Effects of CeO_2 Nanoparticles on the Efficiency and Stability of Biological Wastewater Treatment Systems

López Alvarado, D.[1], Cuevas Rodríguez, G.[2]

Environmental Engineering Laboratory, Engineering Division, University of Guanajuato, MEX.

E-mail: d.lopezalvarado@ugto.mx [1], german28@ugto.mx [2]

Introduction

The industrial use of Cerium Oxide Nanoparticles (CeO_2 NPs) has increased their presence in wastewater treatment plants (WWTPs). These emerging contaminants can interact with microbial flocs, potentially inducing oxidative stress and inhibiting key metabolic enzymes such as polyphosphate kinase. While their interference in biological processes is known, there is still a lack of knowledge regarding dose-dependent effects on simultaneous COD and phosphate removal under cyclic conditions. Most studies focus on acute exposure, overlooking the operational stability across multiple cycles, which is critical for maintaining metabolic pathways like phosphorus accumulation and release. This study represents the initial phase of the research, focusing on the stabilization of activated sludge batch reactors under CeO_2 NPs exposure. The primary goal was to evaluate the impact of different CeO_2 concentrations (1, 10, and 60 mg/L) on reactor stability and treatment efficiency, specifically monitoring soluble COD and phosphate removal, pH dynamics, and overall microbial system behavior across 48-hour cycles. This stabilization phase is essential to establish the baseline for subsequent kinetic studies, which will further characterize the dose-dependent effects of CeO_2 NPs on various response variables within these biological systems.

Next Steps: Detailed kinetic monitoring and metabolic response analysis.

Methodology

The experimental setup and the chronological stages of the research—from nanoparticle preparation to reactor stabilization and response monitoring—are integrated and detailed in the following Flow Diagram (Figure 1). This systematic approach ensured operational stability before proceeding to subsequent kinetic analyses.

