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A Chlorination System for the Scum Manhole at the Sturbridge Wastewater Treatment Plant

A Major Qualifying Project Proposal

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1. Wastewater treatment
2. Nocardioform
3. Chlorination

Abstract

The goal of this project was to design a system for reducing nocardioform bacteria within the Sturbridge Wastewater Treatment Plant in Sturbridge, MA. Nocardioform bacteria at the plant cause foaming in the clarifier and reduce the ability to recover ballast from the foam. Foam samples from the surface of the aeration basin were chlorinated and then analyzed for settleability and cell characteristics via microscopy. A hypochlorite feed design option was chosen to inactivate and separate nocardioform bacteria within a concentrated scum manhole after aeration basin surface wasting. Recommendations for system run-time, the installation of the system, and measuring the success of the system once implemented were provided at the conclusion of this report.

Executive Summary

Nocardioform foaming in wastewater treatment plants creates hazardous working conditions and may compromise the effectiveness of downstream processes. The Sturbridge Wastewater Treatment Plant in Sturbridge, MA experiences foaming due to nocardioform bacteria in the aeration basins. Common methods to control and reduce foam include varying operating factors such as mean cell residence time and pH levels. Surface wasting and disinfection are also commonly used. Currently the plant is using a chemical defoaming agent to reduce foam, but the nocardioform bacteria still persist.

During the completion of this project, the Sturbridge WWTP was undergoing an upgrade to a magnetic ballast addition system called BioMag, prior to secondary treatment. The plant operators were concerned with the amount of magnetite ballast that was being captured within the dense surface foam and ultimately wasted through the sludge handling processes. Thus, a reduction in foam could potentially result in increased magnetite recycle rates and decreased monetary losses.

The goal of this project was to develop an effective nocardioform control strategy that does not compromise downstream processes and reduces or eliminates the use of chemical defoamer. Major objectives included:

- Weekly foam sampling to analyze characteristics of the foam;
- Analysis of chlorine effect on nocardioform bacteria; and,
- Development of an appropriate chemical dosage design necessary to inactivate nocardioform bacteria.

Foam samples were collected four times from October to December 2011 from the scum manhole where surface foam was wasted. Samples were chlorinated with liquid sodium hypochlorite from 0 to 20 mg/L. The samples were analyzed under standard, fluorescence, and phase contrast microscopes to determine the effect of chlorine on the nocardioform bacteria. Samples were also analyzed for foam settleability. Microscopy and settleability tests yielded inconclusive results; therefore, a chlorine dose of 50 mg/L was based on recommendations by Tighe & Bond, Inc. A hypochlorite feed system to the scum manhole was recommended for increased foam control and magnetite recovery.

The chlorination system was designed using a combination of plant water and liquid hypochlorite solution, discharged into the scum manhole via an eductor. The system would run during the time of surface wasting from the aeration basin, chlorinating the foam wasted into the scum manhole. The project includes design and operating recommendations for the chlorination system.

Estimated capital costs for the chlorination system are $310, for equipment and materials. Operational costs are estimated at $82 daily and $29,816 annually based on current hypochlorite solution costs and manufacturer data. The operational cost of the defoaming chemical currently being used to reduce foam at the plan are $47 to $95 daily and $17,255 to $34,509 annually. The newly designed hypochlorite feed system should increase magnetite recovery and improve efforts to control foam.

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- All staff at the Sturbridge Wastewater Treatment Plant for their cooperation and assistance throughout this process.

Without the contributions of these individuals, the success of this project would not have been possible.

Capstone Design Statement

The purpose of this Major Qualifying Project (MQP) was to design a hypochlorite feed system for the Sturbridge Wastewater Treatment Plant in Sturbridge, MA. The aeration basin/clarifier at the Sturbridge WWTP contains nocardioform bacteria, which, cause foaming problems atop the treatment unit. Because the Sturbridge WWTP uses BioMag technology for treatment, these bacteria are also responsible for a reduction in overall magnetite recovery throughout the system. The surface foam containing these bacteria is currently manually treated daily with a chemical de-foamer. This current treatment technique is not producing any noticeable positive results for the plant in terms of magnetite recovery and/or foam reduction. To address the bacteria problem, different treatment options were considered and evaluated. Based on research and conversations with engineers from our external project sponsor, Tighe & Bond, Inc., treatment of surface wasted foam in the scum manhole was recommended. Chlorination of the wasted foam in the scum manhole would allow for direct treatment of the nocardioform bacteria before being sent for magnetite recovery, further treatment, and eventual re-introduction into the plant.

The following design considerations were addressed throughout this project:

- Hydraulic Conditions
    - Plant hydrant pressure (source water for designed system)
    - Flow rates throughout the system
    - Flow rate of foam entering and exiting the scum manhole
    - Eductor sizing
- Sturbridge WWTP Considerations
    - Cost of designed system
    - Increased magnetite recovery
    - Over time, reduction in the foam causing nocardioform bacteria re-introduced into the system
- Economic Considerations
    - Cost comparison between the use of the defoamer and the implementation and use of the designed system

These considerations allowed our team to design a chlorination system appropriate for the Sturbridge WWTP.

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1.0 Introduction

The Sturbridge Wastewater Treatment Plant (WWTP) located in Sturbridge, Massachusetts uses an activated sludge treatment process to treat municipal wastewater from portions of the town. Activated sludge is an aerated biological process in which microorganisms convert soluble organic matter in the influent to biological floc. The flocs are separated from the wastewater by gravity settling in a clarifier. A portion of the settled floc material, or sludge, is wasted and a portion is recycled to maintain a high microorganism concentration in the activated sludge process. The Sturbridge WWTP currently uses BioMag in their activated sludge treatment process. BioMag involves adding magnetite to ballast the flocs, resulting in increased settling rates and increased plant flow capacity. The Sturbridge WWTP recovers the magnetite for reuse to reduce costs.

Solids separation problems are common in wastewater treatment, the most prevalent being foaming. Foaming can cause overflow of the clarifier, odors, and unsafe plant conditions. Foaming results from the growth of filamentous and other forms of bacteria, both in the clarifier and aeration basin. These bacteria attach to air bubbles and float to the surface as foam. The Sturbridge WWTP currently experiences foaming in the aeration basins. The foam causing bacteria can capture portions of the floc, which reduces the settling efficiency. In addition, magnetite in the foam is difficult to recover in the magnetite recovery process. To manage the foam, the Sturbridge WWTP has used a commercial defoaming chemical agent, which is sprayed atop the aeration basin. The plant has also used a surface spray of chlorine at the point before the foam enters a collection pipe for surface wasting into a “scum manhole”. The plant has not seen any noticeable reductions in foaming from these efforts.

Our team collaborated with Tighe & Bond, Inc., the current consulting engineers at the plant, to address the foaming issue. Our project goal was to design a system to chlorinate wasted foam in the scum manhole to reduce the foam causing bacteria that are surface wasted. Reducing these bacteria may improve recovery of magnetite and reduce recycling of foam causing bacteria in the plant.

To design a chlorination system to control foaming, we completed three objectives. First, we collected samples from the scum manhole to identify bacteria in the foam using microscopy. Second, we evaluated the effect of chlorine on bacteria based on microscopic analysis and floc settleability. Lastly, we determined an appropriate chlorine dose for the plant and designed a system for adding hypochlorite to the scum manhole. The following chapters provide background on wastewater treatment, the Sturbridge Wastewater Treatment Plant, the methods used to meet the objectives, and the results and analysis of the work performed.

2.0 Background

Municipal wastewater is treated to meet EPA regulation requirements for discharge to natural sources. An activated sludge treatment process is a commonly used biological process in wastewater treatment. It introduces oxygen into the wastewater to promote the growth of microorganisms, followed by the flocculation and settling of biomass to the bottom of the clarifier. A more recent technology in wastewater treatment, BioMag addition, introduces magnetite into the processes to ballast the floc, resulting in increased settleability of biomass, as well as an increased flow capacity for a treatment plant. The Sturbridge Wastewater Treatment Plant (WWTP) in Sturbridge, Massachusetts utilizes both activated sludge and BioMag addition in their wastewater treatment processes to produce an effluent that meets their permit limits.

2.1 Wastewater Treatment and Regulations

The purpose of municipal wastewater treatment is to treat wastewater so that it can be safely discharged into the environment, without causing adverse effects on the receiving water body. These systems use physical, biological, and chemical processes as described in the following sections.

2.1.1 Wastewater Treatment

Wastewater treatment has four main components: pretreatment, primary treatment, secondary treatment, and tertiary treatment.

Pretreatment

Pretreatment in a WWTP is typically located upstream of primary treatment. The main purpose is to reduce damage to plant equipment by the removal of objects such as large branches or grit, which are often present in this early stage of treatment. The four main stages in the pretreatment process are: bar racks, grit chambers, comminutors, and equalization. Figure 2.1 provides a block flow diagram of the pretreatment processes.

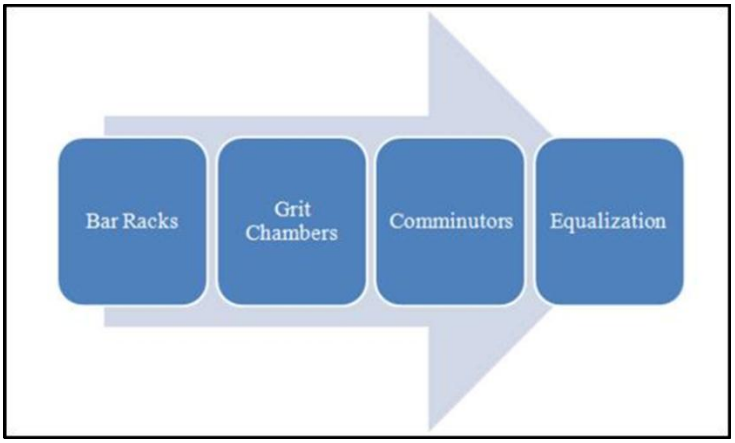


Figure 2.1: Wastewater Pretreatment Block Diagram

Bar racks remove large objects that can damage pumps, valves, and other equipment. The racks, sometimes referred to as screens, filter out logs, rags or other large objects. After passing through the bar racks, the wastewater enters a grit chamber. Grit, a dense material composed of sand, glass, and small rocks, is separated out by gravity. Grit has the potential to damage pipes and reduce flow; therefore, its removal is important to the proper upkeep of the plant. Solids that pass through the first two steps are then broken down in the comminutor. Comminutors physically break apart solids in the wastewater stream. They are typically installed in parallel to ensure redundancy in case of failure. Lastly, the wastewater enters an equalization basin. The equalization basin fills during periods of high flow and is drained during periods of low flow to provide a more steady flow of influent to the primary treatment and throughout the plant (Davis and Masten, 2004).

Primary Treatment

After pretreatment, the wastewater, which contains light organic suspended solids, continues to be processed through primary treatment. Portions of these suspended solids separate from the wastewater by gravity in a sedimentation tank. Figure 2.2 shows a typical primary treatment settling tank. Approximately 50-60% of the raw sewage suspended solids and 30-35% of the raw sewage biochemical oxygen demand (BOD_5) can be eliminated through this treatment tank (Davis and Masten, 2004).

Figure 2.2: Simple Primary Wastewater Treatment (Settling Tank)

(Photo Credit: Madison Metropolitan Sewerage District, Madison, Wisconsin)

Secondary Treatment

Wastewater is further treated through the secondary treatment process. Here, biological treatment is used and has the potential to remove up to 90% of the organics remaining in the wastewater (U.S. EPA, 2011). Microorganisms are introduced into the treatment process where they degrade organic matter and convert a portion of it into cell biomass. Multiple configuration options are available, including suspended growth processes (activated sludge) and fixed film processes such as rotating biological contactors (RBCs) and trickling filters (TFs). In a suspended growth process, the mixture of wastewater, microorganisms, and non-biological material is called the mixed liquor. The cell biomass in this mixture flocculates then settles to the bottom of the secondary clarifier, separating the activated sludge from the partially treated wastewater. In fixed film processes, microorganisms grow attached to a surface, and are sloughed off when the biomass gets thick. As with suspended growth, this biomass is then settled in a clarifier.

