Biological Phosphorus Removal Inhibition by Collection System Corrosion & Odor Control Practices

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The key to a successful biological phosphorus removal (BPR) process is the quality of influent wastewater. For BPR to be effective, the influent wastewater must contain volatile fatty acides (VFA) or a sufficient amount of rapidly biodegradable chemical oxygen demand (COD) that can be fermented to form VFA in order to trigger the phosphorus release mechanism.

Long detention times, high-strength wastes, and an elevated water temperature contribute to fermentation that precedes both VFA and sulfide. Corrosion of sewer pipe by hydrogen sulfide (H_2S) is a concern, but the BPR process benefits from fermentation, which increases the VFA in the wastewater. Recent experience has revealed that the measures implemented to control corrosion and odor in the collection system can reduce the VFA concentration in the wastewater treatment plant influent, and thus adversely affect the BPR process.

Biological Phosphorus Removal Mechanism

To better understand the adverse impacts of odor and corrosion control practices on BPR, it is helpful to understand the phosphorus removal mechanism. Here is a brief explanation of this process and the role of volatile fatty acids play.

Biological phosphorus removal involves contacting phosphorus-accumulating organisms (PAO) in the return activated sludge with influent wastewater containing VFA in a zone free of nitrates and dissolved oxygen (anaerobic zone). Phosphorus is released from this zone and the wastewater flows to an aeration zone, where the phosphorus is taken up again—a process known as luxury phosphorus uptake.

An essential part of the process is a suitable right carbon source—in this case a combination of acetates and propionates, in general, a COD:TP ratio of at least 37:1 or a BOD:TP ratio about 18:1. Some of the COD should consist of short chain VFA. More COD may be required if the process involves also denitrification of nitrates.

As the microbes remove the oxygen from nitrate, they use the oxygen to metabolize readily biodegradable material, VFA, so denitrification competes for the available VFA, and recycling excessive nitrate into the anaerobic zone can limit release of phosphorus by the PAO because of the lack of available VFA.

In most plants, the readily biodegradable material is in short supply and must be reserved for the PAO. When nitrates or oxygen are discharged to the anaerobic zone, they may inhibit phosphorus removal in two ways:

- They could prevent fermentation (formation of more VFA in the anaerobic zone).
- They could serve as electron acceptors for other organisms that will consume VFA and so deprive the PAO of the substance that they need to trigger phosphorus release.

In the absence of an electron acceptor or an oxidizing substance such as dissolved oxygen or nitrates in the anaerobic zone, PAO are favored to grow, since they can take up the VFA under anaerobic conditions.

Only very rarely is phosphorus removal alone required; in most cases, it is a combination of nitrogen and phosphorus that must be removed. In either case, a carbon source is needed. While denitrification organisms can use a number of easily degradable materials, including acetate and propionate, PAO can use only the latter two.

Sulfide & VFA Production in the Sewer

Regardless of how well conveyance systems are designed, some parts of them are likely to become anaerobic. Flat slopes, high-strength wastes, and elevated temperatures all contribute to the generation of VFA and H_2S by fermentation. Long retention times in pumping station wet wells and force mains are favorable to also in H_2S production.

Among the primary sources of sulfide generation is the slime layer on the pipe wall, rather than the wastewater. This is especially true of force mains, because the entire pipe wall is fully wetted. Pipe corrosion is typically not an issue in force mains because acid formation is minimal and because the crown of the pipe is submerged, which prevents *Thiobacillus* from growing. Corrosion is a concern, however, at force main discharge manholes and in gravity sewers.

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Although corrosion of sewer pipe by sulfide production is a concern, the BPR process benefits from fermentation because it results in an increase in VFA—specifically, concentrations of acetic and propionic in the acids needed to trigger the phosphorus release mechanism in PAOs under anaerobic conditions and the phosphorus uptake mechanism in the aerobic basin. If sufficient VFA are produced in the conveyance system, BPR can remove nearly all influent phosphorus.

Sulfide Control Techniques & Case Histories

A wide range of corrosion and odor control techniques are employed in collection systems. Some liquid phase treatment methods have minimal impact on VFA, while others control sulfide formation by alleviating anaerobic conditions, which have a detrimental effect on VFA production. The following case histories involve various sulfide control practices and their impact on either VFA formation or VFA survival in the sewer.

