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Finding Nutrient-Related Problems in Wastewater Treatment Plants

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Abstract. Wastewater treatment plants, especially those employing secondary treatment and anaerobic sludge digestion, have historically encountered phosphate precipitates, one of the commonest being struvite, that foul and encrust the sludge return lines, and the associated pumps and valves. This growth of 'uncontrolled' struvite increases pumping and maintenance cost, as well as reduces the overall capacity of the plant piping system in terms of lost hydraulic capacity and lowered biological treatment capacity. Although uncontrolled formation of struvite can be a nuisance, however, controlled production of struvite can prove beneficial to treatment plants. This is accomplished through reducing maintenance costs, as well as providing extra revenue from the sale of the struvite crystals as fertilizers. This paper investigates what can and should be done before struvite-related problems hamper efficient operation of the treatment plant.

Keywords: Wastewater, Struvite, Sustainable development, Supersaturation ratio

1. Introduction

Struvite, magnesium ammonium phosphate hexahydrate (MAP), is a crystalline structure that occurs naturally in rotting organic material such as guano deposits and cow manure. It has also been observed in sludge derived from the anaerobic digestion of animal farming liquid wastes and agricultural wastes. As well as being found in biologically treated wastewater sludge, struvite has been recognized as a common constituent of renal calcui of both humans and animals (Suzuki *et al.,* 1997).

Accumulation of struvite ($MgNH_4PO_4.6H_2O$) on pipe walls and equipment surfaces of anaerobic digestion and post digestion processes is a problem that plagues the wastewater treatment industry (Fattah, 2008). Struvite is well known for plugging pipes and fouling pumps, aerators, screens and other equipment. Remediation is often impractical and, when possible, is costly in terms of labor, materials and system downtime. The pellets anchor to sludge particles in suspension and to surfaces of equipment, tank and pipe walls in contact with digestion sludge. Pellet growth can be rapid and, if left unchecked, struvite accumulation can foul mechanical equipment and clog pipes within months.Figure 1 illustrates occasions where struvite was formed in the piping at treatment plants.

2. Factors Affecting Struvite Formation

Several factors influence the formation of struvite. The important parameters are (1) concentrations of the constituent ions (ortho-phosphate, ammonium and magnesium), (2) the pH, and (3) temperature of the wastewater. The concentration of the constituent ions depends on the characteristics of the influent and the amount of treatment the source water received. When waste activated sludge is digested anaerobically, much of the phosphate, which was removed in the main treatment train are re-released under the anaerobic conditions. Various studies show that 26% to 90% of the phosphorus entering the head of the treatment plant is due to phosphorus feedback, that is, phosphorus in the return liquors (Fattah, 2009). Some plants have even reported additional phosphorus loads of up to 100% (Pitman *et al.,* 1991). Consequently, the phosphorus circulates in a loop within the treatment system, thus increasing the overall P load. The pH can be increased locally by sudden pressure drops, which can result in the stripping of carbon dioxide, and thereby increasing the pH. Temperature appears to influence the formation potential to a great deal (Fattah (2009).

Fig. 1: Clogging of pipes by struvite at treatment plants

3. Finding Out If There Is A Struvite Problem

It is imperative that treatment plant determines if it has a struvite-related problem or not before the struvite accumulates to a degree that hampers efficient treatment process. Therefore, it is necessary to determine, or calculate, the conditions that will assist struvite formation and growth.

The general equation for the formation of struvite is

$$Mg^{2+} + NH_4^{+} + PO_4^{3-} + 6H_2O \quad \leftrightarrow \quad MgNH_4PO_4.\ 6H_2O$$

Supersaturation ratio (SSR): This value determines the possibility for the formation of struvite at any location. Any value greater than unity indicates that formation is "possible".However, an SSR of just unity does not necessarily mean that struvite will form rapidly or to a great extent. In order to have rapid struvite growth and accumulation, a SSR above unity is usually required. At pilot scale studies by the author a SSR value of 3-5 is used for optimal struvite growth in a struvite crystallizer (reactor). The suspersaturation ratio is given by:

SSR = P_s-sample/ Ps-equilibrium

$$P_s - sample = \{Mg^{2+}\}\{NH_4^{+}\}\{PO_4^{3-}\}$$

P_s-sample: the solubility product of the sample.

Ps-equilibrium: the solubility product in equilibrium under the same conditions (pH, conductivity and temperature) as that of the sample.

Struvite Formation Potential (SFP): The struvite formation potential is a term that is used as the primary indicator in the risk assessment analysis. This is a relative value that depends on the SSR value at a particular system. The probability of the increase in the concentrations of struvite constituent ions (ammonium, magnesium and phosphate)and conditions (pH, temperature and conductivity) at the location will determine the extent of the formation potential.In order to determine these factors of struvite formation, it is necessary for treatment plants to carry out studies to determine this struvite formation potential at different "hot spots" – such as, pumps and elbowsafter anaerobic digestion - within the treatment system where struvite is "likely" to occur and accumulate.

4. Are There Any Solutions to the Struvite Problem?

The development of technologies for phosphorus removal offers the opportunity for recycling and phosphorus sustainability. However, there are a number of technologies both established and under development, which can be used to remove phosphorus from wastewater and can potentially be used within a sustainability strategy. Removal was initially achieved by chemical precipitation, which remains the leading technology today. More recently, however, biological phosphorus removal has become firmly established, crystallization technology has also accomplished great progress towards commercialization and technologies extending chemical precipitation to assist nutrient removal are beyond the pilot scale. In all processes, phosphorus ions in wastewater are removed by converting the phosphorus into a solid fraction. This fraction can be an insoluble salt precipitate, a microbial mass in an activated sludge, or a plant biomass in constructed wetlands.