Most of the cell biomass that is produced in the secondary treatment step is recycled and reintroduced to the system. The biomass is maintained at the appropriate level to retain a consistently high population of organisms to decompose organic matter. Excess sludge that is not recycled back into secondary treatment is redirected to an outlet where is can be exported and properly disposed of.

The last step within the secondary treatment process is disinfection. This step is typically conducted using chlorine to inactivate the microorganisms in the wastewater, including pathogens. Because chlorine can have negative impacts on the receiving water ecosystem, de-chlorination is performed before discharge. Alternatively, non-chemical disinfection methods, such as UV light, can be used in the disinfection phase (Droste, 1997).

Tertiary Treatment

Depending on the needs of a WWTP and the treatment plant permit, a tertiary treatment process may be necessary. One of the main purposes of this process is controlling the level of phosphorus, nitrogen, and toxins, so levels are within regulations implemented by the U.S. Environmental Protective Agency (EPA).

For phosphorus removal and control, ferric chloride, alum, or lime can be used within tertiary treatment. Nitrogen is controlled mainly in the secondary process in the activated sludge process. In the activated sludge tanks, nitrification and de-nitrification occur naturally and biologically. In tertiary treatment, nitrogen can be controlled using chemical processes, such as ammonia stripping (Droste, 1997).

2.1.2 EPA Regulations

In 1948, Congress passed the first major law to protect U.S. water sources from pollution, called The Federal Water Pollution Control Act (U.S. EPA, 2011). It was not until 1972 that noticeable impacts were realized. Before 1972, wastewater and water treatment plants were not required to adhere to any rules or regulations in regards to discharge streams. The Clean Water Act of 1972 regulated the discharge of pollutants into water sources in the States, with the main goal of "maintaining the chemical, physical and biological integrity of water" (U.S. EPA, 2011). Six amendments to the Clean Water Act were approved in 1977 in order to further improve the quality of surface waters in the nation. These amendments:

1. Established structure for regulating pollutants in discharge water in all U.S. bodies of water;
2. Gave authority to the EPA to implement pollution control programs, such as setting standards in the industry for wastewater;

3. Maintained existing requirements in regards to water quality standards for all contaminants in surface water;
4. Made it "unlawful" to discharge pollutants from a point source to navigable waters without the appropriate permit;
5. Funded construction for sewage treatment plants through the Construction Grant Program; and,
6. Recognized the importance of addressing problems associated with nonpoint source pollution (U.S. EPA, 2011).

In 1981, the Construction Grant Program was revised, and in 1987 this program was replaced with the State Water Pollution Control Revolving Fund, or Clean Water State Revolving Fund. These changes created a stronger funding connection between the EPA and the tates (U.S. EPA, 2011).

Wastewater treatment facilities throughout the U.S. are required to monitor physical, chemical, and biological parameters, and meet effluent limits so the receiving water body is not degraded. The parameters that are regulated can include the biochemical oxygen demand over a period of five days (BOD_5), total suspended solids (TSS), total nitrogen, phosphorus, residual chlorine, and metals, among others.

BOD is the oxygen needed by microorganisms to degrade organic and inorganic matter in wastewater. Typically, it is measured over the course of five days, and is referred to as BOD_5. BOD is regulated because when the BOD of the effluent stream is high and enters a natural source of water, it has the potential to deplete the natural supply of oxygen in the water and have damaging effects on the surrounding ecosystem. Five day lab tests are run to find BOD_5, and these levels must be maintained within the set EPA regulations. The BOD_5 is controlled by adjusting the mixed liquor suspended solids (MLSS) concentration and oxygen influent levels (Davis and Masten, 2004).

TSS refer to all of the solid particles in wastewater that will not pass through a filter. TSS are measured in mg/L, and when effluent with high TSS are introduced to natural bodies of water it can be harmful to aquatic life. Suspended solids absorb sunlight and consequently increase the temperature of the water. Warm water holds less oxygen than cold; therefore, when more TSS are present, water temperature is increased and oxygen levels are lowered. Some fish species are sensitive to the amount of oxygen in the water and cannot survive with fluctuating levels. TSS also reduce the amount of sunlight that penetrates the water. This decreases the amount of photosynthesis in the water, and results in a further decrease in oxygen. TSS can be controlled first by a primary settling tank separating the heaviest of the suspended solids from the water. In the secondary treatment, clarifiers target biological solids in the water to separate and reduce the TSS in the process. If TSS still exceed standards, a filter can be applied after the clarifier (Droste, 1997).

Total nitrogen is present in different forms within municipal wastewater treatment systems, but mostly in the form of organic nitrogen from dead cell material and urea. Nitrogen can pose serious health risks to people if it enters drinking water and is consumed.

Phosphorus in wastewater can be damaging to life in surface waters when present at high levels in plant effluent streams. Municipal wastewater can have phosphorus levels of 5 to 20 mg/L (Droste, 1997), and these levels can be reduced through chemical additions in the treatment process. For example, ferric chloride causes phosphorus to precipitate out of the system as sludge. This sludge can then be removed from the system to be landfilled or recycled, lowering the levels of phosphorus in the effluent.

Facilities that handle wastewater are subject to specific rules and regulations implemented by state and federal governments. Any facility discharging wastewater directly to surface water needs to possess a National Pollutant Discharge Elimination System (NPDES) permit from the EPA, or the state of occupancy. The Sturbridge WWTP NPDES permit and regulations have been issued by both the federal government Clean Water Act, and Massachusetts state government. References and regulations in regards to the Sturbridge NPDES permit are discussed in Section 2.6. The current NPDES permit is located Appendix A.

2.2 Activated Sludge Treatment

The activated sludge process is the most widely used secondary treatment process for domestic wastewater. Activated sludge treatment is a biological method based on the introduction of oxygen into wastewater to promote the growth of microorganisms, followed by flocculation and settling of the biomass. Through settling, the treated wastewater is separated from the activated sludge in the secondary clarifier (Droste, 1997).

Activated sludge treatment requires two stages: aeration and solids separation. These two stages may occur in two different unit processes, or may be combined in a single unit. The overall goal of an activated sludge treatment process is to create a secondary effluent low in suspended solids (SS), and low in BOD towards the surface of the secondary clarifier, and to create a thickened activated sludge in the bottom of the secondary clarifier (Jenkins et al., 2004).

2.2.1 Process

Aeration introduces air into the wastewater treatment system in order to create an aerobic environment for microorganisms. Oxygen, compressed air, or mechanical aeration can be used. In the aeration tank, the microorganisms are thoroughly mixed with the wastewater, and the microorganisms utilize organic matter in the wastewater as food, converting a portion of the soluble organic matter into biomass (Droste, 1997).

The microorganisms continue to grow in size as they reproduce and clump together (flocculate), forming an active biomass, also known as floc. The activated sludge flocs are comprised of biological components (bacteria, fungi, protozoa, rotifers, and other microorganisms) and non-biological components (organic and inorganic particles, fibers from the incoming wastewater, and biopolymers). Floc formation relies on the ability of the microorganisms to adhere to each other and to non-biological particles. The mixture of activated sludge and wastewater in the aeration stage is known as mixed liquor (Jenkins et al., 2004).

In solids separation, the flocculated activated sludge settles to the bottom of the secondary clarifier, and thus is separated from the partially treated wastewater. Settling results in a low level of activated sludge SS in the top of the secondary clarifier, and a thickened sludge in the bottom of the secondary clarifier. Most of this settled activated sludge is returned to the aeration tank in order to maintain a high population of microorganisms in the system for the continuous breakdown of organic matter. The activated sludge returned to aeration is known as return activated sludge (RAS) and must be collected from the secondary clarifier. The RAS must be recycled before the dissolved oxygen (DO) has depleted. Without DO, the aerobic organisms cannot survive (Jenkins et al., 2004).

Not all of the settled activated sludge is returned to the aeration tank. Excess activated sludge is sent to a sludge handling system, typically a gravity thickener, for treatment and disposal. This is referred to as wasted activated sludge (WAS). The proportion of settled sludge that is returned versus wasted controls the food to microorganism (F: M) ratio in the aeration tank. The “food” in is the organics and non-organics in the influent wastewater, while the “microorganisms” are the activated sludge solids in the aeration tank. Table 2.1 contains the F:M control ranges based on different types of activated sludge processes (Mishoe, 1999).

Table 2.1: Activated Sludge Process Ranges for F:M Control

Process Type	Common Process Names	F:M Range (Lbs $CBOD_5$/1Lb MLTSS)
Extended Aeration	Extended Aeration Sequencing Batch Reactors Race Track Orbital Ditch	0.05 - 0.15
Standard Activated Sludge	Conventional Activated Sludge Contact Stabilization Step Aeration Complete Mix	0.25 - 0.5
Hi-Rate Activated Sludge	HRAS based on desired removal (75% to 60% efficiency)	1.0 - 10

The F:M ratio is a control number that helps to determine the proper number of microorganisms for a system. A controlled F:M ratio is desired for any system as it maximizes the amount of settled sludge without overworking the system (Mishoe, 1999).

2.2.2 Microorganisms in Activated Sludge

Microorganisms fuel the activated sludge process. Environmental conditions, process design, and the characteristics of secondary influent wastewater impact the types of microorganisms that dominate a system. The most common microorganisms found in activated sludge are bacteria, fungi, protozoa, and rotifers. The microorganisms present in activated sludge are necessary for the conversion of soluble organic matter to flocculated biomass (Jenkins et al., 2004).

Bacteria

Bacteria make up the majority of the microorganisms in activated sludge. Both heterotrophic and autotrophic bacteria exist in activated sludge. The majority are heterotrophic bacteria, which obtain energy from carbon-rich organic matter in the wastewater influent for the production of new cells. Simultaneously, heterotrophic bacteria release energy by converting organic matter from the influent to carbon dioxide, water, and other compounds. Autotrophic bacteria, on the other hand, reduce oxidized carbon compounds for cell growth, obtaining energy by oxidizing ammonia to nitrate through nitrification. Nitrifying bacteria represent a small percentage of the population of microorganisms in activated sludge, and have a slower rate of reproduction than heterotrophic bacteria (Jenkins et al., 2004).

There are also aerobic (requiring oxygen) and anaerobic (active in the absence of oxygen) bacteria. The activated sludge process is aerated to favor the growth of aerobic bacteria, as the aerobic bacteria are mostly responsible for flocculation in this process. Without these bacteria, organics in the influent wastewater would not be broken down and settled (Jenkins et al., 2004).

Fungi

Fungi have the ability to metabolize organic compounds, much like bacteria, under the right environmental conditions. Because fungi are similar to bacteria, they are another microorganism vital to the activated sludge process. In addition, some fungi can oxidize ammonia to nitrite, and other fungi have the ability to oxidize nitrite to nitrate (Jenkins et al., 2004).

Protozoa

Protozoa are able to metabolize organic compounds. They are single-celled, strictly aerobic organisms. Because protozoa are strictly aerobic organisms, their presence indicates an aerobic environment in the aeration basin. Protozoa can also indicate a toxic environment, more so than bacteria, as they are present with the existence of large amounts of toxins (Jenkins et al., 2004).

Rotifers

Rotifers are multi-cellular microorganisms and are able to metabolize both microbes and organic compounds. Rotifers are similar to protozoa in that they are strictly aerobes, more sensitive than bacteria to toxic conditions in a system. Rotifers are typically present in a very stable activated sludge environment, and absent in an unbalanced system (Jenkins et al., 2004).

2.2.3 Solids Separation Problems: Foaming

Solids separation problems in the secondary clarifier can often indicate an imbalance in the biological stage of a wastewater treatment process. Foaming is one of the most common solids separation problems to occur in wastewater treatment (Jenkins et al., 2004).