Chemical Oxidation

Strong oxidants such as chlorine,

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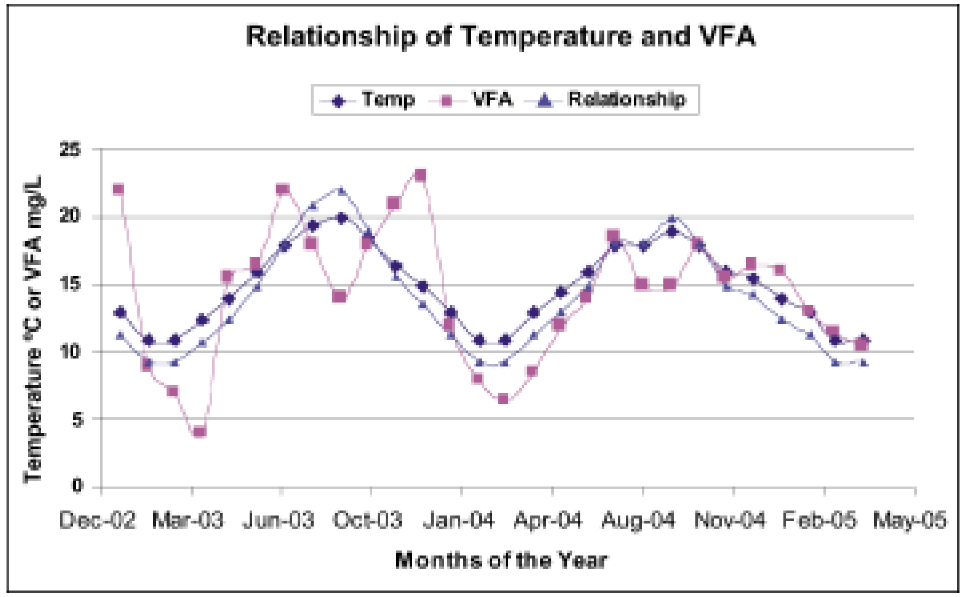

Figure 1: Influent Temperature and VFA

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sodium hypochlorite, and hydrogen peroxide are used to oxidize H_2S. These chemicals are not sulfide-specific and will react with other constituents in the wastewater. In practical terms, they react with readily oxidizable material, including BOD, in the sewer. Unfortunately, VFA are a subset of BOD and are easily oxidized.

The authors are waiting for the results of pilot testing of peroxide use to determine whether peroxide reacts to oxidize VFA or oxidizes only the higher molecular weight forms of BOD. Typically, chlorine is dosed at a weight ratio of 8 to10 milligrams (mg) chlorine per mg of sulfide. On a weight ratio basis, only about 2 mg of chlorine is needed to oxidize sulfide to sulfur; but the remaining 6 to 8 mg of chlorine is consumed by reaction with other materials such as VFA, or by oxidizing sulfur to sulfate.

At a plant in Perth, Australia, no phosphorus removal was occurring when 40 milligrams per liter (mg/L) of chlorine was injected for liquid phase odor control at the headworks. The secondary process was not designed to remove phosphorus, but when vapor phase odor control was added and chlorination stopped, the plant removed phosphorus to low concentrations, even in anoxic zones.

At the Douglas L. Smith Middle Basin Wastewater Treatment Plant in Johnson County, Kansas, chlorine is used to control sulfide in the influent. The chlorine oxidizes sulfide effectively; however, it also oxidizes soluble organics.

The plant influent can be characterized as having a low soluble BOD fraction, and special sampling has shown a VFA concentration averaging only 10 mg/L as acetic acid. This shortage of influent VFA and soluble BOD has forced the plant to install a fermenter in its current plant upgrade.

Nitrate Addition

The application of nitrate salts is a widely used method of sulfide control. The nitrate creates anoxic conditions and prevents fermentation, so H_2S is not formed, but the production of VFA is also inhibited. Nitrate serves as an electron acceptor for biological actions, very similar to aeration, in the collection system.

Under anoxic conditions, readily oxidizable VFA is consumed by the bacteria, so nitrate addition not only prevents VFA formation but also can destroy VFA that already exists. In some instances, industrial discharges of nitrate may have an adverse impact on VFA production.

