ABSTRACT
IMMOBILIZED PHOSPHATE-BINDING PROTEIN SYSTEMS TO REMOVE AND RECOVER PHOSPHATE

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Inorganic phosphorus (P_i) is a critical element for all life and a major component of our DNA backbone. Rapid growth and high crop productivity requires P_i to support global agriculture. Yet, the P_i needed for cellular growth is in short supply in nature, and P_i reserves are unevenly distributed around the world. In contrast, surplus P_i in water poses a serious pollution problem as it can cause eutrophication. Scarcity of non-renewable P_i resources combined with pollution in the form of overabundant P_i presents a phosphorus paradox. Tackling this issue is necessary and using innovative approaches targeting P_i removal to ultra-low levels with subsequent recovery for reuse applications can help.

The purpose of this research was to provide insights on potential sustainable solution to simultaneously remove and recover P_i under controlled conditions by utilizing the phosphate-binding protein PstS (PBP). PBP is naturally expressed by many microorganisms as it is responsible for P_i transport into cells under conditions of low surrounding P_i levels. High affinity and selectivity towards P_i even at low concentrations is a superior advantage for removal and recovery efforts addressing the phosphorus paradox. Utilizing PBP as an adsorbent offers a potential sustainable treatment option for P_i removal and recovery from water/wastewater.

This research investigated three prospective immobilized PBP systems to evaluate their performance for P_i removal and recovery. Surface-displayed PBP on the outer membrane of E. coli was designed, characterized, and tested for P_i capture and release. Increasing temperature and ionic strength increased phosphate release by 20% and 50%, respectively. Both acidic and basic pH conditions promoted P_i release from cells induced to over express PBP. Surface-displayed PBP systems increased P_i release under controlled conditions compared to periplasmic PBP overexpressed in the periplasm and control cells without PBP overexpression.

Micro-structured immobilized PBP (PBP-NHS resin) was tested in a fixed-bed column configuration. Highly selective P_i separation was observed, and there was no significant decline in the column’s performance over three consecutive cycles in either synthetic solution or tertiary wastewater, substantiating PBP-NHS resin’s reusability. Resin capacity was unaffected by competing anions, whereas a comparative LayneRT™ ion exchange column experienced a 20% drop in capacity in the presence of other anions.

A PBP-loaded iron oxide particle adsorbent (PBP-IOPs) was shown to improve P_i adsorption capacity. The PBP-IOPs offered rapid P_i adsorption kinetics, with near-complete removal in less than 5 min. The P_i adsorption isotherms showed that adsorption was best described as a monolayer adsorption mechanism (Langmuir). Higher P_i removal was observed at room temperature, low ionic strength, and slightly acidic conditions. The PBP-IOPs released 99% of total adsorbed P_i whereas IOPs alone (without immobilized PBP) released only 12%, such that PBP-IOPs offer enhanced potential for P_i recovery.