Foaming is associated with the presence of filamentous bacteria, particularly nocardioforms and *Microthrix parvicella*. Nocardioforms and *M. parvicella* possess poolyr wettable cell surfaces. When these microorganisms grow in sufficient numbers in activated sludge, they make the floc prone to attaching to air bubbles. The air bubbles and floc float to the top of the secondary clarifier. This results in the formation of a foam/scum layer on the top of the clarifier (Jenkins et al., 2004).

Foaming can also be caused by nutrient deficiency and de-nitrification. The nitrate produced by nitrification during aeration serves as an oxygen source for microorganisms in the sludge layer at the bottom of the secondary clarifier. The nitrate is converted to nitrogen gas. The gas is released inside the flocs, which can then float to the surface of the secondary clarifier. If the denitrifying sludge also has high filamentous organism content, the foam/scum issue has the potential to worsen as the filamentous bacteria also trap nitrogen gas bubbles (Jenkins et al., 2004).

2.3 Foam Causing Filamentous Bacteria

The presence of foam in wastewater treatment plants is primarily attributed to the presence of filamentous bacteria. The Sturbridge WWTP has identified *Nocardia* and *M. parvicella* as the main bacterial components of the foam found in their activated sludge tanks. The following sections discuss causes of foaming in the activated sludge process, and the common methods used to control and manage foaming.

Foaming can be caused by number of problems associated with the growth of filamentous bacteria. Nocardioform foams refer to stable, brown foam usually seen in activated sludge aeration basins and secondary clarifiers. Nocardioforms are a type of actinomycete bacteria. Actinomycetes are a large group of gram positive, filamentous bacilli bacteria. Nocardioform bacteria can be identified as irregularly bent with short (10-20 µm) branch filaments. Figure 2.3 shows 100X and 1000X magnification images of nocardioform bacteria. The left image exhibits the clustering characteristics of nocardioform and the right image exhibits true branching. Nocardioforms and fungi are the only filaments to exhibit “true branching” in activated sludge. True branching characterizes a filament in which intercellular fluids flow freely throughout all branches of the filament. Intercellular fluids cannot flow through false branches. False branches are attached to the bacteria (Jenkins et al., 2004).

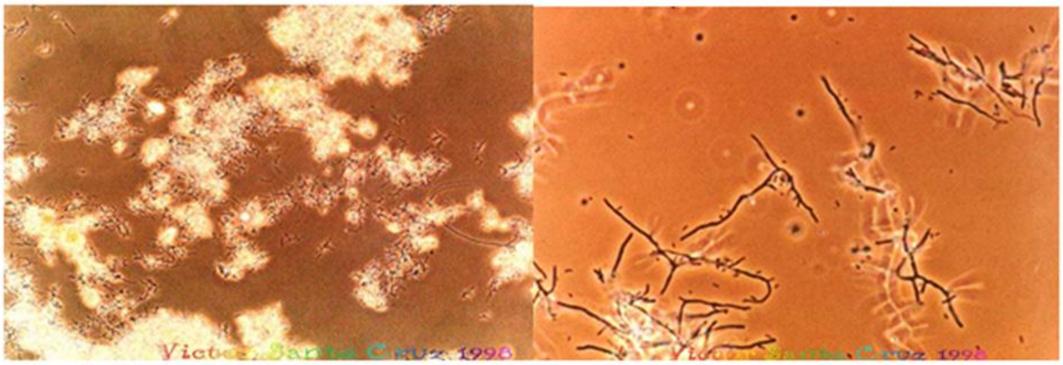


Figure 2.3: Nocardioform Bacteria Viewed by Phase Contrast Microscopy (Left: 100X Magnification; Right: 1000X Magnification)

(Photo Credit: Santa Cruz Productions, 1998)

Nocardioform organisms contain members of the *Corynebacterium*, *Dietzia, Gordona, Mycobacterium, Nocardia, Rhodococcus, Skermania,* and *Tsukamurella* genera. *M. parvicella* creates similar foam and is also related to nocardioforms. Nocardioform organisms are the most commonly observed foam causing filamentous bacteria in activated sludge in U.S. WWTPs (Jenkins et al., 2004). The foam consists of flocs that contain large amounts of *Nocardia* filaments growing from the organisms' surface. The foam achieves stability due to the physical interlocking of the *Nocardia* filaments. The branched Gram positive filaments in the foam can be identified under a microscope (Richard et al., 2003).

2.3.1 Foaming Problems

Foaming causes significant operating problems in WWTPs, including negative aesthetics, odors, and safety hazards. Severe foaming in aeration basins can potentially overflow the basins and cover surrounding areas, creating hazardous conditions for plant operators. Foam can also trap portions of the suspended solids at the surface of the basins. Suspended solids carrying foam can be discharged into the effluent, compromising downstream processes (Jenkins et al., 2004). Process control calculations can be compromised if a significant amount of the plant's solids inventory is present in the foam.

2.3.2 Common Methods to Control Filamentous Bacteria Foaming

Various process control techniques can be used to reduce nocardioform growth in the activated sludge process. A bench-scale experiment was performed in Sacramento, California with primary effluent to determine the effect of process control factors on *Nocardia* population in activated sludge (Cha et al., 1992). The study suggests that foaming could be reduced by operating activated sludge at low mean cell residence times (MCRTs). MCRT, or sludge age, is one of several process factors contributing to foaming. Other processes must be regulated in conjunction with MCRT to effectively reduce foam. Increasing pH levels can slightly decrease *Nocardia* organism counts, but the effect is dependent on MCRT. At lower MCRTs the influence of decreased pH is less pronounced. It is commonly reported that *Nocardia* growth and foaming is associated with high MCRTs, low F:M ratios, and high waste temperatures (Pitt and Jenkins, 1990).

Filamentous organism growth can be minimized by utilization of a selector. A selector is a process tank configuration installed before the aeration basin containing small separate initial mixing zones for RAS and influent wastewater. The term selector describes the role of the device in selecting activated sludge organisms with desirable settling characteristics. The selector directs the substrate carbon source to the floc-forming microorganisms, which incapacitates the growth of filamentous organisms. Selectors can utilize an aerobic, anoxic, or anaerobic environment within the tank. Other design and operating parameters, mainly MCRT, can be used in conjunction with selectors to improve sludge settleability by limiting the growth of filamentous bacteria (Gray et al., 2006).

The buoyancy of nocardioforms can be used to selectively float them from settleable activated sludge flocs in a classifying selector. The classifying selector was first introduced into the wastewater industry in 2001 as a revised approach to the typical selector. It involved continual surface wasting of mixed liquor with high foam causing organism concentrations as a means to select against the organisms (Parker et al., 2001, 2003). The classifying selector wastes the organisms before they cause foam. The common perception is that if the organisms from this selector are not returned to the aeration basin, nocardioforms could be eliminated (Jenkins et al., 2004). It is emphasized that 1 to 3 cm of liquid is removed continuously from the mixed liquor or RAS stream. Surface wasted material should be combined with WAS for treatment. It is also important that the solids being wasted are accounted for in sludge wasting calculations (Parker, et al., 2001, 2003).

Disinfection methods such as chlorination are also used to control foam. RAS chlorination is not very effective for controlling nocardioforms in activated sludge, because the filamentous bacteria are well contained inside the sludge flocs. An overdose of chlorine is necessary to break up the floc. These large doses can degrade effluent quality. However, RAS chlorination can be effective in an aeration basin that utilizes subsurface withdrawal surface wasting. Subsurface withdrawal produces free-floating nocardioform filaments that are accessible to the chlorine. A chlorine solution can also be applied as a fine surface spray directly to the aeration basin surface. The installation of a fine bubble aeration system enhances surface foam, which improves the chlorine solution spray system efficiency on controlling the filamentous bacteria (Jenkins et al., 2004).

2.4 BioMag Addition

BioMag addition in wastewater treatment is patented by Cambridge Water Technology (CWT). CWT's overall company goal is to provide low cost solutions to industries and municipalities for the purification of wastewater (Cambridge Water Technology, 2009). BioMag is an emerging technology which enhances the activated sludge system and costs less than other alternatives. It is capable of tripling flow capacity, achieving total nitrogen levels less than or equal to 3 mg/L, and/or achieving total phosphorus removal less than or equal to 0.2 mg/L (Cambridge Water Technology, 2009). As of 2011, there are only two wastewater treatment plants in the United States that use BioMag addition: the Sturbridge WWTP in Sturbridge, MA and the Allenstown WWTP in Allenstown, NH; however, this technology is emerging in the wastewater treatment industry.

2.4.1 BioMag Addition Details

BioMag is not a process in itself; it is an addition to an existing activated sludge process. The technology requires the addition of magnetite (Fe_3O_4) into an activated sludge system. Due to the low cost of magnetite (approximately $0.50 per pound), BioMag is a cost effective solution in wastewater treatment. Magnetite has a specific gravity of 5.2 and a strong attraction to biological floc, and is used as a ballast. Figure 2.4 shows a treatment process using BioMag; note that magnetite is added in the aeration tank and recovered after secondary clarification (Cambridge Water Technology, 2009).

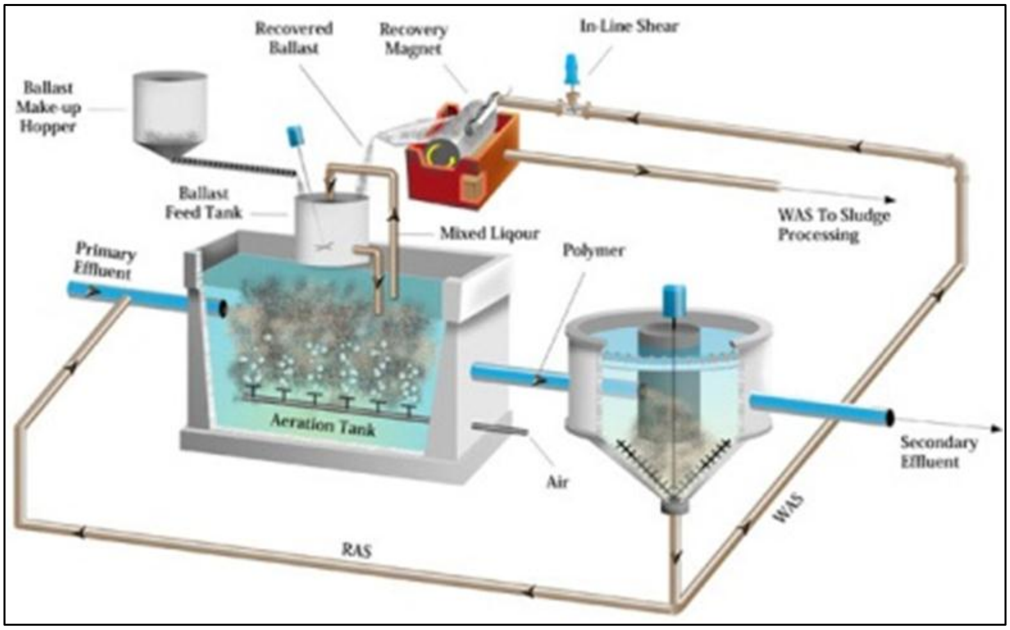


Figure 2.4: BioMag Addition in Wastewater Treatment

(Source: Cambridge Water Technology, 2011)

BioMag enhances the biological wastewater treatment processes. The magnetite increases the specific gravity of the biological floc, resulting in faster settling rates in secondary clarifiers. This allows a treatment plant to double or perhaps even triple its flow capacity and operate with a higher MLSS concentration (Cambridge Water Technology, 2009). Table 2.2 shows average performance when using BioMag (Cambridge Water Technology, 2009).

Table 2.2: Expected Effluent Wastewater Quality with BioMag Addition

Parameter	Value
BOD_5	< 5 mg/L
TSS	< 5 mg/L
NH_3-N	< 0.5 mg/L
Total Nitrogen	< 5 mg/L
Total Phosphorus	< 0.1 mg/L
Turbidity	< 1.0 NTU
Clarifier Solids Loading	> 90 lb/day-ft^2
SVI (sludge volume index)	< 40 mL/g

Overall, CWT states that BioMag is a cost effective solution in wastewater treatment, and is ideal for an activated sludge WWTP looking to increase its treatment capacity. BioMag is not a replacement for a biological process, but can substantially improve settling rates, treatment capacity, and the nitrification efficiency of a WWTP (Cambridge Water Technology, 2009).