The range of VFA concentrations in the influent to the Eagles Point plant in Minnesota, together with the mixed liquor temperature, is shown for a period of two years in Figure 1. The VFA production in the fermenter averaged 0.1 gram VFA per gram volatile suspended solids, both expressed as COD. This was not sufficient, especially during the cold period during March and April, when both the VFA in the influent and VFA production in the fermenter dropped to a low point. The influent VFA concentration, which was temperature-dependent, dropped as low as 5 mg/L during snowmelt when the wastewater temperature was around 11°C.

As noted in Figure 1, the VFA data showed an unexpected drop during midsummer. One possible explanation is that part of the VFA was fermented to methane gas. Another more likely explanation is that the influent could have contained some industrial discharge during this period. No specific industrial discharger was identified, but a nitrate concentration as high as 10 mg/L was recorded, as shown in Figure 2.

It is not possible for fermentation to occur in a sewer system and in the influent to contain nitrates unless it is from a specific non-domestic origin. The 7 mg/L of nitrate-nitrogen recorded represents a load of about 360 kg/d (800 lb/d) of sodium nitrate. Because of the potential for denitrification in the sewer system, the source of nitrates could be much larger than that measured at the plant.

Pre-construction sampling indicated that the influent to the new Eagles Point Wastewater Treatment Plant would contain sufficient VFA, but at start-up, high concentrations of nitrates and low concentrations of VFA were noted. A subsequent extension of the collection system, which would mean a longer detention time, could have reduced nitrate and generated more VFA, but the collection system personnel were not aware of the BPR concern at the plant and elected to use air injection to control sulfide formation and corrosion in the new reach of sewer.

The aeration successfully controlled the sulfide, but it further inhibited VFA formation. Not only did it inhibit fermentation, but it also added oxygen to the wastewater, making it available for microbial oxidation of VFA. To overcome this problem, the utility added a fermenter as well as supplemental carbon for fermentation at the plant.

Iron Addition

Iron addition is one of the most common and economical methods of controlling sulfide. As an added benefit, iron salts precipitate sulfide without significantly altering the wastewater chemistry, and they do not destroy VFA or affect its formation.

A new twist to using iron, however, is to add hydrogen peroxide at a downstream location to oxidize the precipitated sulfide and reactivate the iron for sulfide precipitation. It should be recognized that the peroxide dose needed for reactivation of the iron will result in simultaneous oxidation of other organics.

The authors are waiting for results from a study that will determine whether the peroxide used in this process will oxidize VFA. The peroxide supplier has indicated that peroxide does not react with VFA.

pH Control

One technique used to keep H_2S in solution is pH control. Because H_2S is a weak acid, it dissociates into HS^- and S^{-2} ions. Maintain-

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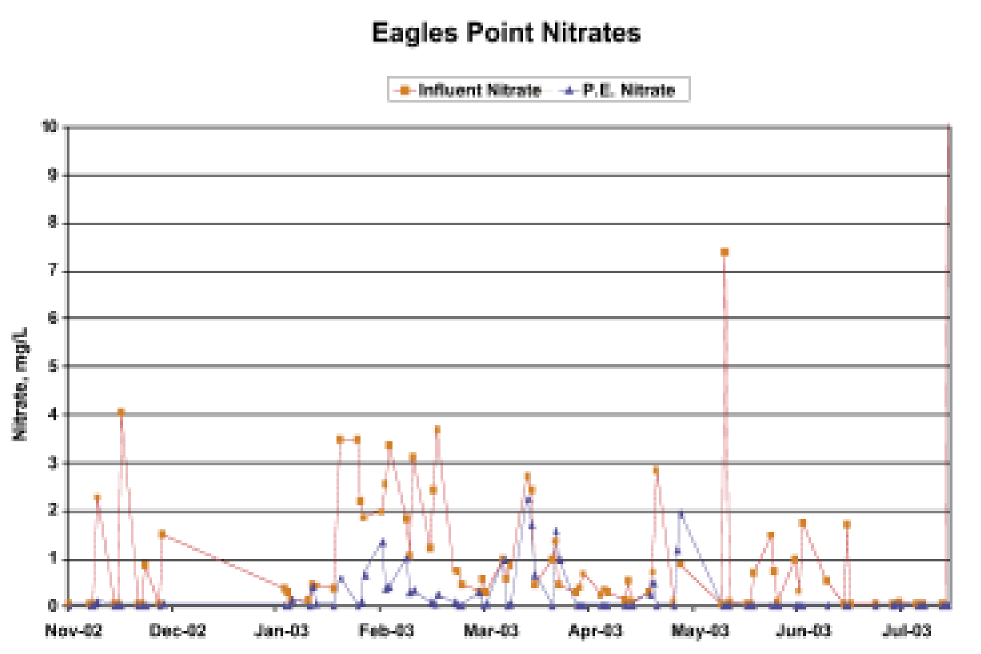

