Abstract

The aim of this study was to develop guidelines for the design, operation, and implementation of a modular system for phosphorus removal from wastewater using Rockfos® material. In the laboratory phase, a P-filter model with meander flow was developed, in which vertical baffles forced the wastewater to extend its contact time. It was demonstrated that under laminar flow conditions, the pressure drop is described by the Kozeny-Carman equation. The study also analyzed the effect of operating conditions and parameters on phosphate sorption efficiency, taking into account different initial phosphate concentrations in the solution, temperature, and granulation of the sorption material. It was found that both higher temperature and larger initial concentration favored sorption, while the effect of particle size was ambiguous. Analysis of sorption isotherms demonstrated good agreement with the Langmuir model. Furthermore, the results of thermodynamic parameters and the separation coefficient confirmed that sorption is largely irreversible (chemisorption), and that the process proceeds spontaneously and endothermally throughout the entire temperature range studied. Phosphorus sorption kinetics studies showed that the process was best described by a pseudo-second-order kinetic model, indicating the dominance of chemisorption.

During the implementation phase, after a year of operation of the wastewater treatment plant, the full-scale P-filter was modified by introducing baffles forcing a meandering flow. Hydraulic analysis showed that in the full-scale filter before the modification, the presence of dead zones limited phosphorus removal efficiency (average 9.4%). After the modernization, efficiency increased to 40.1%, reaching 42.6% throughout the entire study period (May 2022 – July 2025). Additionally, a significant effect of the filter on pH, turbidity, electrolytic conductivity, total alkalinity, and BOD_5 was demonstrated, while no effect on total nitrogen or COD concentrations was observed.

The obtained results confirm the suitability of the Rockfos® material as an active sorption bed. The use of a meander flow filter increases the efficiency of phosphate retention, and the determined Rockfos® sorption parameters can be the basis for designing effective filtration systems in small and medium-sized wastewater treatment plants, ensuring compliance with environmental requirements.

Keywords: wastewater treatment phosphorus removal; Rockfos® material, meander-flow, phosphorus sorption