2.5 Chlorination

Chlorination is a common method of disinfection used in wastewater treatment in order to reduce microorganism concentrations. Chlorine can be applied in the form of a gas (elemental chlorine), liquid (hypochlorite solution), or solid (calcium hypochlorite).

2.5.1 Chlorine Applied Dosage, Demand, and Residual

The amount of chlorine initially introduced to the system is referred to as the chlorine dose or applied dose. The chlorine added can then be used in reactions, including those with organic matter, ammonia, microorganisms, and inorganics that get oxidized. The chlorine used in these reactions is referred to as chlorine demand. After all of these reactions are complete, any remaining chlorine is referred to as residual chlorine. The chlorine dosage, demand and residual are particularly important to treatment of microorganisms in addition to the quality of the effluent reentering a natural source of water post treatment. For example, if the dosage is less than the demand, there is the possibility that microorganisms will remain alive, which is unwanted in this stage of the treatment. Alternatively, if the demand is met in extreme excess, ensuring microorganism death and a large residual, it would be dangerous to send a heavily chlorinated runoff into a natural source (Viessman and Hammer, 1998).

2.5.2 Effectiveness of Chlorination and Dosage for Wastewater Treatment

In order to measure effectiveness of microorganism inactivation via chlorine, the “CT” concept can be used. Microbial inactiviation is a function of C, residual disinfectant concentration, and T, contact time (Viessman and Hammer, 1998). The needed chlorine dose is dependent upon the concentration of the wastewater, and can also be affected by temperature, alkalinity of the water and nitrogen content. Typically chlorine doses for wastewater treatment are maintained in a range from 5 to 20 mg/L (Solomon, 1998). In order to produce a residual chlorine amount of 0.5 mg/L, an initial chlorine dose of approximately 5 mg/L is needed. The residual chlorine dose is often monitored and adjusted for optimum efficiency for productivity and cost (Mountain Empire, 2011). Chlorine concentrations ranging from 20 mg/L sodium hypochlorite to 150 mg/L as a maximum dosage have been used (Droste, 1997).

2.6 Sturbridge Wastewater Treatment Plant

The Sturbridge WWTP is located in the town of Sturbridge, Massachusetts off New Boston Road Extension, adjacent to Route 84 and the Quinebaug River. The plant treats wastewater generated in portions of the town and discharges treated effluent to the Quinebaug River under NPDES Permit No. MA0100421. The Sturbridge WWTP is currently operated by Veolia Environmental Services under a contract with the town (Tighe & Bond, 2008). Detailed information on pre-upgrade plant conditions, effluent loads and limits, and treatment operations are located in Appendix A.

The Sturbridge WWTP was constructed in 1971 with a design flow capacity of 0.31 million gallons per day (MGD) of wastewater. Originally, the WWTP contained two 60-foot diameter package treatment units (PTUs), which act as combined aeration basins and secondary clarifiers. From the time of its original construction to 1997, the plant was expanded to treat increasing wastewater flow rates. In 1982, a third 71-foot diameter PTU, new aeration blowers, and a belt filter press (BFP) for sludge dewatering were added, bringing the plant flow capacity to 0.505 MGD. In 1997, the plant was upgraded to include a single effluent sand filter for filtration. This addition increased the capacity of the WWTP to 0.75 MGD. At the same time, facilities were added to allow the blending of dewatered sludge with lime in order to reduce the potential for odor generation prior to and during landfill disposal of the sludge (Tighe & Bond, 2008). Table 2.3 summarizes the dimensions of each PTU.

Table 2.3: Package Treatment Units System Summary at Sturbridge WWTP (Tighe & Bond, 2008)

Tank Dimensions	PTU #1	PTU #2	PTU #3	Total
Overall Tank Diameter (ft)	60	60	71	NA
Tank Water Depth (ft)	14.97	14.97	14.97	NA
Aeration Tank Volume (gal)	184,830	184,830	261,270	630,930
Secondary Clarifier Diameter (ft)	30	30	35	NA
Secondary Clarifier Surface Area (ft^2)	707	707	962	2,376
Sludge Holding Tank Vol. (gal)	47,840	47,840	67,590	163,270

Two 100 HP and one 75 HP aeration blower units provide process air to the aeration tanks, sludge holding tanks, and an air lift pump. From the aeration tank, the wastewater flows by gravity to the secondary clarifiers in each unit. An air lift pump is used to return activated sludge to the aeration tank. This pump is also used to waste sludge from the clarifier to the sludge holding tank. Figure 2.5 shows the surface of the aeration tank in PTU #2.

Figure 2.5: PTU #2 Aeration Tank (Pre-Upgrade)

(Photo Credit: Emily Dudley, 9/2/2011)

Before the upgrade, the Sturbridge plant PTUs utilized coarse bubble aerators to introduce oxygen to the aeration basins. The coarse bubble aerators were replaced with fine bubble aerators as part of the upgrade (see section 2.6.1). The aeration tanks run in extended aeration mode. Currently, the WWTP operates at a F:M of approximately 0.08, and an average MLSS concentration of 3,200 mg/L. A secondary clarifier is located in the middle of the circular PTU and is used to settle solids. The aeration basins and clarifier can treat between 0.55 to 0.85 MGD during summer months.

In recent years, flows to the plant have commonly exceeded 0.75 MGD due to increased residential development and added sewer extensions. Average flows, as reported in the Tighe & Bond Comprehensive Wastewater Management Plan (CWMP), are approaching this permitted limit of 0.75 MGD (Tighe & Bond, 2008). To address these increases in flow, the town developed bylaws which limit new sewer connections and began diverting portions of the town’s wastewater to Southbridge, MA. In addition, the plant also implemented operation and equipment upgrades as described in the following section.

2.6.1 Sturbridge Wastewater Treatment Plant Upgrade

In March 2008, the town of Sturbridge received a CWMP from the engineering consulting firm Tighe & Bond, Inc. in Worcester, MA (Tighe & Bond, 2008). The plan recommended wastewater management activities for the town to implement over a twenty year period. The recommendations addressed ways to improve overall plant operations through process improvements and capital upgrades.

The major recommendation of the CWMP is an upgrade of the existing WWTP from a flow capacity of 0.75 MGD to a capacity of 1.3 MGD. Project drivers for this upgrade include stringent future NPDES permits on nutrient removal and aging and obsolete equipment. The December 2006 NPDES permit required the plant to reduce summer effluent phosphorous concentrations to 0.2 mg/L by December 2010. The future NPDES permit will decrease effluent phosphorus levels to 0.1 mg/L. The existing facility was unable to achieve this level. In addition, some mechanical components at the plant have been in service for over 38 years. Upgrading these components will increase the efficiency of the plant. The 2011 NPDES permit for the Sturbridge WWTP, although currently expired, remains effective until a new permit is issued.

Design Conditions

Influent loading and flow parameters were defined in order to design an upgrade to the WWTP. The Clean Water Act limits future effluent discharges to current pollutant loadings. This ensures that an increase in flow is offset by lower effluent contaminant concentrations so that there is no increase in the mass of pollutants being discharged to the receiving water. Historic operating data, along with future NPDES permits, were analyzed to develop design conditions and effluent limitations.

The WWTP upgrade is based on a design flow of 1.3 MGD, which anticipates both a future increase in flows from the town and NPDES permit flow requirements. The CWMP also established peaking flows for various durations and recurrence intervals. The projected average daily flow and peaking flows are summarized in Table 2.4 (Tighe & Bond, 2008).

Table 2.4: Design Flow Projections

Flow Parameter	(MGD)	Peaking Factor
Average Annual Flow	1.3	NA
Maximum Monthly Flow	1.6	1.24
Maximum Weekly Flow	1.9	1.44
Maximum Daily Flow	2.2	1.66
Peak Hourly Flow	2.7	2.07

Past WWTP records were used in the analysis of historic influent pollutant loadings. Projected influent pollutant loadings were estimated in the CWMP for BOD, TSS, ammonium, and total phosphorus. More information regarding estimated conditions is located in Appendix A under Design Conditions.

Conceptual Upgrade Design

Two of the primary goals of the Sturbridge wastewater treatment system upgrade are:

- Consistent performance and reliability in meeting stringent effluent limits established in the town's existing and future NPDES permit; and,
- Minimization of capital, operating, and life cycle costs.

In order to reduce costs, much of the existing infrastructure is being reused. New technology, including BioMag addition, is being implemented to increase capacity without the need for new infrastructure construction. The BioMag addition design described below addresses these goals through the reuse of existing PTU tanks and other structures on-site.

The conceptual design addresses the following processes:

- Process Building: The new process building houses blowers, return activated sludge pumps, chemical feed systems, and the new headworks facility. It also houses RAS/WAS pumps, magnetite storage, and additional recovery equipment.
- Headworks: The plant headworks system includes 2 mm fine screens and a Parshall flume for flow measurement. The system is sized around a peak hourly flow of 1,875 gpm.
- Biological Process Capacity: The PTU upgrade includes a total aerated volume of 400,000 gallons along with an oxygen requirement of 225 lb/hr. An anoxic volume of 300,000 gallons is also included in the upgrade.
- Chemical Addition System: The chemical addition system is designed to provide 221 GPD of ferric chloride to the influent flow splitter for phosphorous removal.
- Sludge Storage: A total sludge storage volume of 150,000 gallons has been established. Waste sludge will be routed to one of two storage tanks for storage and additional decanting of excess water.
- Disinfection: The upgraded plant will utilize ultraviolet (UV) disinfection. New UV equipment will be installed in the existing chlorine contact chamber.

- BioMag Addition: The upgrade includes a magnetite ballast addition to aid sludge settleability. The BioMag addition and recovery system is described in the following section.

BioMag Addition Conceptual Design

Tighe & Bond, Inc. developed a conceptual design for BioMag wastewater treatment addition. The BioMag addition utilizes the following processes and components:

Ballast Addition and Recovery System: The ballast addition system is comprised of a 1,000 gallon tank equipped with a mixer, hopper material storage facility, and an air injection system. The air injection system adds the ballast, or magnetite, to the mix tank. The mixer integrates the ballast into the biological floc, which is then discharged as slurry to the anoxic tanks. A portion of the RAS/WAS line from the secondary clarifier in the PTU is routed through a shear mill. The shear mill separates magnetite from the biological floc, which is then recovered by a magnetic recovery drum. Figure 2.6 shows the magnetite recovery drum. The remaining portion of the RAS flow is routed to the magnetite mix tank.

Figure 2.6: Magnetite Recovery Drum

(Photo Credit: Emily Dudley, 9/2/2011)

Biological Treatment Tanks: The three existing PTUs will be upgraded to include anoxic and aeration tanks within the outer ring of the vessel. Influent from the ballast addition system is routed through the anoxic tank for de-nitrification and alkalinity recovery. The water is then routed into the aerobic tank for BOD removal and nitrification. The anoxic and aerobic tanks are separated by steel baffles.

Secondary Clarifiers: The existing steel clarifiers are being replaced by new steel clarifier vessels and influent wells. RAS/WAS and effluent piping from the clarifiers are being designed to accommodate the new process building and sludge storage facilities.

CoMag Alternative to Second Sand Filter: CWT and the town of Sturbridge decided to install a CoMag addition process to replace sand filtration. Similar to BioMag, CoMag uses magnetite ballast to improve settling. The current sand filtration unit building will not need to be modified as the CoMag addition can fit in its footprint. The CoMag addition includes two trains of chemical addition and mixing tanks, two tertiary clarifiers, and a magnetite recovery system similar to BioMag. The recovered magnetite is recycled to the head of the process. The effluent from this process is discharged to the UV disinfection system.

