Microbiological Basis of Phosphate Removal in the Activated Sludge Process for the Treatment of Wastewater

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Abstract. Several strains resembling members of the Acinetobacter-Moraxella-Mima group of bacteria were isolated from activated sludge-type sewage treatment plants designed for phosphate removal. The bacteria are obligate aerobes but utilize as carbon and energy sources low-molecular intermediates generated anaerobically, particularly acetate and ethanol. These bacteria can be shown to be responsible for the phosphate luxury uptake occurring in these treatment plants. The bacteria are physiologically unusual in that they perform luxury uptake of phosphates in a complete growth medium. Phosphate release occurs on addition of a carbon source to the carbon-starved bacteria, lowering pH or both. The bacteria persist in the system by virtue of their ability to form floc.

Removal of phosphates from wastewater is important in order to protect lakes and other natural waters from cultural eutrophication. Conventional biological treatment processes remove only 50% or less of the sewage phosphate, and substantial improvement is needed to achieve 90% or more removal to reach effluent concentrations of 0.5 to 1.0 mg phosphate per liter. This can be accomplished by chemical means either in physical-chemical treatment processes or as part of the activated sludge process of wastewater treatment [22]. In these processes, salts of iron, calcium, or aluminum are added to form sparingly soluble phosphates, which are then removed by settling.

Observations at treatment plants in San Antonio, Texas [23] and Baltimore, Maryland [15] have indicated that activated sludge can accumulate substantial amounts of phosphorus without chemical additions. A controversy has arisen as to whether such accumulation is a biological phenomenon or a chemical effect. In the latter case the calcium from naturally hard water presumably forms an insoluble phosphate on the activated sludge floc during aeration, when carbon dioxide is expelled and the pH rises, and the precipitate is again dissolved in the settling tank, when respiratory carbon dioxide accumulates and the pH value decreases. This purely chemical mechanism, which has been advanced particularly by Menar and Jenkins [13], resembles calcium phosphate deposition on the surface of algal cells in high phosphate media under the effect of a light-dark cycle [3].

By contrast, Levin and Shapiro [10, 19, 20] advanced the theory that aeration promotes the uptake of excess phosphate by activated sludge bacteria, while lowering the pH value or anaerobiosis causes this phosphate to be released.
into the medium. Inhibition of phosphate accumulation by 2,4-dinitrophenol tends to support the idea of biological uptake. Such a mechanism would permit a "stripping" of phosphates from sewage during sludge aeration and a release into a much smaller volume during extended settling, when anaerobic conditions prevail. From the concentrated supernatant in the settling tank the phosphates can be removed chemically with greater efficiency than is possible with the wastewater.

Such processes have in fact been developed on a purely empirical basis. An aerobic-anaerobic cycle has been incorporated into the Seneca Falls, New York wastewater treatment system ("Phostrip" Process by Biospherics, Rockville, Md.), while a conventional flow scheme is adhered to at the City of Baltimore Back River Wastewater Treatment Plant [15]. At the Baltimore plant, operators report that phosphate removal efficiencies have been quite variable. We believe, and our results confirm, that such failures are the result of the poor understanding of the underlying mechanisms and, as a consequence, poor process control.

Prediction from biological theory would be that under the conditions of the activated sludge process, phosphate accumulation by bacteria in excess of immediate need ("luxury uptake") is a highly unlikely event. Luxury uptake typically occurs when growth is arrested by lack of a nutrient other than phosphate and of a source of carbon and energy. (An energy source is required for phosphate uptake. Also required but rarely ever limiting are potassium as a neutralizing cation and magnesium as a cofactor [7].) In the activated sludge process, by contrast, with domestic wastewater as the substrate, bacterial growth is limited by the supply of carbon and energy sources, while all other nutrients are present in excess.

A phenomenon often confused with luxury uptake is the "phosphate overplus phenomenon," which also consists of uptake in excess of immediate need and which occurs when phosphate-starved microorganisms are transferred into a phosphate-rich growth medium [24]. Since phosphate starvation does not occur at any step in the treatment of domestic wastewater, the overplus phenomenon is not likely to occur.

The more recent literature gives conflicting evidence with regard to the biochemical nature of the phosphate stored in activated sludge. Some describe it as an acid-soluble granular polyphosphate [16] and others as an acid-soluble fraction [28].

In preliminary experiments with a bench-scale activated sludge plant which had been run under completely aerobic conditions with synthetic sewage [25] and which contained mainly zoogloea-type bacteria and a variety of Pseudomonas and Flavobacterium, we were able to reproduce the reversible chemical precipitation of phosphate on the floc as a function of water hardness. We could also demonstrate the capability of the bacteria for luxury uptake of phosphate and for the