Figure 2: Nitrates in the Influent of Eagles Point Plant

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ing a pH above 9 will keep most of the H_2S in its ionized form and prevent its release to the headspace. A pH between 9 and 10 will not adversely affect VFA formation, but above 11 it will slow the rate of fermentation or stop it altogether.

Oxygenation or Sewer Aeration

Speece (Speece, 2008) proposed a system for super-oxygenation of wastewater in collection systems or in force mains that will ensure super-saturation of the collection system with oxygen to prevent odor formation. The super-oxygenation would have a very beneficial effect on both the subsequent wastewater treatment process and on odor generation by development of preventing septic conditions that would lead to sulfide formation; however, it would also eliminate the VFA production in that section of the collection system.

Force mains are particularly favorable locations for VFA production, since the slime layers on the pipe surfaces serve as attached-growth media for their development. The dissolved oxygen in the influent wastewater will also serve as an electron acceptor for heterotrophic bacteria that have a great affinity for VFA. In the collection system, this will result in an overall reduction of the COD.

Keeping the wastewater fresh may not be detrimental in itself, because it will preserve the readily biodegradable volatile suspended solids in the influent for further fermentation in the plant. Overfeeding oxygen into the collection system or the force main will stop fermentation, and the excess oxygen will be used by the organisms in the slime layer to oxidize readily biodegradable COD or VFA.

Vapor-phase Odor Control

In some cases, sewer corrosion is managed by installing new corrosion-resistant pipe or adding corrosion-resistant liners. In either case, VFA production is maintained, but vapor phase treatment may be required for local odor control.

Some aspects of vapor-phase odor control may have a detrimental impact on VFA. For example, the chemical blowdown from wet scrubbing can contain a high concentration of chlorine. Whether routed to the wastewater treatment plant headworks or simply discharged to the sewer, the chlorine will oxidize VFA.

If caustic-impregnated carbon is regenerated on-site for collection system odor control, the high pH discharge from this process may affect the VFA in the sewer. The drainage from the biofilters typically has a low pH but a very small in volume, so it should not affect the VFA. Bio trickling filters also discharge an acidic waste stream that is returned to the sewer, but as long as sufficient dilution is available in the sewer, its impact should be minimal.

As new odor-control systems are developed, operators should examine the blowdown or liquid discharges from these systems to determine whether they are harmful to fermentation or to the VFA.

Industrial Activity

Industrial activity has the potential to alter the VFA and sulfide mass balance significantly. Some industries have a high wastewater temperature, while others have an elevated BOD concentration, or both. Both the high temperature and high BOD concentrations promote fermentation.

The effluent discharged by some industries remains the same year round. Discharges from others change seasonally in terms of both volume and composition.

For example, meat production may shift from five days per week to six or even seven days per week. In some industries, peak production takes place around major holidays. Still other industries, such as pharmaceuticals manufacturers produce a product in campaign runs. They produce one product or a series of products until the orders have been filled or quotas have been met, then tool up to make other products.

Many industries are ruled by the federal pretreatment guidelines, while others are regulated locally. Cities have no choice but to follow the federal guidelines, although they have considerable latitude in dealing with other discharges.

Pretreatment for pollutants like oil and grease may also impact the amount of BOD or readily biodegradable COD discharged to the sewer and can change the VFA balance in the WWTP influent. BOD can cause fermentation anywhere in the sewer; thus, pretreatment at the upper end of the collection system can have an adverse impact on VFA formation throughout the collection system.