Solids Handling: The BioMag addition is expected to produce a sludge concentration between 2% and 4% solids. The wasted sludge is diverted to a 150,000 gallon aerated sludge storage tank. The thickened sludge that is trucked off site is expected to be 4% solids.

The design summary for the BioMag addition upgrade is summarized in Table 2.5 (Tighe & Bond, 2008). Process tank volumes and equipment design values for the major units mentioned in this section are included.

Table 2.5: BioMag Design Summary

Process Component	Design Value	Number of Units (Duty/ Standby)	Notes
Anoxic Tank Volume	300,000 gal	3	Split 30/30/40% between units
Aeration Tank Volume	400,000 gal	3	Split 30/30/40% between units
RAS Pumps	375 gpm	3/1	1 Flow Rate Recycle Capacity
Internal Recycle Pumps	1,500 gpm	3/0	4 Flow Rate Recycle Capacity
Shear Mill	30 hp	1/1	High speed shear for magnetite recovery
Magnetic Recovery Drum	30-40 gpm	1/1	Rotating drum for magnetite recovery
Process Aeration Blowers	900 scfm	2/1	Aeration using Invent mixer
Clarifiers	2 @ 30 ft 1 @ 35 ft	3/0	Solids loading rate 80-100 lb/d-ft^2
Sand Filters	270 sf @ 3-5 gpm/sf	1/1	Duplicate of existing for redundancy

Figure 2.7 shows a simplified schematic of the Sturbridge WWTP.

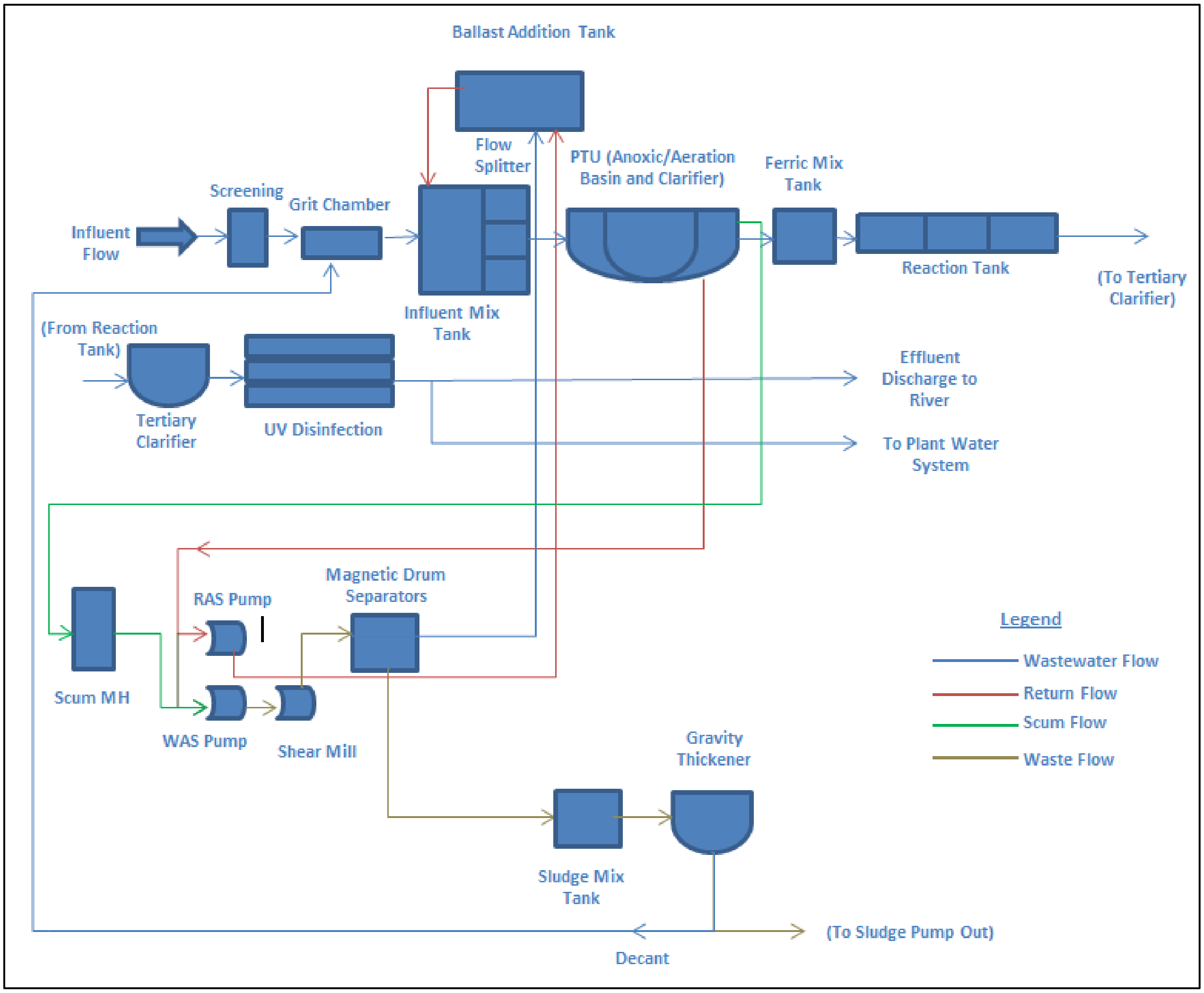


Figure 2.7: Simplified Schematic of the Sturbridge WWTP

BioMag Pilot Study System Performance Study

CWT entered into a contract with the town of Sturbridge to conduct a full scale BioMag trial using one of the three PTUs at the Sturbridge WWTP. The pilot system was installed in December 2007 and ran until April 2008. The purpose of the pilot test was to test performance and reliability to meet future effluent limits.

During the pilot testing, PTU #1 ran as a BioMag pilot addition while PTU #2 was run as an experimental control unit. Over the trial period, the flow rate into PTU #1 was steadily increased from 0.2 MGD to over 0.5 MGD, replicating the future maximum month operating condition. Overall, the BioMag system was capable of handling a wide variation of flows without influent flow equalization. BioMag system data for MLSS, BOD_5, TSS, ammonia, and total kjeldahl nitrogen are located in Appendix A. CWT, Tighe & Bond, Inc., and the town of Sturbridge concluded that the BioMag pilot test demonstrated adequate performance for full scale implementation at the Sturbridge WWTP.

2.7 Foam Control

Foaming is an issue in all three PTUs. Foaming in the PTUs creates negative aesthetics, odors, and safety hazards. SS that are trapped in the foam can be discharged into the effluent and can compromise disinfection operations.

During the time frame of our project with the Sturbridge WWTP, PTU #2 was still running in pre-upgrade mode and PTU #3 was in the process of being upgraded; therefore, we focused our efforts on foam control in PTU #1. PTU #1 was fully upgraded and running with BioMag addition.

Foam on the surface of the aeration tanks contains magnetite from the BioMag addition system. The BioMag system is designed to recycle the magnetite ballast to the magnetic recovery drums at the head of the plant for cost effectiveness; however, the purpose of the system is compromised by the foaming in PTU #1. The plant operators utilize surface wasting, shown in Figure 2.8, to remove surface foam from the aeration basin. The foam is sprayed with a weak dose of chlorinated plant water and collected in a scum trough. The foam then flows by gravity to be collected in a scum manhole. An AutoCAD drawing of the scum manhole provided by Tighe & Bond, Inc. is shown in Figure 2.9.

Figure 2.8: Foam Surface Wasting, PTU #1

(Source: Tighe & Bond, Inc., 2011)

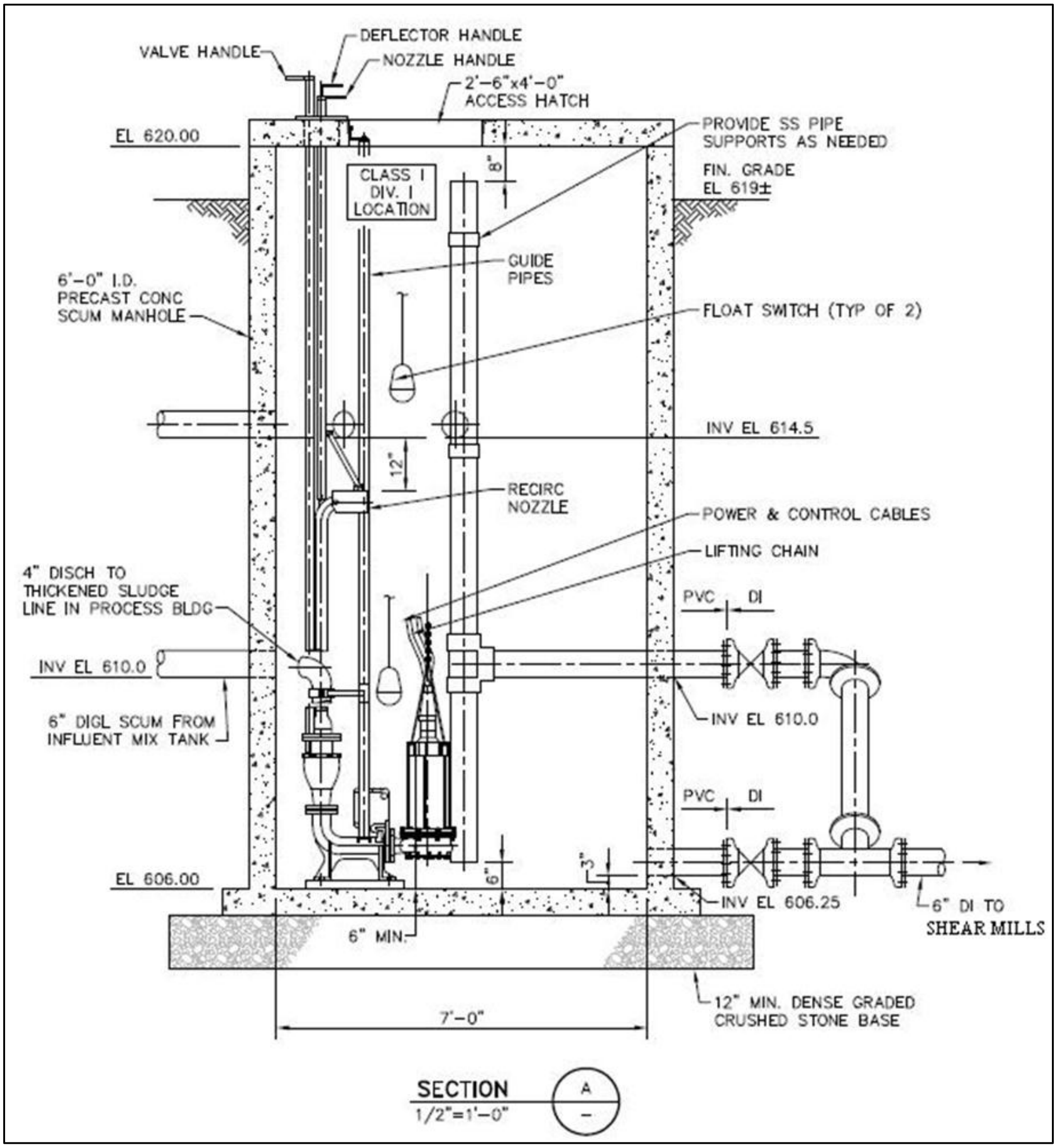


Figure 2.9: Scum Manhole AutoCAD Drawing

(Source: Tighe & Bond, Inc., 2010)

Foam in the scum manhole is pumped to the basement where it is sent through a shear mill. The purpose of the shear mill is to physically shear the magnetite from the foam so that it is more readily recovered on the magnetite recovery drums. Once passed through the recovery drums, the sludge is ultimately sent to the gravity thickeners. The settled sludge is wasted, while the supernatant from the gravity thickeners is overflowed and recycled to the head of the plant. There are two main issues with the current process operation. First, it is difficult to separate the magnetite from the dense foam. Depending on the severity of the foaming and the consistency of surface wasting, a percentage of magnetite cannot be recovered from the dense foam and is thus wasted, resulting in monetary loss over time. The second issue is that foam causing bacteria are still present in the clear effluent that is recycled to the head of the plant after overflowing the gravity thickeners. The nocardioforms are constantly reintroduced into the system and continue to grow and cause foaming issues in the aeration basins. Based on these concerns, the objective of this project was to create a system to effectively reduce or remove nocardioforms from the scum manhole.