Now-a-days, the main commercial processes for removing phosphorus from wastewater effluents are chemical precipitation and to a lesser extent, biological removal. The chemical precipitation of phosphorus from wastewater is brought about by the addition of the salts of multivalent metals ions that form precipitates of sparingly soluble phosphates. These precipitated are subsequently settled out by sedimentation. The most commonly used multivalent metal ions are calcium [Ca(II)], aluminum [Al(III)] and iron [Fe(III)].

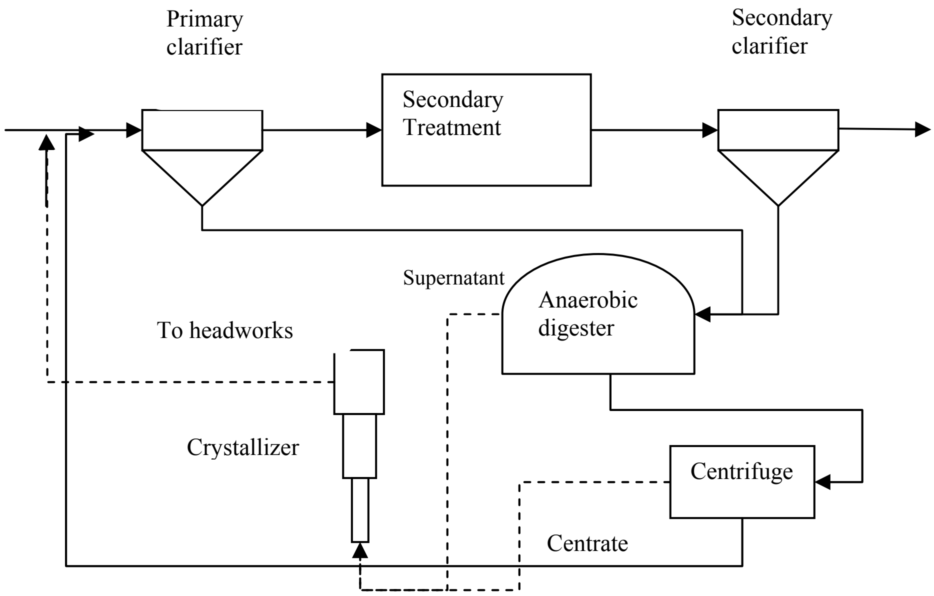

Fig. 2: Locations of phosphorus recovery options

5. Finding a Sustainable Solution to Struvite Problem

The most common method of treatment/preventing the formation of struvite, or other forms of phosphate precipitates, in wastewater is to change the characteristics of the wastewater, such as removing phosphate ions and reducing the pH. However, in the current age of sustainable process development, treatment does not necessarily end with removal – rather it is important to provide recovery of material as well. Both phosphorus (present as phosphate in wastewater) and nitrogen (present as ammonium in wastewater) are important nutrients that sustain life on earth. However, like oil, phosphorus is a limited resource, and with dwindling phosphate reserves, it is ever imperative that methods to recover phosphorus from other processes be investigated.

Sidestream treatment of digester supernatant and centrate to recover phosphorus as struvite or HAP appears to be the most efficient method of treatment to control phosphate precipitation /struvite/vivianite at wastewater treatment plants. This is because the end product can be used without the need for extensive treatment and processing, as needed with conventional chemical phosphorus removal techniques. Sidestream treatment for phosphorus and ammonia removal usually involves the treatment of digester supernatant, belt-filter press filtrate or centrate (Fattah *et al.* 2008). The processes usually occurs in a system called a fluidized bed reactor, which is essentially a circular/cylindrical tank that promotes upwards flow of liquid by injecting the feed (ingredients) from the bottom of the reactor. Sometimes air bubbles are introduced from the bottom of the reactor to fluidize the struvite pellets. The primary difference between the conventional precipitation and the crystallization process is that in the crystallization process the transformation is controlled accurately. This results in the formation of pellets with a typical size ranging from 1 mm to 5mm. The desired size range depends on the use of the struvite; small pellets for quick solubilisation and larger pellets for slow release of the nutrients (nitrogen, phosphorus and magnesium). Without controlling the precipitation process, fine dispersed, microscopic sludge particles are usually formed that reduce the efficiency of nutrient recovery.

Conditions suitable for phosphate-based precipitates such as struvite (MAP) and hydroxyl apatite (HAP) are governed primarily by the suspersaturation ratio, which is the degree of supersaturation of the solute (i.e.

MAP or HAP) in the solvent. The supersaturation ratio is, in turn, governed by the pH, temperature and presence of competing/impurity ions. To initiate precipitation in the reactor, an increase in pH, though the addition of a base such as sodium hydroxide, is most often used.

6. Struvite As A Fertilizer

Although struvite might be considered as a main problem occurring in wastewater treatment plants, it can be used in the production of fertilizers and soil conditioners. There is a significant demand for phosphorus as a fertilizer for agricultural purposes due to its slow release properties. If phosphorus recovery happens in form of struvite, it can be used as a slow-release fertilizer which will not leach like conventional fertilizers. One study on the performance of struvite as a fertilizer in comparison to other commercial fertilizers, found that struvite fertilizers were more effective in the growth of Chinese cabbage due to high levels of phosphorus, potassium, nitrogen, and magnesium (Lim*et al.*2012). Another benefit of struvite as a fertilizer is consideration of heavy metals which are regulated in fertilizers for agricultural purposes. One study showed that struvite formation at certain conditions could be free of a wide range of heavy metals and other heavy metals which precipitated were much lower than the regulatory limits (Fattah *et al.* 2008).

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