Research Progress in Phosphorus Recovery and Reuse

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Abstract: As a kind of non-renewable and irreplaceable resources, phosphorus resource is very important for people. It is very necessary to study the shortage of phosphorus resource and the recycling of phosphorus in waste water. This paper discussed the current basic measures for phosphorus recovery from waste streams and the reuse of phosphorus. Some suggestions for future research were provided.

1. Introduction
Phosphorus is a kind of non-renewable and irreplaceable resource, it is very important for the growth of all organisms and is a necessary element in the process of life. With the growth of population and the rapid development of economy, the demand for phosphorus resources is constantly increasing, and the exploitation and consumption of phosphate ore are increasing year by year. The problem of phosphorus shortage has become an important global problem in the 21st century[1]. The United States Geological Survey (USGS) estimates that the planet's phosphate reserves last only 90 years[2].

Nowadays, with the development of society and industry, a large number of phosphorus resources are constantly losing from the environment, it not only leads to the decrease of oxygen content and the increase of toxin in water, but also accelerates the process of water eutrophication[3], and causing an overgrowth of bad algae and aquatic plants, meanwhile, water quality deteriorates and aquatic ecosystem has been destroyed. However, there is no substitute for phosphorus in fertilizer production, and now that phosphorus stocks are being depleted, so the lack of phosphorus makes a major challenge to world food supplies. Under the dual pressures of eutrophication and phosphorus deficiency, it becomes necessary to remove and recover excess phosphorus from wastewater[4].

With the rapid increase in the world's population and food demand, the demand for phosphorus resources is soaring. Phosphorus recovery and reuse from waste streams is one of the practical strategies to deal with this depletion[5]. Therefore, phosphorus is not only an increasingly scarce precious resource, but also an important factor causing environmental pollution. It is of great research value to reduce phosphorus loss, recover and reuse phosphorus resources. In this way, realizing the maximum release and recycling of phosphorus resources in sewage sludge can meet the sewage discharge standards, protect the environment, and it can protect natural resources, improve the reuse rate of resources, and ensure the needs of sustainable and rapid economic development. Phosphorus treatment, recovery and reuse not only bring huge environmental benefit, but also bring huge economic benefit, it has laid a foundation for promoting the sustainable utilization of resources in China[6]. Therefore, in this article, I will introduce some methods of phosphorus recycling.
2. Soil remediation

2.1. Improved acid soil

At present, China's soil becomes more and more acidic. Acidic soil has become one of the main problems affecting agricultural production and ecological environment[7]. The cause of soil acidification is the increase of H+, Al³⁺ concentration, the decrease of Mn content and the low contents of P, K, Ca and Mg[8]. Acidic soils reduce soil microbial activity, and have toxic effects on crops, disrupt cell membrane structure and affect nutrient absorption[9]. Existing research mainly uses soil amendments to effectively improve the physical and chemical properties of the soil[10]. The main methods are: lime, biomass charcoal and soil conditioning agent dolomite and alkali residue[11]. Lime is one of the commonly used methods, but if people use long-term or large-scale, it will lead to soil hardening, it may also lead to soil nutrient imbalance and reduce crop production[12]. Therefore, the phosphate recovered from the waste stream was used to improve the soil. Phosphorus-struvite has higher phosphorus and magnesium content, which is beneficial to improve the low content of phosphorus and magnesium in the acid soil[13]. Moreover, it can balance plant nutrients, and can improve soil nutrients, soil physical and chemical properties, at the same time, it also can improve soil moisture and nutrient retention capacity, and the overall quality of soil[14]. Qi Bufan[15] explored the struvite, a biogas slurry source made in the laboratory, it was mixed and cultivated with acid yellow loam soil in different ratios of soil nitrogen content. The results showed that struvite had a certain improvement effect on the soil due to the high content of phosphorus and magnesium. In this study, 0.3% struvite from biogas slurry was applied to the soil, which had the best effect and could improve the soil pH. Single application of struvite was not obvious, so it may required continuous application, and then the effect of improving acidic soil will be better, which requires more experiments to verify.