3.0 Methods

This chapter covers the methods we used to achieve our project objectives. Our overall project goal was to design a chlorination system for the foam that is wasted to the scum manhole. The purpose of the system was to reduce foam causing bacteria throughout the plant and increase magnetite recovery efficiency.

Our team completed the following project objectives to achieve our project goal:

1. Identified bacteria in the foam;
2. Evaluated chlorine doses based on bacteria reduction and foam settleability; and,
3. Designed a chlorination system for the scum manhole based on future plant flows.

To meet our objectives, we collected samples from the scum manhole following surface wasting. We completed a settling test to determine the effect of chlorine on foam settleability, and microscopically viewed samples before and after dosing. Using an appropriate dosage, we designed the chlorination system.

3.1 Foam Sampling

We collected foam samples from the scum manhole at the Sturbridge WWTP to determine the presence of filamentous bacteria. These samples were used in chlorine dosing experiments as described in Section 3.2. We collected samples on four occasions from October 18, 2011 to December 7, 2011.

A staff member at the Sturbridge WWTP used a long wooden pole with a large beaker on the end for collecting samples. He immersed this tool into the manhole directly after surface wasting from the clarifier. The sample was then transferred into a 250 mL plastic Nalgene sampling bottle and sealed. Two samples were collected in this manner during each sampling event at the WWTP. Samples were labeled, transported back to Worcester Polytechnic Institute (WPI), and stored at 4^{o}C for future testing/microscopy work. Holding time between sampling and testing ranged from 4 hours to 10 days.

3.2 Chlorination Experiments

Our team dosed the collected samples with varying concentrations of chlorine to evaluate the settleability of the foam, and effects on the bacteria in the samples. We used a diluted stock of sodium hypochlorite (NaOCl) for chlorination.

3.2.1 Chlorine Dosing

We chlorinated the foam samples by using liquid NaOCl. First, we measured the free chlorine concentration of the NaOCl stock using a colorimetric method (Method # 8021) on the Hach-DR/3000 spectrophotometer. The maximum chlorine concentration that can be measured with this method is 1.7 mg/L; therefore, we diluted the NaOCl stock to 1/1000 of its original strength by preparing a 100 mL mixture of Epure water and 0.1 mL NaOCl stock. We then measured the free chlorine concentration of the diluted solution as follows.

We prepared two 25 mL glass cuvettes with the diluted solution. One cuvette was placed in the spectrophotometer to zero the instrument. Then we added the contents of one DFD Free Chlorine Reagent Powder Pillow to the second cuvette with diluted solution. We stoppered the cuvette, mixed the sample and powder for 20 seconds, and placed it into the spectrophotometer, which provided the chlorine concentration in mg/L. This value (1.00 mg/L) was multiplied by 1000 to determine the concentration of the NaOCl stock (1000 mg/L).

The volume of NaOCl stock needed to chlorinate 50 mL volumes of foam was calculated. An example calculation is shown below determining the volume of NaOCl stock for a 5 mg/L dose.

$$Concentration_{NaOCl\,(\frac{mg}{L})} Volume_{NaOCl\,(mL)} = Chlorine\ Dose_{(mg/L)} Foam\ Sample\ Volume_{(mL)}$$

$$C_{NaOCl}V_{NaOCl} = Dose * Foam\ Volume$$

$$(1000)\frac{mg}{L}\ V_{NaOCl} = 5\frac{mg}{L} * 50\ mL$$

$$V_{NaOCl} = \frac{5\frac{mg}{L} * 50\ mL}{1000\frac{mg}{L}}$$

$$V_{NaOCl} = 0.25\ mL$$

NaOCl stock volumes were calculated for chlorine doses of 5, 10, and 20 mg/L. The calculated volumes of stock were added with a micropipette into graduated cylinders. We then added surface wasted foam, which was obtained and stored four hours prior, until each solution reached the 50 mL mark on the graduated cylinder. We sealed the cylinders with parafilm, and inverted them to mix. Samples were then analyzed for floc settleability and used for bacteria identification, as described in the following sections.

3.2.2 Foam Settleability

We performed a visual comparison of foam settleability in four glass 50 mL graduated cylinders. The cylinders were prepared with chlorine doses of 0, 5, 10, and 20 mg/L as discussed in section 3.2.1. Then, visual observations were made of the cylinders at thirty minute intervals for three hours, with specific focus on settling characteristics. Photographs of the samples at each time interval were also taken.

3.2.3 Microscopy

Based on information provided by the Sturbridge WWTP, our team knew that nocardioform bacteria were present in the foam, but were uncertain as to which types. We examined the surface wasted foam samples by standard microscopy, florescence microscopy, and phase contrast microscopy to identify bacteria and compare chlorinated and unchlorinated foam samples.

3.2.3.1 Standard Microscopy

We used an American Optical (AO) Photostar Trinocular Research Microscope with bright field white light illumination for standard microscopy. The magnifications used were 400X and 1000X. First, we placed a small amount of the foam sample onto a slide with a disposable pipette. We then placed a cover slip over the sample and placed the slide underneath the microscope lens. Oil immersion was used for the 1000X magnification, which is an oil interface between the cover slip and the lens that prevents the light from scattering. Both control samples and samples dosed with chlorine were analyzed by standard microscopy. The samples dosed with chlorine were viewed after a holding time of three days.

3.2.3.2 Fluorescence Microscopy

We used the red (555 nm), blue (488 nm), and violet (320 nm) lights/wavelengths of a German Zeiss Research Florescence Microscope for fluorescence microscopy. The magnification used was 1000X. First, we confirmed the fluorescence with acridine orange stained cheek cells, specifically looking for the variations in light. The acridine orange stain allows for the florescence of phosphates, which are in DNA and RNA. After confirmation of the light, we combined the foam sample with acridine orange stain, inverted the vial, and placed a small amount of the mixture onto a slide with a disposable pipette. We then placed a cover slip over the sample and placed the slide underneath the microscope lens. This microscope does not work properly if there is white light entering, so in order to obtain a clear image and use this microscope with the varying lights/wavelengths, we covered the white light entrance. Control samples were viewed with this method. Samples dosed with chlorine were not analyzed under this microscope.

3.2.3.3 Phase Contrast Microscopy

We used a German Zeiss Phase Contrast Microscope for phase contrast microscopy. The magnification used was 1000X. The phase contrast microscope separates the layers of the sample, similar to a 3-D image, identifying all structures on a slide to obtain a clear and sharp image. Slides were prepared using the same process as for standard microscopy. We used phase contrast microscopy twice, each occurrence with different samples. The chlorinated foam samples discussed in section 3.2.1 were viewed with this method after a holding time of ten days. Additionally, we examined all doses (0, 5, 10, and 20 mg/L) for 50 mL foam samples after a holding time of four hours using this method.

4.0 Results and Analysis

This chapter summarizes the results of foam sampling and testing from the scum manhole at the Sturbridge WWTP in Sturbridge, MA. Results from the chlorine settling test and microscopy methods discussed in Chapter 3 are presented and analyzed. Microscopy methods were inconclusive for determining a chlorine dose for the foam; therefore, we estimated a dosage based on research as well as recommendations from engineers at Tighe & Bond, Inc., further described in Chapter 5.

4.1 Chlorine Settling Test

Our team analyzed the settling characteristics of foam from the scum manhole using the methods described in Chapter 3. Foam was collected from the scum manhole at the Sturbridge WWTP, distributed into four graduated cylinders, and dosed with varying levels of chlorine. The effect of chlorine on the settleability of foam was evaluated visually. The purpose of settling the foam is to increase the efficiency of the shear mills, thereby increasing the efficiency of the magnetite recovery process.

Three graduated cylinders were dosed at 5, 10, and 20 mg/L of chlorine. The fourth was used as a control (0 mg/L dose). No settling occurred in any of the four graduated cylinders over the three hour observation period. If settling had occurred, we would have observed a notable division between the opaque sludge and translucent supernatant. Because this division was not observed, we concluded that the chlorine dosage was ineffective in causing the foam to settle. It is likely that the nocardioforms are well contained inside the large sludge flocs in the scum manhole. It is also possible that killing the nocardioforms has no effect on the settleability of the foam. Additional observation of the effect of chlorine on the nocardioforms was performed via microscopy, as described in the next section.

4.2 Microscopy

Microscopy was used to examine nocardioform bacteria in the surface wasted foam and evaluate the impact of chlorine on foam characteristics. Nocardioform bacteria can be identified via microscopy by their true branching, short filament length, and clustering characteristics.

Using standard microscopy at 1000X magnification, we identified bacteria in the control and chlorinated foam samples; however, we could not positively identify the bacteria as nocardiofrom bacteria. The branching characteristics of nocardioform bacteria could not be positively identified using standard microscopy.

Using florescence microscopy, we identified nocardioform bacteria. Unchlorinated samples were stained with acridine orange and examined with three light/wavelength variances: red (555 nm), blue (488 nm), and violet (320 nm). Nocardioform branching and cluster characteristics were noted.

4.2.1 Phase Microscopy

Using phase contrast microscopy, true branching and intracellular granules could be detected. Figure 4.1 provides an image of the foam samples showing true branching.

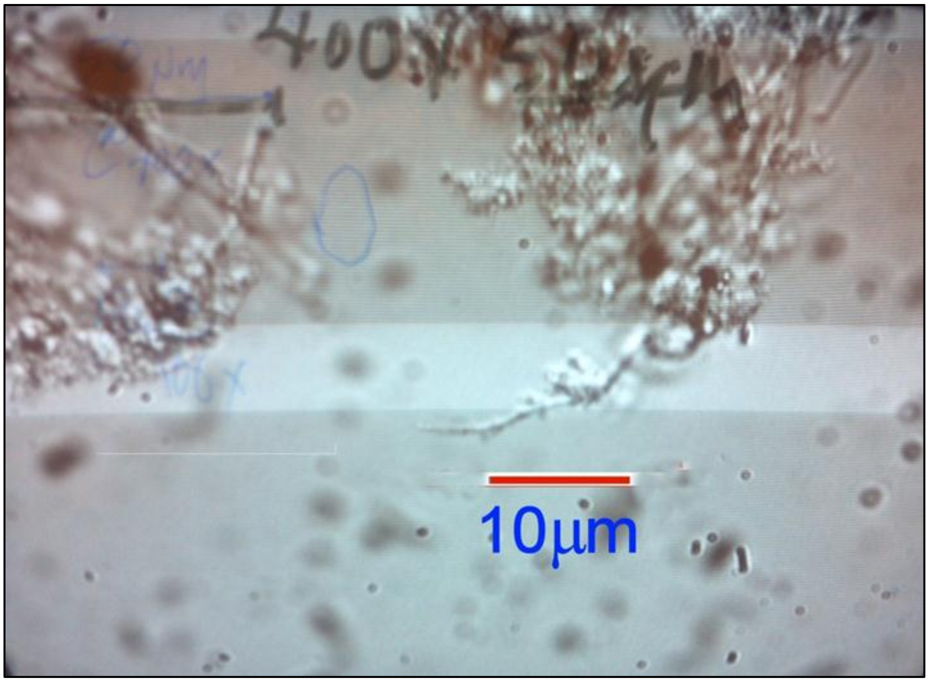


Figure 4.1: Image of Foam from Scum Manhole using Phase Contrast Microscope at 1000X, 0 mg/L (Control Sample)

(Photo Credit: Professor Daniel Gibson, 2011)

With this microscope, we further confirmed the presence of filamentous bacteria. In the first trial, samples with a holding time of ten days were examined. Results were inconclusive, as no differences were observed between the different chlorine doses. We conducted a second trial using samples with a chlorine contact time of four hours. No differences were found between the control sample (0 mg/L chlorine dose) and the 20 mg/L chlorine dosed sample. We were unable to determine a dosage for killing the bacteria present in the foam through these microscopy methods. We estimated a chlorine dosage for the design based on these microscopy data and other research described in Chapter 5.

