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Process optimization and application of a charcoal-ceramic composite to treat cesium-contaminated aqueous waste

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The decommissioning of the Fukushima Daiichi Nuclear Power Station faces a critical bottleneck: the continuous accumulation of over 1.25 million m^3 of radioactive wastewater. While the Advanced Liquid Processing System (ALPS) reduces radionuclide concentrations, the resulting volumes still require secondary treatment to meet regulatory discharge limits. This study evaluates a charcoal-ceramic composite derived from locally sourced biomass (cedar/cypress) as a sustainable, cost-effective sorbent for radionuclide volume reduction. The composite was synthesized by coating charcoal with porous ceramics and firing at 700–800°C. The material was optimized using a 'washing' protocol, determining that four washing cycles maximized cesium (Cs) retention by removing competing natural impurities (Ca, K, Mg, Na) and creating active vacancy sites. Characterization via SEM, BET, and XPS confirmed a stable, mesoporous structure ideal for sorption. Batch experiments indicated that Cs sorption reached equilibrium within 1 h, following pseudo-second-order kinetics (R^2 = 0.999), suggesting chemisorption as the rate-limiting step. Isotherm data fitted the Langmuir model well (R^2 > 0.98), indicating monolayer sorption with a maximum capacity (q_m) of 6.46 mg/g. The mechanism involves a synergistic combination of ion exchange, electrostatic interaction, and surface complexation. Validation using real contaminated water from *Suzuuchi* Pond (Fukushima) achieved a quantitative retention rate of ~99% for r-Cs. The results suggest that the optimized charcoal-ceramic composite offers a scalable and environmentally friendly solution for the secondary treatment of cesium-contaminated aqueous waste.