2.2. Improved soil contaminated by heavy metals

These phosphorus recyclers can also improve soils that are overloaded with heavy metals. In recent years, the discharge of mining wastewater and residue, excessive application of pesticides and fertilizers, abuse of sludge and incomplete combustion of fossil fuels have led to the continuous accumulation of heavy metals in the soil[16]. Some researchers combine waste phosphate ore with soil remediation and reuse it. Cheng Xuejun[17] studied the recovery of phosphate from wastewater in the form of struvite and applied it to the passivation of copper in soil. By measuring the pH, available content of copper and various forms of copper in the soil, it studied the passivation and remediation ability of phosphorus recovery product on soil heavy metal copper. The XRD and other characterization results showed that: add a certain amount of load of struvite synthetic zeolite, the effective state content of copper in the soil, it reduced the copper in soil biological activity, the same as this kind of phosphate dosing, the content of available p in soil increases, and it increased the ability of the soil for phosphorus, and met the requirements of the crops on phosphorus removal. It realized the effective recycling of phosphate in wastewater. Hao Wang[18] explored the environmental pollution caused by the discharge of industrial effluent into surface waters from industrial activities, such as mining, metal smelting and alloy manufacturing[19]. Although copper is an essential element for the growth of plants and animals, excess copper in the environment can have adverse effects on living organisms, particularly given its bioaccumulative and non-biodegradable nature[20]. Therefore, it is necessary to immobilize copper in contaminated soil. Traditional methods of soil metal remediation, including excavation and soil cleaning, they have been shown to be inappropriate due to considerable environmental disturbance and are not economically viable for large-scale application[21]. Therefore, it is an important task to use reclaimed phosphorus as a soil remediation agent.

3. Slow-release phosphate fertilizer

Struvite, a phosphorus recovery substance, is a kind of slow-release fertilizer, which is not easy to be washed by rain. It is often used as base fertilizer for agricultural production and high quality fertilizer for forestry[22]. Phosphorus is an indispensable nutrient for crop growth and an indispensable resource.
The depletion time span of phosphorous rock reserves is 30-300 years. With the passage of time, the high concentration of phosphorous rock reserves will be irrevocably depleted and the reserve quality will decline\cite{23}. The economic and energy costs of phosphorus extraction are high. The results show that struvite is a good agricultural fertilizer with the advantages of a slow release rate and low impurity content\cite{24}. In addition, because struvite is slightly dissolved in water and soil solutions, slow-release struvite has been found to be a highly efficient source of phosphorus, nitrogen, and magnesium for plants. It is applied through leaves and soil. Qi Bufan\cite{15} studied that through the lab homemade biogas slurry source struvite, it mixed with the soil according to certain proportion for Chinese cabbage potted experiment, the experimental results showed that add a certain amount of struvite. Chinese cabbage fresh weight, chlorophyll and soluble sugar content were increased, but would not affect the nitrate content in Chinese cabbage, and safety quality of Chinese cabbage. Xiaoning Liu\cite{25} studied that through the greenhouse pot experiment, the soil mixed with a certain amount of struvite and commercial purchase of phosphorous fertilizer, and plant rapeseed, by comparing that, the results showed that the soil after using struvite soil available phosphorus content significantly higher than that of commercial purchase of phosphorous fertilizer, with the same struvite processing plant leaves leaf concentration, it higher than the ground biomass. The potential and prospects of struvite as a phosphate fertilizer, it also is a compound fertilizer containing both magnesium and nitrogen resources, it will also benefit crop growth as struvite dissolves in the soil. Struvite can be stored in a compact form and is easy to handle, transport and apply, especially in granular form. Struvite as a fertilizer significantly increased soil total phosphorus. Hong-Duck Ryu\cite{26} studied the precipitation of struvite from semiconductor wastewater plant (wastewater containing high concentration of ammonia nitrogen and phosphoric acid), and judged the fertilizer effect of struvite precipitation through pot experiment, and compared it with commercial composite fertilizer. The results showed that: in the process of experiment, the average struvite the cabbage leaf at the longest. In addition, it was clear that struvite significantly increased the average fresh and dry weight of cabbage in studies of the effects of heavy metals on cabbage growth., and application of struvite led to the accumulation of copper in the vegetable group the lowest, in addition, cadmium, arsenic, lead, and nickel elements even detected in struvite tank, struvite and other commodities as fertilizer, it provided a necessary cabbage nitrogen, phosphorus, potassium, calcium, magnesium and other crop nutrient. The results showed that struvite sediment recovered from semiconductor wastewater was an effective multi-nutrient fertilizer. The amount of soil in pot experiment is limited, and the adjustment of soil acidity and alkalinity by biomass charcoal and biomass charcoal based phosphate fertilizer is a long-term process, so we need long-term pot experiment and field experiment data support that.

