adsorption. Upcycled MSWI-FA presents a promising solution for solving eutrophication, a significant environmental concern that is caused by excessive phosphate discharge and results in the degradation of aquatic ecosystems, hazardous algal blooms, and oxygen depletion. This results in effectively reducing phosphate concentrations. This study emphasizes the dual advantages of waste valorization and water pollution mitigation, therefore calling for MSWI-FA as a cost-effective, circular economy-based adsorbent for sustainable phosphate management However, the effectiveness of upcycled MSWI-FA may vary depending on its composition and the specific environmental conditions, which could limit its applicability in diverse settings. Additionally, reliance on this method might divert attention from addressing the root causes of phosphate discharge, such as agricultural runoff and wastewater treatment inefficiencies.