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Combined Physicochemical Processes for Quaternary Wastewater Treatment

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This study investigates the effectiveness of combined coagulation, sand filtration, and ozonation for advanced treatment of wastewater effluent from a municipal wastewater treatment plant. Coagulation using $FeCl_3$ followed by sand filtration served as a pre-treatment step prior to ozonation. This approach proved to be essential not only for partial pollutant removal but also for enhancing the efficiency of subsequent ozonation. The pre-treatment significantly improved water quality, achieving a 51% reduction in COD_{Cr} (from 21.8 to 10.67 mg/L), a decrease in total nitrogen from 35.9 to 30.5 mg/L. Total phosphorus was effectively removed to below the detection limit (<0.033 mg/L), essentially confirming the high efficiency of phosphorus precipitation by inorganic salts. In addition to chemical parameters, a significant reduction in microbial contamination was observed. Coliform bacteria and *Escherichia coli* were reduced by approximately two orders of magnitude, while thermotolerant coliform bacteria and intestinal *Enterococci* decreased by up to three orders of magnitude after coagulation and filtration. Ozonation was applied at different generator outputs (20%, 40%, and 60%), with relatively small differences in removal efficiency between the tested conditions. However, pre-treated samples consistently showed higher pollutant removal compared to untreated wastewater. Ozonation of raw effluent resulted in minimal improvements in COD_{Cr} and nitrogen removal, highlighting the importance of pre-treatment. Complete microbial inactivation was achieved after ozonation, demonstrating its strong disinfection capability without the addition of residual chemicals. Kinetic analysis of COD_{Cr} degradation indicated that the process does not follow zero-order kinetics. Instead, a second-order kinetic model provided the best fit with coefficient of determination $R^2 = 0.9328$, suggesting a non-linear reaction mechanism. Overall, the combined application of coagulation, sand filtration, and ozonation represents an effective quaternary treatment strategy, significantly improving physicochemical and microbiological water quality and supporting the safe reuse of treated wastewater.

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