4. Preparation of sulfuric acid and phosphoric acid
Recycled phosphate ore can not only be used as the above mentioned soil amendments and as slow-release phosphate fertilizer, but also can be used to produce yellow phosphorus, phosphoric acid, sulfuric acid and other products used in pharmaceutical, chemical, national defense and other industrial sectors. Wim Moerman\cite{27} explored that the effluent from the upstream anaerobic sludge bed reactor (UASB) of the potato processing plant was recovered by calcium phosphate as a means of phosphorus recovery, which was then mixed with phosphate ore and thus used for phosphate production. Ma Hongwen\cite{28} explored that the material and energy consumption of ammonium phosphogypsum transfer process and carbothermal sulfuric acid process, and then compared the methods. The results showed that the ammonium transfer method had less primary resource consumption and less CO$_2$ emission, and the by-product was calcium carbonate powder, which saved the development of limestone. Using phosphogypsum to produce sulfuric acid, there is no need to consume pyrite resources, and the process of producing sulfuric acid by ammonium conversion has a carbon fixation effect. If complete resource utilization of phosphogypsum is realized, it is expected to reduce CO$_2$ emissions by 18.2 million tons per year. This not only realizes the clean utilization of phosphorus resources, but also realizes the intensive utilization of a variety of associated resources. It can also promote the green and sustainable development of the entire rare earth industry. Eventually it
has an important impact on the healthy development of China's phosphorus chemical industry.

5. Conclusions and Prospects
Now, sustainable development is not a choice, but a necessity. The shortage of agricultural phosphate fertilizer will be a problem that must be solved for a long time. Phosphorus should be fully recycled as a typical nutrient. At the same time, rational utilization of food waste, animal manure, slaughtering by-products and human excreta can be carried out, and we can pay attention to the evolution of phosphorus from waste to treasure, so as to fully realize the recycling of phosphorus. Phosphorus can also be recovered and reused from waste streams such as sewage, sludge and municipal solid waste. In short, the recycling strategy of tracking the whole process of phosphorus should be implemented from the source to all links of production and life. The key point is the utilization of manure, sewage and biodegradable wastes. The improved recovered phosphorus can not only be used as soil amendments to improve soil fertility. It can also be used as a slow-release fertilizer to gradually replace the traditional agricultural fertilizer. It can protect the environment, and recycle waste. Similarly, the waste phosphorus can also be used to make sulfuric acid and phosphoric acid, it can be used in the chemical industry. In order to improve resource efficiency, prevent environmental damage and ensure supply security. China can establish relevant phosphorus availability and recycling management policies, and this policy should be coordinated with other environmental policies (such as pollution reduction, energy recovery). Although there are many ways to recycle phosphorus, we need to continue to explore more practical ways to use it. Combined with the characteristics of phosphorus containing waste streams in different industries, we need to develop more economical and effective technologies to recycle phosphorus and improve the efficiency of recycling phosphorus.

Acknowledgments
This study was supported by the key project of Jilin provincial science and technology department of China (No.20180201073SF) and by the project of Jilin education department (No.JJKH20180577KJ).

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