5.0 Design

Results in Chapter 4 showed no noticeable difference in foam settleability or microscopic analysis for chlorine doses up to 20 mg/L. Our team assumed that the doses tested were too low. We consulted our project advisors and consultants at Tighe & Bond, Inc., and estimated that an applied dose of 50 mg/L may be needed for nocardioform control. The design estimations were based on this dose estimate.

The following sections describe the design of a hydraulically driven scum manhole chlorination system to reduce the presence of nocardioform bacteria in the scum manhole. Design parameters, example calculations, and a cost analysis are provided. Detailed calculations and manufacturer data can be found in Appendix D and F, respectively.

5.1 Chlorination System Design

We selected a hydraulic system to chlorinate the surface waste in the scum manhole. The system uses plant water as a motive fluid to deliver a hypochlorite feed to the scum manhole via an overhead spray outlet. The system consists of PVC piping connected to an existing plant water hydrant located adjacent to PTU #1. The complete design includes a Venturi eductor, a source of 12.5% bleach, and a spray head to deliver the final discharge.

A Venturi eductor is used as a pumping device to deliver hypochlorite solution to the plant water. The hypochlorite solution consists of 12.5% hypochlorite laundering bleach. Figure 5.1 depicts a simple eductor design.

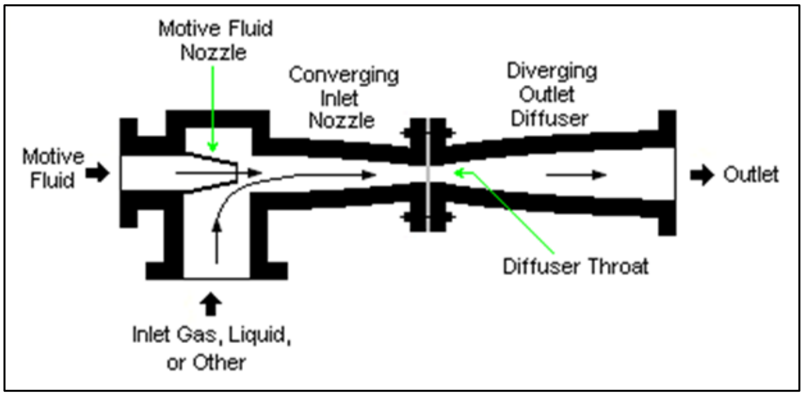


Figure 5.1: Simple Eductor Design

The motive flow, plant water from the hydrant, enters a decreasing pipe diameter causing a temporary increase in velocity and decrease in pressure. The resulting low pressure zone draws the inlet hypochlorite solution. The two fluids are mixed and distributed through the outlet flow. The eductor is sized according to motive flow rate, motive pressure, volume of bleach (suction fluid) desired, and a final concentration and flow rate of discharge. The motive, suction, and discharge connections are fitted to a 1/4", 1/8", and 1/4" nominal PVC pipe, respectively. The combined hypochlorite and plant water solution is carried to a spray head located 1 ft above the scum manhole.

5.2 Venturi Eductor Design

The addition of a Venturi eductor will allow for a controlled amount of 12.5% sodium hypochlorite solution to be added to the scum manhole and result in an applied chlorine dose of 50 mg/L to the surface waste being processed through the scum manhole.

In order to properly size an eductor for the addition of sodium hypochlorite to the scum manhole, eductor parameters in three categories were calculated. These categories were: the influent liquid conditions (hydrant plant water), suction liquid conditions (12.5% bleach), and discharge condition (hypo solution exiting eductor, entering scum manhole), as seen in Figure 5.2.

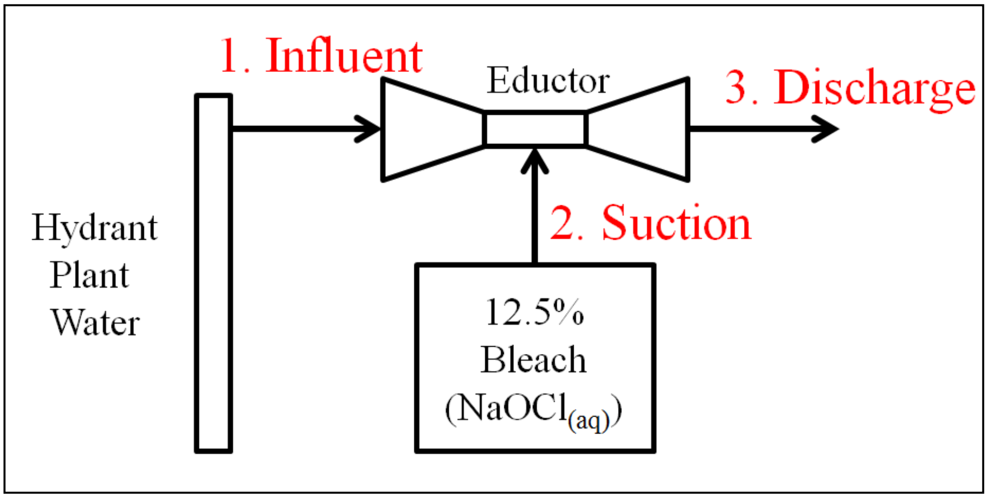


Figure 5.2: Eductor Diagram

5.2.1 Flow Rates and Chlorine Concentrations

In order to determine the flow rates of the three eductor streams, the amount of surface waste processed from the PTUs through the scum manhole was analyzed. The applied chlorine dose, flow rates around the scum manhole, and stream concentrations around the scum manhole were evaluated.

The Sturbridge WWTP maintains an inventory of 10,000 mg/L MLSS by wasting primarily from the 3% concentrated bottom sludge. The bottom sludge, containing 3% suspended solids is currently wasted at 8,000 gpd in order to maintain a MLSS concentration of 10,000 mg/L. If surfacing wasting were to be used to maintain that same level of MLSS, three times the amount would need to be wasted because the surface waste is concentrated at 1% SS. Three times the 8,000 gallons results in 24,000 gallons of surface waste. In order to process 24,000 gallons from the PTUs at a flow rate of 30 gpm into the scum manhole, it takes 800 minutes (0.56 days) of wasting (Equation 1).

$$\frac{Volume\ of\ Surface\ Waste\ (gal)}{Flow\ Rate\ of\ Surface\ Waste\ (gal/min)} = Total\ Surface\ Waste\ Time\ (min)$$

(Equation 1)

With the addition of the eductor, three main flow rates govern the chlorine level in the scum manhole. Figure 5.3 displays the layout, flow rates, and concentration of chlorine throughout the system. The influent and effluent flow rates can run simultaneously. The effluent flow rate from the scum manhole can be manually controlled; therefore, the effluent flow rate can be set as the sum of the two influent flow rates to ensure consistent flow through the scum manhole.

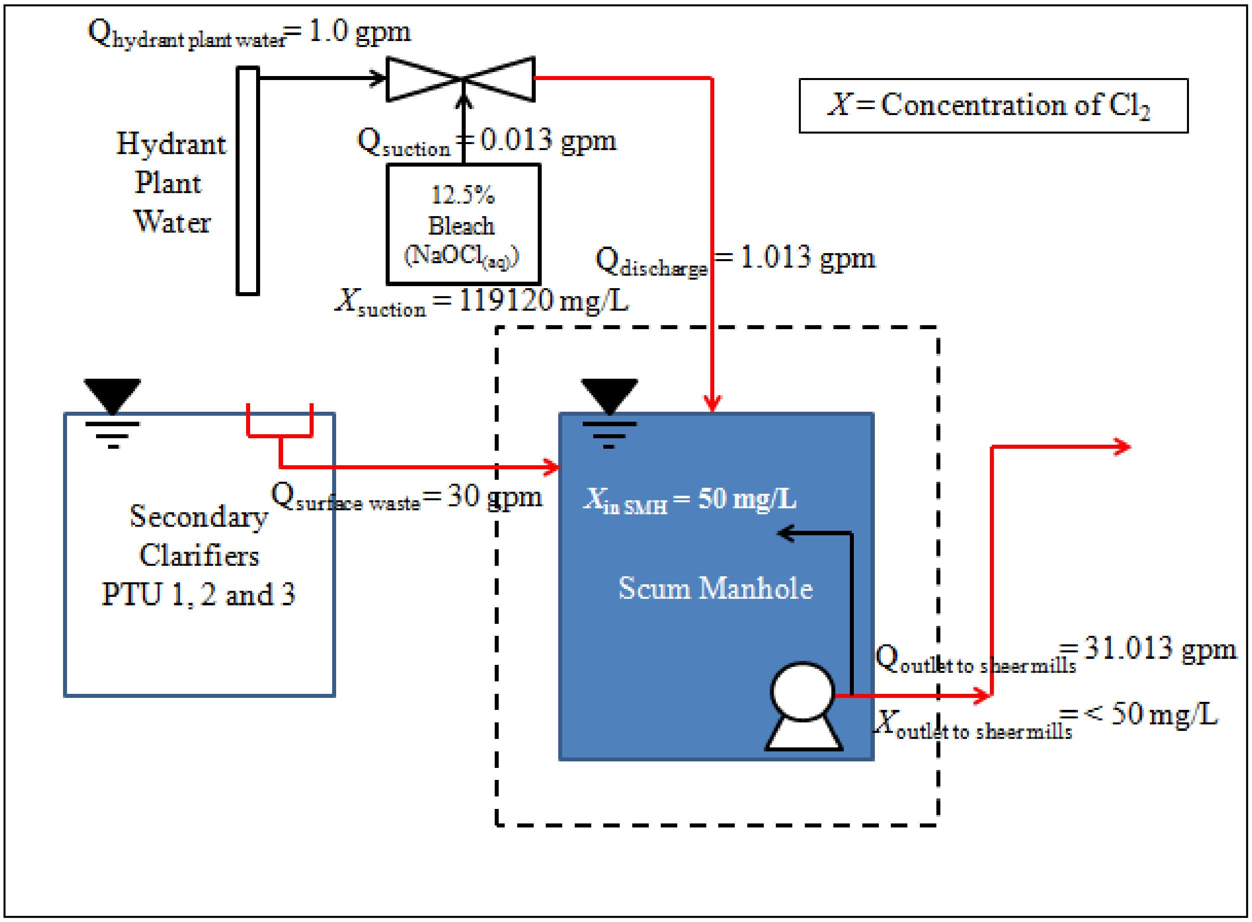


Figure 5.3: Schematic of Designed Chlorination System for the Scum Manhole

The scum manhole has an inlet flow from the PTU troughs, an inlet flow from the eductor, and a pump to control and maintain an outlet flow to the sheer mills and magnetite recovery drums.

The total volume processed through the scum manhole consists of the influent from the PTUs and discharge from the eductor. The flow through the eductor is 1 gpm, a rate that is easily maintained because the 1 1/2" hydrant has a pressure of 75 psig. According to Tighe & Bond, Inc. consultants, this pressure is sufficient enough to maintain this flow rate. Additionally, the total volume discharged from the eductor at 1 gpm results in 3% of the total volume processed; therefore, 97% of the material processed is the surface waste.

