Phosphorus and Struvite – Rethinking Their Existence

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***Abstract*—**Phosphorus is an essential element that is required for sustaining life on the planet. Not only is it an essential component of our body, it is required for plant growth, and is applied in the form of fertilizers. Despite the high demand of phosphorus, its reserves around the world is limited and sparsely distributed. This leads us to look for new sources of phosphorus, not from the earth but somewhere else. Domestic and agricultural wastewaters contain significant amounts of phosphorus. Without proper management of phosphorus in the wastewater treatment plants, its presence can lead to the formation of cement-like material called struvite. Struvite has been linked to clogging of pipes, damages to machinery and process downtime. However, controlled struvite formation in wastewater treatment plants can have several benefits. A major benefit of struvite is it being a sustainable source of phosphorus that could potentially prevent the global phosphorus diminishing crisis.

***Keywords*—**Fertilizer, phosphorus, struvite, wastewater

I. Introduction

AMONG the elements discovered, phosphorus sits at the top group of elements that is essential for sustaining life – human beings, plants, animals etc. – on the planet. It is also a key ingredient in fertilizers, the product that sustains proper plant growth and which ultimately determines the fate of food production to the ever increasing global population. With the increase in demand for food and consequently fertilizers, phosphate rocks are being mined at an unsustainable rate. The phosphorus problem is heightened by the fact that global phosphorus rock reserves are limited and it is a non-renewable resource. This means that once the rock reserves are exhausted the source of phosphorus as we know today will cease to exist.

II. Phosphorus and Our Environment

In addition to sustaining life and its use in the production of food, phosphorus plays an important role in the health of water bodies around the world. The phosphorus cycle of old was essentially a transition from mined ore to people, plants and animals to the soil via dead and decay of plants and animals. The phosphorus cycle and balance that has been around for thousands of years is now at a risk of breaking down. The reason is the dramatic increase in the discharge of phosphorus into the water bodies and groundwater. With urbanization and more people living in urban areas, the concentration of wastewater being discharged into the neighboring water bodies is at an all-time high. Wastewater contains a significant amount of phosphorus, with approximately half a kilogram of phosphorus being discharged per person annually [1] and, if not properly treated at wastewater treatment plants, can increase the phosphorus content in rivers, lakes and oceans. This rapid increase is responsible for eutrophication, which leads to poor water quality and ultimately death of aquatic life. In addition, with globalization, phosphorus is extracted in one country, transported to another for fertilizer production, used by another nation for agricultural purposes and the product sold in another country, thereby not necessarily replenishing the phosphorus from where it was first mined. This makes managing wastewater phosphorus discharge a high priority.

III. Global Phosphorus Reserves and Use

According to [2], the majority of phosphorus reserves are controlled primarily by five countries – Morocco, China, South Africa, US and Jordan. Recent years have seen these global players hold on to their reserves or make profitable deals as phosphate price, a direct effect of fertilizer demand and price, has increased tremendously. There are various reports that show phosphorus reserves being exhausted within the next 50 years to the reserves lasting more than 100 years [3] – [5]. The problem with phosphorus reserves is that it is not a renewable resource. The phosphate that we mine today was most likely formed millions of years ago. Although new phosphate ore deposits are discovered and exploited worldwide, the quality of ore is diminishing. This means more cost to recover the phosphorus. In addition, these ores are more likely to contain significantly greater heavy metals that are not removed and ultimately end up in phosphate-based fertilizers.

Reference [6] provides a good overview of the key phosphorus flows through the global food production and subsequent consumption of the material. The figure also illustrates the phosphorus usage, losses and recovery at each key stage of the process. A report in 2000 mentioned that 90% of all the phosphate used was for food production that included the use for fertilizer, animal feed and food additives [7]. Recent studies forecast that the global demand for phosphorus may increase annually by around 3-4% until the year 2011 [8]. Most of this demand is expected to come from emerging countries, primarily in Asia and Africa. The change in diets in Asia and the lack of previous fertilization in Africa, combined with ever increasing population was determined as the cause of this increase. Reference [9] concluded that within the middle of this century the global food production would have to increase by about 70% to fulfill the needs of the people. The food production demand directly influences the phosphate requirement.

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Before the economic crash in 2008, the rapid and unsustainable demand for fertilizer resulted in the price of the commodity to increase by as much as 700% within a 14-month period [10].

IV. PHOSPHORUS IN WASTEWATER TREATMENT PROCESS

With the dwindling phosphate ore reserves and the continued increase in phosphate demand, the world is currently faced with the task of finding an alternative to phosphate-based fertilizer. However, that is not possible due to the nutritional need of plants. Although phosphorus is limited in nature, there are other places, such as wastewater, that provide a potential for phosphorus recovery. A study by [11] reported that nearly all of the phosphorus eaten in food is ultimately excreted, which ultimately ends up in wastewater being treated in treatment plants. It is estimated that 3.0 to 3.3 million metric tons of phosphorus are generated and discharged as wastewater [12]. Until recently, most of this phosphorus was lost through discharge of treated wastewater into water bodies, with limited quantities of biosolid being applied to agricultural land in the form of fertilizers. However, growing concerns with the quality of biosolid, the heavy metal and other pharmaceutical waste quantity present in the biosolid, has forced the closure of agricultural land application. Adding to the problem is the fact that more and more people are expected to live in cities in the near future. This will force wastewater treatment plants to upgrade their plants to deal with this sudden increase in phosphorus load.