Industry also has its operating quirks. Many food-related industries will reserve Friday night or Saturday as cleanup days, when tanks and process equipment are cleaned and sanitized, which can generate major slug loads of BOD to the wastewater treatment plant.

Such slug loads may or may not cause a surge in VFA formation or sulfide production. The cleaning/sanitizing solutions can contain nitric acid, which will have the same effect as nitrate salts added for hydrogen sulfide control.

Industry practices activity can impact VFA formation. With BPR, it may be counterproductive to require removal of BOD by the industries; however, removal of suspended BOD, which is usually all that an industry will remove, may have no effect on VFA formation. It is recommended that the characteristics of the effluent from major BOD dischargers be defined in the same terms as used for the member connection points. The filtered flocculated COD concentration from industrial sources may have a large impact on the BPR process.

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Internal Policies & Procedures

The wastewater treatment plant should be reviewed to determine whether its processes generate a need for more VFA. Anaerobic digestion will liberate phosphorus and ammonia, which will be returned to the plant influent in the dewatering sidestream.

The effect of these returned materials on the plant is one of timing: The mass load is there, but the instantaneous rate of return depends on the plant's dewatering schedule. If the dewatering schedule is eight hours a day, five days a week, the sidestream reaches the liquid treatment system over the eight hour shift, concurrently with the majority of the domestic load, which may cause a short-term nitrogen and phosphorus overload.

Blowdown from wet scrubbers is the prime source of chlorine at a treatment plant. If the plant has a tight VFA balance, the blowdown can destroy enough VFA to upset/interfere with the BPR. In such cases, it may be advisable to dechlorinate the scrubber blowdown.

As new distribution lines are built, the water plant will be discharging pipeline disinfection waste to the sanitary sewer because new potable water piping has to be superchlorinated before it is place in service. Although discharge of the superchlorinated water into the sewer is intermittent, the water will still interfere with the formation and preservation of VFA.

Industrial cooling tower blowdown often is not subject to the usual permitting procedures because it is "clean" water. This practice may have to be reviewed to determine whether these discharges should be subject to permitting and monitoring to ensure that the wastewater is dechlorinated, which would be a considerable policy change. Before the BPR process was implemented, chlorine discharged to the sewer was beneficial for odor and corrosion control, but now chlorinated wastewater from any source may cause problems.

Multi-Jurisdictional Issues

Many utilities serve several communities. There are many ways in which such agreements can be structured, and this discussion is not meant to solve all the associated legal issues. It is meant to highlight the issues that must be considered in and coordinated between municipalities served.

As discussed previously, collection system management does impact wastewater quality—specifically the components needed for biological phosphorus removal. The basic problem is the same as when one entity controls the collection system. How can the production of the VFA and sulfides be controlled to maximize the production of VFA and prevent sulfide from harming the collection system?

In many multi-jurisdictional arrangements, the member communities continue to own their respective collection systems. If one entity owns the entire collection system, the problems of coordination are significantly reduced, but when the entity that owns the treatment plant does not own the collection system or does not have direct control over it, a master collection system policy is needed.

This policy would be similar to the agreement that governs the industrial pretreatment program. It would have to define the financial responsibilities of each member and how joint decisions are made.

An important part of the agreement is how decisions are made. In essence, this involves joint decisions by committee, which are usually the hardest systems to manage, since each entity has its own agenda. Such agreements are necessary, however, and they must be made to function if the utility is to continue to provide reliable conveyance and treatment of wastewater at the lowest possible cost.

One of the biggest issues is coordinating collection system odor and corrosion control procedures. Each entity owning a sewer line will be responsible for maintaining the sewer in good condition and minimizing odors and corrosion throughout it. Each odor and corrosion control project will be carried out by using the least costly technology without considering the impact to formation and preservation of VFA and the cost to the treatment plant for making or adding VFA.

The first step is to develop a systemwide mass balance for both VFA formation and sulfide production. The mass balance should also include the BOD contributions and the temperature of the wastewater discharged from member communities.

The key issues are VFA formation and VFA formation precursors. Any member may implement its own pretreatment practices requirements, and the reduction of BOD or lowering the temperature can adversely affect VFA formation downstream, possibly in another community's section of sewer.

