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Phosphorus recovery from municipal and fertilizer wastewater: China's potential and perspective

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ABSTRACT

Phosphorus (P) is a limited resource, which can neither be synthesized nor substituted in its essential functions as nutrient. Currently explored and economically feasible global reserves may be depleted within generations. China is the largest phosphate fertilizer producing and consuming country in the world. China's municipal wastewater contains up to 293,163 Mg year of phosphorus, which equals approximately 5.5% of the chemical fertilizer phosphorus consumed in China. Phosphorus in wastewater can be seen not only as a source of pollution to be reduced, but also as a limited resource to be recovered. Based upon existing phosphorus-recovery technologies and the current wastewater infrastructure in China, three options for phosphorus recovery from sewage sludge, sludge ash and the fertilizer industry were analyzed according to the specific conditions in China.

Contents

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Introduction

Phosphorus (P) is a non-regenerable and non-replaceable limited resource (Asimov, 1959). Currently explored and economically feasible global reserves may be depleted within only a few generations (Childers et al., 2011). By 2050, the world's population is estimated to reach 9.1 billion; in order to feed the growing population, agricultural production would need to increase by 70% overall and nearly 100% in developing countries (FAO, 2009).

China is a big country with a large population and limited farmland area per capita, with only 0.08 ha per capita in 2012 compared with the world average of 0.2 ha per capita, according to the World Bank (2014). The production of sufficient food to feed the population is of vital importance to the country. In the year 2001, P was identified by the Ministry of Land and Resources of the People's Republic of China (MLR, 2012) as one of the most important 20 minerals which, after 2010, cannot meet the development needs of the national economy.

According to statistics from the United States Geological Survey (USGS, 2015), China's P reserves are 3.7 billion Megagrams, 5.52% of the global total volume. Based on the current phosphate rock mine production of 100 million Mg in 2014 (USGS, 2015), Chinese P ore may run out within 37 years. It is a remarkable fact that there is only a small amount of high-grade phosphorus ore, but the country is rich in low-grade phosphorus ore. More than 80% is low grade phosphate rock and the average grade only reaches 17% of the phosphorus content of phosphorus pentoxide (P_2O_5) (Huang et al., 2014; Lu, 2004).

In Europe, phosphate rock was officially considered to be one of the 20 critical raw materials by the European Commission in 2014 (EC, 2014). The recovery of phosphorus has been repeatedly discussed due to the strong dependency on imports, above 90%, (De Ridder et al., 2012) and the food security needs of the growing population worldwide. Various P recovery technologies have been developed and tested at pilot or industrial scale. Among these technical options, P is mostly recovered by precipitation or crystallization processes in the form of HAP (hydroxyapatite, $Ca_5(PO_4)_3OH$) or struvite ($MgNH_4PO_4 \cdot 6H_2O$). The recovered products can be utilized as fertilizer in agriculture or in specific industries.

Consequently, closure of the anthropogenic P cycle through recovery and recycling of P from municipal wastewater and sludge, as well as from special industry wastewater, may help to avoid eutrophication, promote resource conservation and increase the value chain efficiency of this precious resource.

1. Status of the municipal wastewater infrastructure in China

1.1. *The development of urban sewage treatment*

In 1984, as the first large-scale wastewater treatment plant (WWTP), the Tianjin Jizhuangzi Wastewater Treatment Plant was built and put into operation with a treatment capacity of 260,000 m^3 (Fu et al., 2008). After 1990, with the rapid development of the economy, rapid urbanization and industrialization and the increasing environmental standards in China, the wastewater treatment infrastructure stepped into a rapid development period and improved the quantity of wastewater treatment facilities and also the effectiveness of treatment.

Fig. 1 shows the development of treatment capacity for urban sewage and the number of facilities from 2005 to 2013. During the past several years, China's sewage treatment sector has experienced rapid development. In April 2015, the General Office of the State Council issued the "National Water Pollution Prevention and Treatment Action Plan of China" (MEP, 2015) to address nationwide water protection; the objective of municipal wastewater treatment is that by the end of 2020, the city and county municipal wastewater treatment rates should reach 95% and 85% respectively.

Although China's urban wastewater treatment industry has seen much progress in terms of scale and number since the 1990s, the conditions of the municipal water networks and the treatment rate in rural areas still need to be improved. In 2013, the wastewater treatment rate of the cities, counties, towns and villages was respectively 89%, 79%, 19%, and 5% (MOHURD, 2016). The majority of wastewater generated in rural areas undergoes limited treatment or discharge to water bodies without treatment. According to the corresponding population distribution in different areas (MOHURD, 2016), 37% of the population is connected to wastewater treatment systems in China.

1.2. *Wastewater treatment process*

There are three major steps in state-of-the-art wastewater treatment schemes, *i.e.*, primary physical treatment, secondary biological treatment and tertiary treatment (Halling-Sørensen and Jorgensen, 1993). Most sewage treatment plants in China are centralized, with biological wastewater treatment.

Fig. 2 shows the variety and distribution of different processes in WWTP in China. According to the statistics of the Ministry of Environmental Protection of the People's Republic of China (MEP, 2014) for 4136 commissioned wastewater treatment

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