V. NUTRIENT LOOPING IN WASTEWATER TREATMENT PLANTS

Managing phosphorus in a wastewater treatment plant is vital for efficient treatment processes. Most treatment plants in the world still do not employ processes to remove phosphorus from their system. The consequence of non-removal of phosphorus species means that the phosphorus, which is a nutrient for plants, remains within the treatment system, thereby increasing the concentration over time. This process of recirculation of phosphorus within a treatment plant is called nutrient looping. A study [13] determined that as much as 20% of the incoming phosphorus and nitrogen to the secondary treatment was due to nutrient looping. Wastewater treated by biological methods using microorganisms has to control their phosphorus content. Failure to keep the phosphorus to a certain target level will reduce the efficiency of the microorganisms to treat the wastewater. The lack of phosphorus removal process and its subsequent increase in concentration through nutrient looping poses a secondary problem in wastewater treatment plants. Solids having characteristics like concrete called struvite are formed in the later stages (biosolid dewatering) of the treatment process. Struvite, magnesium ammonium phosphate hexahydrate ($MgNH_4PO_4.6H_2O$), once formed is very hard to get rid of and has been implicated in the reduction of process efficiency through blocking of pipes (Fig.1), corroding valves and motors and process downtime. This solid formation is enhanced through nutrient looping in the wastewater treatment plant.

VI. ROLE OF STRUVITE IN PHOSPHORUS RECOVERY FROM WASTEWATER TREATMENT PLANTS

Although the formation of struvite is a nuisance to the efficient operation of a wastewater treatment plant, struvite itself is a commodity that has other benefits when produced and used efficiently. With a high percentage of phosphorus and nitrogen, struvite is an established and efficient slow-release fertilizer [14]-[15. Struvite has also been used to fertilize nutrient-deficient streams and rivers [16]. However, the uncontrolled struvite formation that occurs in the treatment plant cannot be used as fertilizer as it is difficult to remove once formed in the pipes and pumps, and often require the use of concentrated acid and hot water blasting.

Fig. 1 Struvite formed in pipeline

Controlled struvite precipitation in a struvite reactor that can be operated as a sidestream process offers a number of benefits. Not only does it reduce the occurrences of unwanted struvite formation in different locations within the plant, it is able to reduce phosphorus and nitrogen concentrations in the wastewater. From an operational point of view controlled struvite formation will reduce nutrient looping. Struvite precipitation is also able to, on an average, remove and recover above 85% of phosphorus and 15% of nitrogen from the wastewater [16]. This relates to potentially over 2.55 million metric tons of phosphorus recovery if all wastewater was treated for struvite precipitation. Recovering this phosphorus can potentially alleviate the current problem with limited phosphorus reserves. The removal of looped nitrogen also helps in reducing the amount of air needed to treat the wastewater for nitrogen. Lower air requirement equals lower energy consumption that equals carbon credits. In addition, the nitrogen removal relates to reduced operational costs from lower air requirement and increase in the treatment capacity of existing plants. Thus, future plant expansions can be postponed. Table 1 summarizes some of the benefits of recovering phosphorus as struvite from a wastewater treatment plant.

TABLE I
CASE FOR RECOVERING PHOSPHORUS AS STRUVITE IN WASTEWATER TREATMENT PLANTS

- 20-25% reduction in total plant phosphorus load with at least 80% phosphorus recovery
- 3-5% reduction in the total plant nitrogen load with at least 15% recovery
- 2-8% reduction in sludge volume
- No chemical required to reduce phosphate in the water
- Revenue from sale of struvite as slow-release fertilizer
- Sustainable source of phosphorus leading to reduced fertilizer cost
- Reduced fertilizer cost leading to lower food prices
- Reduced energy required for nitrogen removal
- Reduced energy requirement leading to carbon credits
- Increase in treatment plant capacity leading to delay in future expansion

VII. CONCLUSION

Dwindling phosphorus reserves around the world is slowly but surely leading to increased fertilizer shortages and higher prices. This in turn is responsible in part to higher crop prices. Since phosphorus is a vital and at the same time a non-renewable resource, it is important that new sources of phosphorus be searched. Wastewater contains substantial quantity of phosphorus that often leads to wastewater treatment plant operational problems and reduced process efficiency. Discharge of wastewater that has not been treated for phosphorus often leads to eutrophication in the discharging water bodies.

The recovery of phosphorus as struvite from wastewater provides for the development of the important principle of sustainability and closes the natural phosphorus cycle – earth (mined phosphorus ore) to earth (fertilizer). Additionally, phosphorus recovery as struvite can help in increasing treatment plant efficiency and provide a source of revenue. With increasing demand but decreasing availability of natural resources, the paradigm shift from viewing wastewater as a waste to being a resource is slowly being accepted all over the world, not only among the people who deal with the topic but also among the general public. Public acceptance of a product derived from wastewater is vital to its successful and sustainable long term use.

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