The VFA and/or the readily biodegradable COD demand of the wastewater treatment plant should be defined to quantify the minimum VFA loads needed. Any sewer project that reduces loads to less than these minimum values essentially forces the treatment plant to add or produce more VFA. The costs associated with fermentation or VFA addition should be determined and updated regularly.

Each member community should be required to submit to the community that owns the treatment plant a report detailing any planned projects of collection system odor and corrosion control, including a detailed economic analysis. The economic analysis should then be amended to include the impacts of such projects to the treatment plant capital and operating costs to determine whether the project will still be cost-effective.

The member communities may have to be convinced of the need to generate or add VFA. The treatment plant should prepare an economic analysis that converts all capital costs into an impact on operating costs, or basically what the member community must pay because of its actions.

The mass balance must be used to determine whether the actions of the member community affect only the VFA generated in its section of the collection system or also that generated by others. This may seem to be a frivolous exercise, but when assigning costs to the responsible party, the true impact of this action must be made known to all. Why should Member A pay for the actions of Member B?

All members of a multi-jurisdictional group must agree to abide by the results of the economic analysis. A method to penalize any member who refuses to follow the agreed-upon policy must be developed and accepted by all members.

The other members of the group must be able to bring pressure to bear on any member not working toward the most economical overall solution even, though that solution may cost them more money in the short run. Simply put, this will be the hardest task faced by the wastewater treatment plant staff.

Conclusions

The big question is how to control corrosion and odors and keep from upsetting nutrient removal at the wastewater treatment plant. The first step is to map problem areas in the collection system and to perform mass balances of hydrogen sulfide and VFA.

Problem areas should be classified either as locations of persistent anaerobic conditions or where sulfide is released to the headspace—or both. Plant personnel should determine whether the problem areas contribute a major portion of the VFA to the treatment plant, prioritize the problem areas, and determine which approach to sulfide control is most economical.

An important consideration in selecting a sulfide control method is whether it affects

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VFA formation or destroys VFA. Decisions should also include consideration of the cost to add fermentation or carbon supplementation at the treatment plant. In this way, the true costs for sulfide control and plant operation can be determined and the most economical solution can be selected.

Timing is another important consideration. If the treatment plant is planning to convert to BPR in five or 10 years, there is less pressure to install a system that preserves VFA today; however, any decision to install a hydrogen sulfide control system knowing that it is a "temporary fix" or a short-term solution should be carefully documented.

If the most heavily corroded areas or those having the greatest potential for corrosion are in smaller sewers that do not contribute much VFA to the treatment plant, any method of sulfide control will be acceptable. If the primary areas sulfide problems coincide with the areas where most of the VFA is produced, the plant influent must be analyzed to determine how much VFA is left or how much VFA must be produced or added to support biological phosphorus removal. In some cases, switching to chemical phosphorus removal rather than biological phosphorus removal could be the least costly approach.

There is no single right answer for hydrogen sulfide control and VFA preservation; there are only poor decisions that have been made based on incomplete information. It's essential to remember that the collection system is a utility's single largest asset and one that must be protected because of the substantial replacement cost and potential liability for property damage if sewers collapse and/or back up into private residences. An informed decision can be made by comparing the cost of replacing or treating the affected sections of a collection system against the cost of producing or adding VFA at the treatment plant.

For some cities, the affected portion of the collection system may be several miles long; for others, it may consist of a few small sections. Site-specific problems require site-specific solutions.

The collection system and the wastewater treatment facilities are joined at the influent manhole, and what happens upstream affects the quality of the incoming wastewater—and in the case of BPR, it affects wastewater treatment plant operation.

The overall objective is to take into account all related capital and operating costs in the collection system and treatment plant when selecting the lowest-cost approach for controlling corrosion and odor, while simultaneously managing phosphorus removal. Once an approach has been selected, the budgets of the collection system and the treatment plant can be adjusted accordingly. Regardless, effective internal communication is essential for making sure that a good decision has been made!

This is not a one-time exercise. New sulfide control procedures will continue to be developed and should be studied to define their effectiveness for sulfide control and their impact on VFA formation and survival to be able to determine the true cost to the entire utility (collection system and wastewater treatment plant).

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