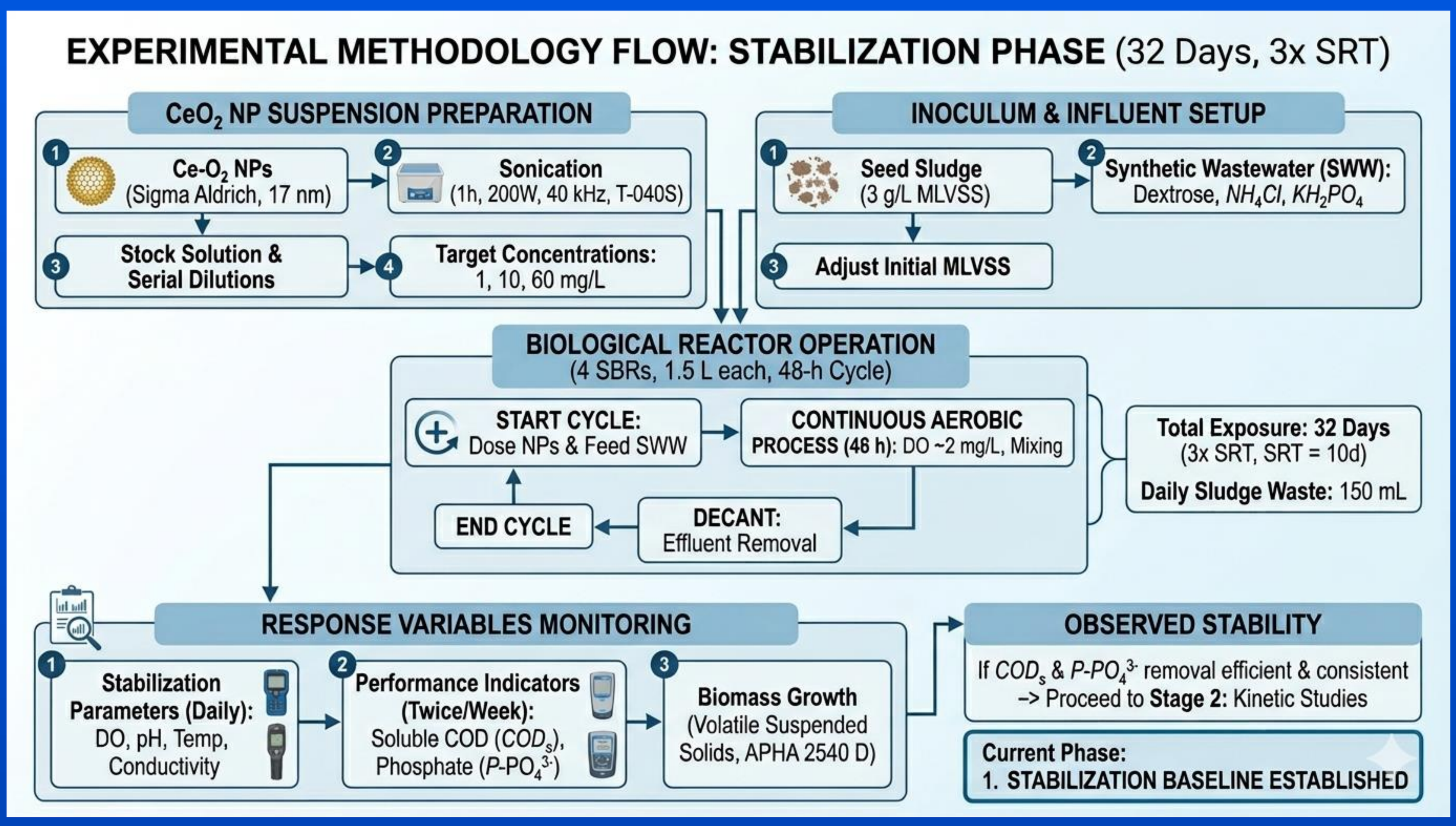

Figure 1: Experimental Workflow

Sludge Waste Control: A constant SRT of 10 days was maintained by a daily purge (**V_{purge}**) of 150 mL. This volume was determined by the mass balance:

$$V_{purge} = \frac{MLSS \cdot V_{reactor}}{SRT \cdot MLSS_{purge}} = 150 \text{ ml/day}$$

Where **MLSS** is the biomass concentration (3,000 mg/L), **$V_{reactor}$** is the working volume (1.5 L), and **$MLSS_{purge}$** represents the solids in the waste stream.

Results & Discussion

Physicochemical Monitoring and System Stability

Longitudinal monitoring confirmed a resilient operational environment, with stable mesophilic temperatures (22–25 °C), consistent conductivity (800–900 uS/cm), and adequate biomass levels (2.6–3.9 g/L SSV) across all treatments (Figure 2). While the control and 10 mg/L reactors exhibited persistent acidification (pH < 5), the 1 mg/L dose promoted a significant shift toward neutrality (approx 7.6) after day 22, likely due to the catalytic buffering capacity of CeO_2 NPs (Ce^{3+}/Ce^{4+}), which favored organic matter degradation and enhanced phosphorus removal.

