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Review

Recent advances in nutrient removal and recovery in biological and bioelectrochemical systems

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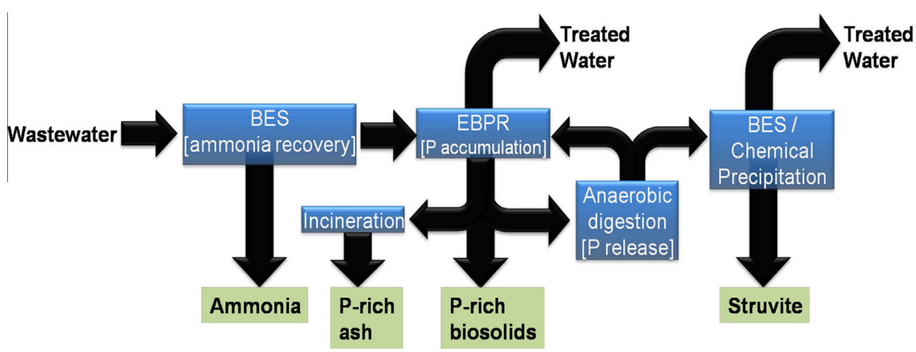
HIGHLIGHTS

- Recent trends in nutrient removal and recovery are reviewed and summarized.
- Bioelectrochemical systems are promising for recovering ammonium nitrogen.
- Recovery of lost phosphorus from sewage and livestock waste allows P sustainability.
- Recovery of valuable reusable phosphorus products from P-rich biomass is needed.
- Integration of biological and bioelectrochemical systems allows developing new waste biorefineries.

GRAPHICAL ABSTRACT

Wastewater biorefinery concept: integration of biological and bioelectrochemical systems (BES) for recovering nitrogen and phosphorus from wastewater. BES are promising technologies for niche applications, i.e. for recovering nutrients from nutrient-rich waste streams.



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ABSTRACT

Nitrogen and phosphorous are key pollutants in wastewater to be removed and recovered for sustainable development. Traditionally, nitrogen removal is practiced through energy intensive biological nitrification and denitrification entailing a major cost in wastewater treatment. Recent innovations in nitrogen removal aim at reducing energy requirements and recovering ammonium nitrogen. Bioelectrochemical systems (BES) are promising for recovering ammonium nitrogen from nitrogen rich waste streams (urine, digester liquor, swine liquor, and landfill leachate) profitably. Phosphorus is removed from the wastewater in the form of polyphosphate granules by polyphosphate accumulating organisms. Alternatively, phosphorous is removed/recovered as Fe-P or struvite through chemical precipitation (iron or magnesium dosing). In this article, recent advances in nutrients removal from wastewater coupled to recovery are presented by applying a waste biorefinery concept. Potential capabilities of BES in recovering nitrogen and phosphorous are reviewed to spur future investigations towards development of nutrient recovery biotechnologies.

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Contents

1. Introduction

Nitrogen (N), phosphorus (P) and potassium (K) are the essential elements required for the growth of living organisms. These nutrients are supplied in the form of chemical fertilizers to replenish the soil fertility and to maintain the soil nutrients reserve to increase food production in modern agriculture. The demand for chemical fertilizers production is increasing modestly at about 1.8% per annum to secure the food supply for the growing global population (Ledezma et al., 2015). Global fertilizer use has been estimated to show moderate annual growth to reach 199.4 million tonnes by 2018 (Heffer and Prud'homme, 2014). Increases in average annual growth rates of all three major nutrients are projected with 1.5%, 2% and 2.9% for nitrogen, phosphorus and potassium respectively. Industrial production of chemical fertilizers heavily depends on the use of non-renewable energy (e.g. natural gas) and limited mineral deposits (e.g. phosphate rock).

Nitrogen is a renewable resource, but molecular nitrogen, abundantly present in the atmosphere can be used by only a few living organisms. In nature, atmospheric nitrogen is converted to ammonium and nitrate nitrogen through, respectively, nitrogen fixation by nitrogenase and lightning. Increased supply of reactive nitrogen (e.g. ammonia) via chemical fertilizers helped to increase the food grains required for the growing human population. Fertilizer nitrogen is chiefly obtained by converting atmospheric nitrogen to ammonia nitrogen in industry by the Haber–Bosch process (Fowler et al., 2013). Presently, the amount of ammonia nitrogen produced annually by the Haber–Bosch process exceeds the nitrogen fixed by natural terrestrial processes (Fowler et al., 2013). Anthropogenic production of reactive nitrogen compounds has skewed the natural global nitrogen cycle with tremendous benefits of increased food production but also impacts on human health and the environment (Erisman et al., 2013).

Unlike nitrogen, phosphorus and potassium for chemical fertilizers are mainly sourced from mineral deposits. In recent times, phosphorus availability for food security is extensively discussed mainly because of limited phosphate rock minerals and no substitute for phosphate sourcing. It has been predicted that global phosphorus production rates will reach a maximum or peak by 2033 and commercial phosphate rock reserves will be depleted in 50–100 years (Cordell et al., 2009). Moreover, more than 90% of the phosphate rock reserves are located only in five countries namely Morocco, Iraq, China, Algeria and Syria (Jasinski, 2012). Western Europe and India are totally dependent on imports for meeting domestic demand of phosphorus fertilizers. The availability of nutrients is linked to modern agriculture and food security in many nations. This scenario calls for an urgency in adoption of improved nutrient management practices as well as identification of alternative phosphorus sources.

Substantial amounts of unutilized nutrients (e.g. nitrogen and phosphorus) that are applied through fertilizers will eventually enter the environment and contaminate water bodies and the atmosphere. A major portion of nitrogen and phosphorus consumed through crops by the animals and humans will reach wastes such as manure and sewage, respectively. The nutrient content of these wastes is substantial and estimates show that the total phosphorus available in sewage, if recovered fully, can supply about 15–20% of the global phosphorus demand (Mihelcic et al., 2011). Manure is widely used as a fertilizer although its economic value is low because of low nutrient concentrations. After treatment, sewage is either used for gardening or discharged to the water bodies. Agricultural runoff and inefficient nutrient removal during wastewater treatment can lead to an increase in nutrient concentrations of water bodies. Nutrient pollution of lakes and coastal regions causes eutrophication of water bodies which impacts ecosystem and economy associated with tourism (Duce et al., 2008). Human-induced eutrophication of water bodies (lakes, rivers, estuaries and coastal seas) has resulted in degradation of water quality, loss of biodiversity, hypoxia and fish kill in many parts of the world (Duce et al., 2008).

Nitrogen and phosphorus are key pollutants in sewage and other industrial waste streams. In the past decade, considerable