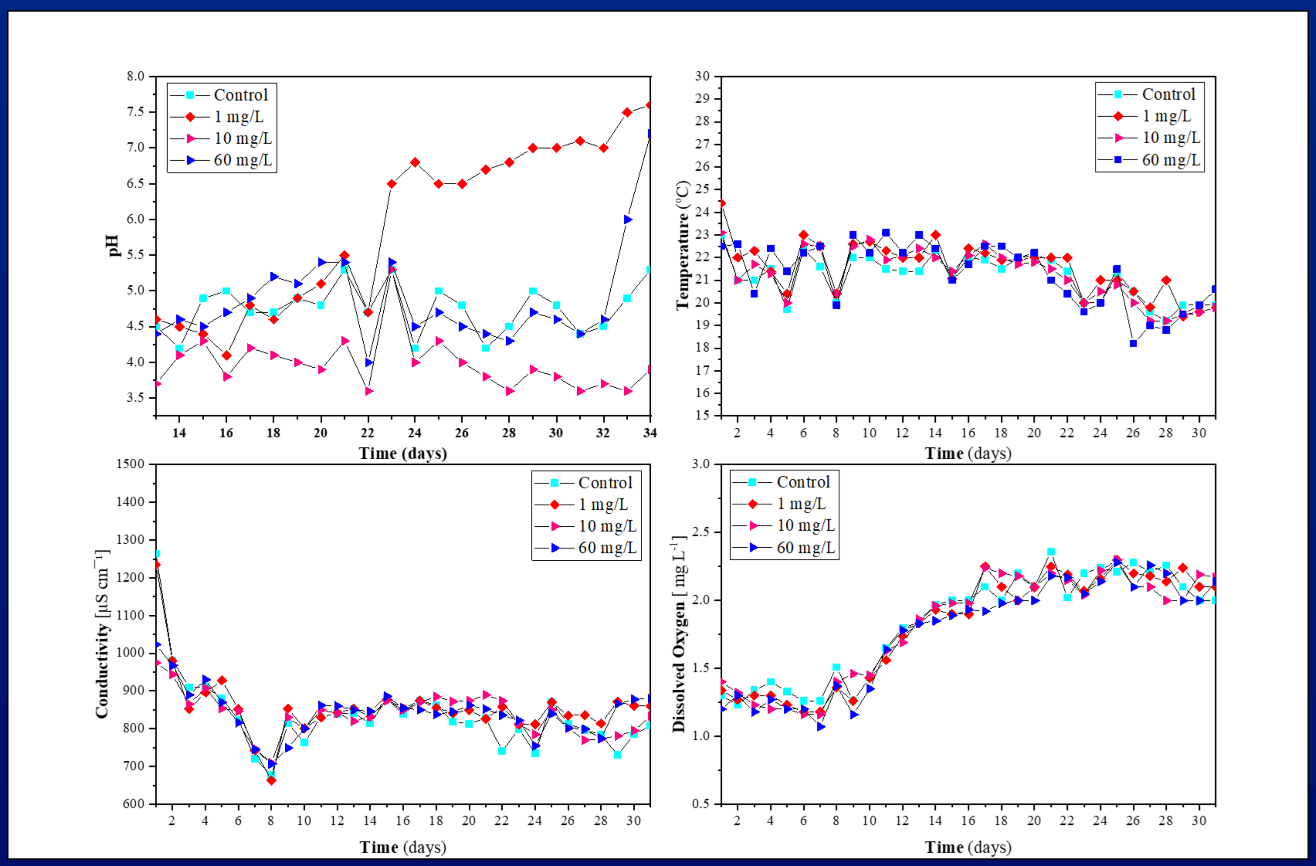

Figure 2: Operational environment parameters

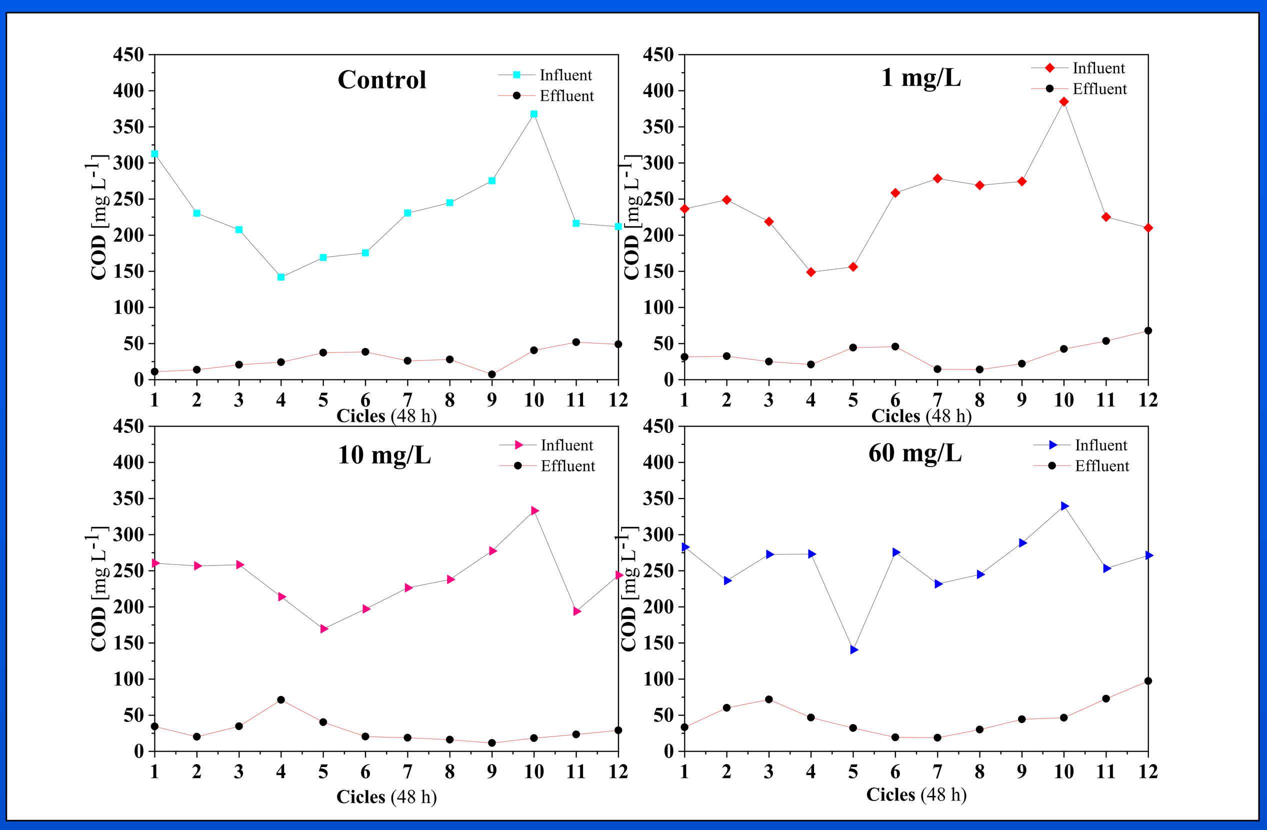

Figure 3: COD removal in biological reactors

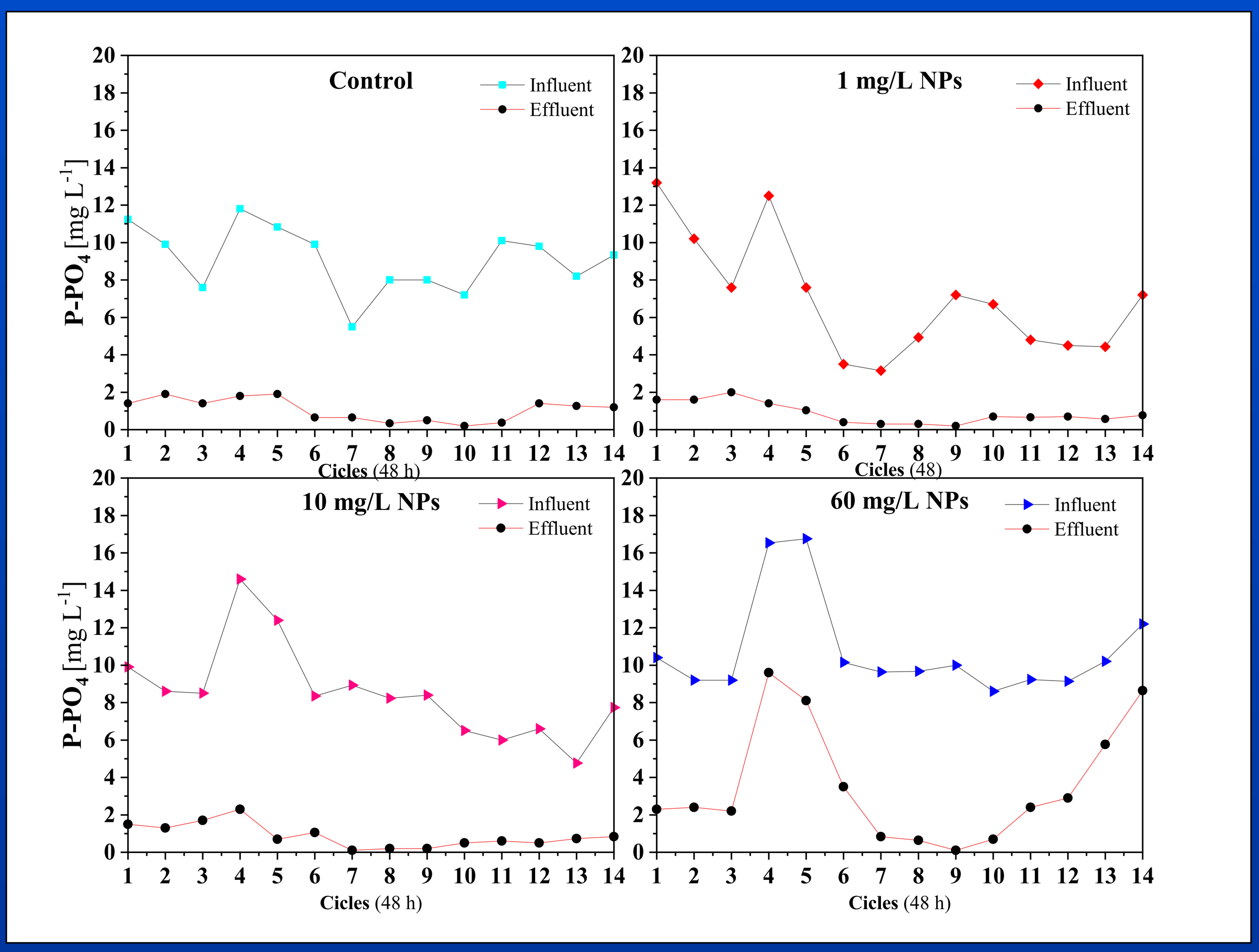

Figure 4: Phosphorus removal in biological reactors

High NP exposure (60 mg/L) induced a critical transient instability—marked by a sharp increase in effluent COD and phosphorus during cycles 4 and 5—attributed to oxidative stress and enzymatic inhibition. The subsequent recovery in phosphorus removal is primarily linked to the formation of insoluble cerium phosphate phases ($CePO_4$) and surface adsorption, combined with microbial adaptation. By the final cycles (7–10), effluent quality stabilized with removal efficiencies exceeding 90% for both COD and $P\text{-}PO_4^{3-}$ in all treatments, proving that the activated sludge process maintains long-term functional stability under CeO_2 nanoparticle pressure (Figures 3 and 4).

Conclusions

CeO_2 NPs exhibit dose-dependent effects on reactor stability. Low concentrations (1 mg/L) acted as a favorable buffer, maintaining neutral pH (approx 7.6) and optimal metabolic activity. Conversely, higher doses (10–60 mg/L) induced transient instability—including biomass fluctuations and residual phosphorus peaks—likely due to oxidative stress and enzymatic inhibition. Despite these perturbations, the system demonstrated high resilience; all treatments achieved >90% removal efficiencies by the final cycles, confirming successful microbial adaptation to nanoparticle pressure.

The authors would like to express appreciation for the support of the sponsors: Guanajuato Uiversity and SECITHI