The total volume processed through the scum manhole is 24,800 gallons (93,878 L) (Equation 2). In order to maintain the applied dose of 50 mg/L, approximately 4,690,000 mg of chlorine needs to be applied to total volume processed, as demonstrated in Equation 3.

$$[Flow\ rate\ PTU\ (gpm) \times\ run\ time\ in\ (min)] + [Flow\ rate\ eductor\ discharge\ (gpm) \times\ run\ time\ in\ (min)] = volume\ processed\ (gallons)$$

(Equation 2)

$$Applied\ Cl_2\ Dose\ \left(\frac{mg}{L}\right) \times Total\ Volume\ Processed\ (L) = mass\ of\ Cl_2\ (mg)$$

(Equation 3)

Next, we determined the volume of 12.5% bleach to be suctioned through the eductor to create the desired concentration in the discharge. Based on stoichiometric relations and molecular weight of NaOCl and Cl_2, 12.5% NaOCl solution contains 11.9% Cl_2. The NaOCl concentration in the bleach is 125,000 mg/L; therefore, the concentration of Cl_2 in the bleach is 119,000 mg/L (Equation 4).

$$\frac{Conc.NaOCl\ \left(\frac{g}{L}\right)}{mol\ wt\ NaOCl\ \left(\frac{g}{mol}\right)} \times \frac{mol\ Cl_2}{mol\ NaOCl} \times \frac{g\ Cl_2}{mol\ Cl_2} \times \frac{1000\ mg}{1\ g} = Conc.Cl_2\ (mg/L)$$

(Equation 4)

The suction volume of bleach (L) into the eductor is calculated using a proportion between the chlorine concentration of the bleach (mg/L) and the amount of applied Cl_2 (mg) needed to maintain an applied dose of 50 mg/L. The volume is 10.4 gallons, and that volume processed over a run time of 800 minutes provides a suction flow rate of 0.013 gpm (18.7 gpd) as seen in Equation 5 and Equation 6.

$$\frac{Mass\ of\ Cl_2(mg)}{Cl_2\ Conc.of\ bleach\ (\frac{mg}{L})} \times \frac{1\ gallon}{3.7854\ L} = suction\ volume\ of\ bleach\ (gallons)$$

(Equation 5)

$$\frac{Suction\ volume\ of\ bleach\ (gallons)}{Run\ time\ (minutes)} = suction\ flow\ rate\ (gpm)$$

(Equation 6)

All calculations for equations used can be found in Appendix D. Table 5.1 shows a summary of these values.

Table 5.1: Flow Rates and Chlorine Concentrations in the Eductor and Scum Manhole (SMH) Process

Flow Rates		Concentration of Cl_2	
Parameters	(gpm)	Parameters	(mg/L)
$Q_{\text{hydrant plant water (motive)}}$	1	$X_{\text{hydrant plant water (motive)}}$	0
$Q_{\text{bleach into eductor (suction)}}$	0.013	$X_{\text{bleach into eductor (suction)}}$	119000
$Q_{\text{hypo solution into SMH (discharge)}}$	1	$X_{\text{hypo solution into SMH (discharge)}}$	1190
$Q_{\text{surface waste}}$	30	$X_{\text{surface waste}}$	0
$Q_{\text{outlet to sheer mills}}$	31.013	$X_{\text{outlet to sheer mills}}$	<50

5.3 Eductor Sizing

We consulted with Fox Venturi eductors (Dover, NJ) and presented our influent, suction, and discharge parameters to have a Venturi eductor selected to meet the Sturbridge WWTP flow needs. The design parameters and calculations were processed by the Fox Company where the appropriate educator was selected for use. See Appendix F for the Fox eductor data sheet.

5.4 Materials

The proposed design will run from the plant hydrant near PTU #1 to the scum manhole through a series of PVC Schedule 40 pipe and fittings. The design requires PVC adapters (female to male and vice versa), needle valves, and a spray head for delivery of the hypochlorite solution to the scum manhole. Our team was able to obtain approximate pricing for all of the required materials from various manufacturers via the U.S. Plastic Corporation. Based on February 2012 material prices, the materials required for the design will cost $310. See Appendix E for the materials list and design schematic for the eductor addition.

5.5 Cost Analysis

The Sturbridge WWTP currently uses a chemical defoamer when foam levels increase in the PTUs. The defoamer costs approximately $1,300 per 55 gallon barrel, and plant operators typically apply 2-4 gallons per day of defoamer to the PTU surface by hand. The resulting daily defoamer cost incurred by the plant is between $47 and $95 per day. The unit price for a 55 gallon drum of 12.5% sodium hypochlorite, commonly known as bleach, was determined to be $432, based on an average cost found at ChemDirect, a chemical distributing company out of New Hampshire. Based on this price, and the determined use of 10.4 gallons per day of bleach, the resulting cost is $82 per day.

Another factor to consider in the cost comparison is initial start-up cost. Based on the cost for materials discussed in Section 5.4, the initial start-up cost for the recommended chlorination system is $310. The unit prices were converted to daily and yearly operational costs based on applied dosage in gallons and are summarized in Table 5.2.

Table 5.2: Cost Comparison (Defoamer versus Chlorination System)

ESP FC 435 Defoamer ($24 per gal)			Hypochlorite/Plant Water Solution ($1 per gal)			Yearly Price Difference
Usage (gpd)	Daily	Yearly	Usage (gpd)	Daily	Yearly	
2	$47	$17,255	10.4	$82	$29,816	-$12,561
3	$71	$25,882				-$3,934
4	$95	$34,509				$4,693

Normally, the start-up cost for the chlorination system would need to be considered in this comparison. However, the yearly chemical costs are in the tens of thousands while the capital costs are in the hundreds; therefore the capital costs are negligible. As shown in Table 5.2, the defoamer is a less expensive alternative if 2 to 3 gallons per day are used. However, since the defoamer has had no significant effect on foam control, the chlorination system is still recommended.

6.0 Conclusions and Recommendations

6.1 Conclusions

The goal of this project was to design a chlorination system for the scum manhole at the Sturbridge WWTP. The purpose of the designed system was to reduce foam causing bacteria throughout the plant and increase magnetite recovery efficiency. Our major project objectives included:

- Weekly foam sampling to analyze characteristics of the foam;
- Analysis of chlorine effect on nocardioform bacteria; and,
- Development of an appropriate chemical dosage design necessary to inactivate nocardioform bacteria.

Samples from the scum manhole were analyzed using standard, fluorescence, and phase contrast microscopes to determine the effect of chlorine on the nocardioform bacteria. The microscopy methods yielded inconclusive results. Foam settleability tests were also inconclusive. Due to this, a chlorine dosage of 50 mg/L was determined based on recommendations from Tighe & Bond, Inc.

With this dosage, the chlorination system was designed using a combination of plant water and liquid hypochlorite solution, which was discharged into the scum manhole via an eductor. The recommended design was determined using projected surface wasting flow rates from all three PTUs. A list of required materials (PVC Schedule 40 piping and fittings, an appropriately sized eductor, needle valves, and adaptors), as well as a projected design set-up appropriate to the Sturbridge WWTP is provided.

The estimated capital cost for the chlorination system is $310, which includes all required materials for construction. The anticipated daily operational cost is based on the use of 10.4 gallons of sodium hypochlorite (bleach) per day, estimated at $82 daily and $29,816 annually.

6.2 Recommendations

System operation recommendations and ways for measuring the effectiveness of the design are provided for operators at the Sturbridge WWTP.

6.2.1 System Operation

In order to achieve maximum dosing efficiency, we recommend that the designed chlorination system be run during the time of surface wasting from the aeration basin, chlorinating the foam wasted into the scum manhole. Future surface wasting rates at the Sturbridge WWTP are scheduled for approximately half the day. The scum manhole can operate as a continuous system, constantly chlorinating while surface wasting.

The needle valves included in the design allow for throttling of the system. Flow can be manually throttled down as necessary to achieve a smaller controlled flow rate.

6.2.2 Chlorination Effectiveness

After implementation of the chlorination system, we recommend that the plant operators monitor the effects, specifically: overall magnetite recovery and decrease of the foam in the clarifier/aeration basin over time. If the desired effects are not observed, the chlorine dosing to the scum manhole can be adjusted.

The Sturbridge WWTP measures the approximate recovery percentage of the magnetite used in their BioMag addition process. Over the past several months, the plant has seen a decrease in the recovery percentage. The foam causing bacteria are attaching to the magnetite in the system, and due to the strong bond to the bacteria, the magnetite is not released as easily when going through the shear mill and eventually not recovered over the recovery drum. With the chlorination system in use, there is the potential it will kill a significant amount of the foam causing bacteria surface wasted into the scum manhole. The eradication of the bacteria should result in the release of the magnetite from the bacteria, and therefore the magnetite recovery percentage should increase. We recommend the Sturbridge WWTP monitor and record magnetite recovery on a regular basis to verify improvements in recovery.

There is a direct correlation between the existence of foam causing bacteria and the presence of foam on top of the clarifier/aeration basin. It is difficult to implement a strategy successful in reducing the foam because the foam causing bacteria are eventually re-introduced into the head of the plant and into the process. The chlorination system is intended to kill foam causing bacteria surface wasted into the scum manhole, reducing the amount of living bacteria re-introduced at the head of the plant. Thus, the plant should see a reduction in the foam atop the clarifier/aeration.

7.0 References

Cambridge Water Technology. (2011). Introduction to BioMag Technology. Retrieved September 23, 2011 from http://cambridgewatertech.com/technology/biomag.

Cha, D. K., Jenkins, D., & Lewis, W. P. (1992). *Process of Control Factors Influencing Nocardia Populations in Activated Sludge*. (1 ed., Vol. 64, pp. 37-43). Berkeley, CA: University of California, Berkeley.

Davis, M.L., & Masten, S.J. (2004). *Principles of Environmental Engineering and Science*. New York, NY: McGraw-Hill.

Droste, R.L. (1997). *Theory and Practice of Water and Wastewater Treatment*. New York: J. Wiley.

Gray, D., De Lange, V. P., Chien, M. H., Esquer, M. A., & Shao, Y.J. (2006). *Investigating the fundamental basis for selectors to improve activated sludge settling*. Oakland, CA: East Bay Municipal Utility District.

Jenkins, D., Richard, M., & Daigger, G. (2004). *Manual on the Causes of Activated Sludge Bulking, Foaming, and other Solids Separation Problems*. Florida: CRC Press LLC.

Madison, Wisconsin Metropolitan Sewerage District. (2007). Image at the District. Retrieved October 12, 2011 from http://madsewer.org/.

Mishoe, G.L. (1999). F/M Ratio and the Operation of an Activated Sludge Process. *Florida Water Resources Journal*.

Mountain Empire Community College. (2000). Chlorine Residual. Retrieved January 13, 2011 from http://water.me.vccs.edu/courses/ENV115/chlorine.htm.

Parker, D., Geary, S., Jones, G., McIntyre, L., Oppenheim, S., Pedregon, V., Pope, R., Richards, T., Voight, C., Volpe, G., Willis, J., & Witzgall, R. (2001). *Making Classifying Selectors Work for Foam Control in the Activated Sludge Process*. (2001 ed., Vol. 11, pp. 251-268). Walnut Creek, CA.

Parker, D., Geary, S., Jones, G., McIntyre, L., Oppenheim, S., Pedregon, V., Pope, R., Richards, T., Voight, C., Volpe, G., Willis, J., & Witzgall, R. (2001). *Making Classifying Selectors Work for Foam Control in the Activated Sludge Process*. (1 ed., Vol. 75, pp. 83-91). Walnut Creek, CA.

Pitt, P., & Jenkins, D. (1990). *Causes and Control of Nocardia in Activated Sludge*. (2 ed., Vol. 62, pp. 143-150). Berkeley, CA: University of California, Berkeley.

Richard, M., Brown, S., & Collins, F. (2003). *Activated Sludge Microbiology Problems and Their Control*. Paper presented at the Proceedings of the 20th Annual USEPA National Operator Trainers Conference.

Santa Cruz Productions. (1998). Nocardia. January 10, 2012 from http://santacruzproductions.com/Nocardia.aspx.

Tighe & Bond, Inc. (2008). *Comprehensive Wastewater Management Plan*. Worcester, MA: Tighe & Bond, Inc.

U.S. EPA. (2011). Clean Water Act. Retrieved October 10, 2011 from http://cfpub.epa.gov/npdes/cwa.cfm?program_id=45.

U.S. EPA. (2011). NPDES Permit Program. Retrieved February 16, 2012 from http://cfpub.epa.gov/npdes/home.cfm?program_id=45.

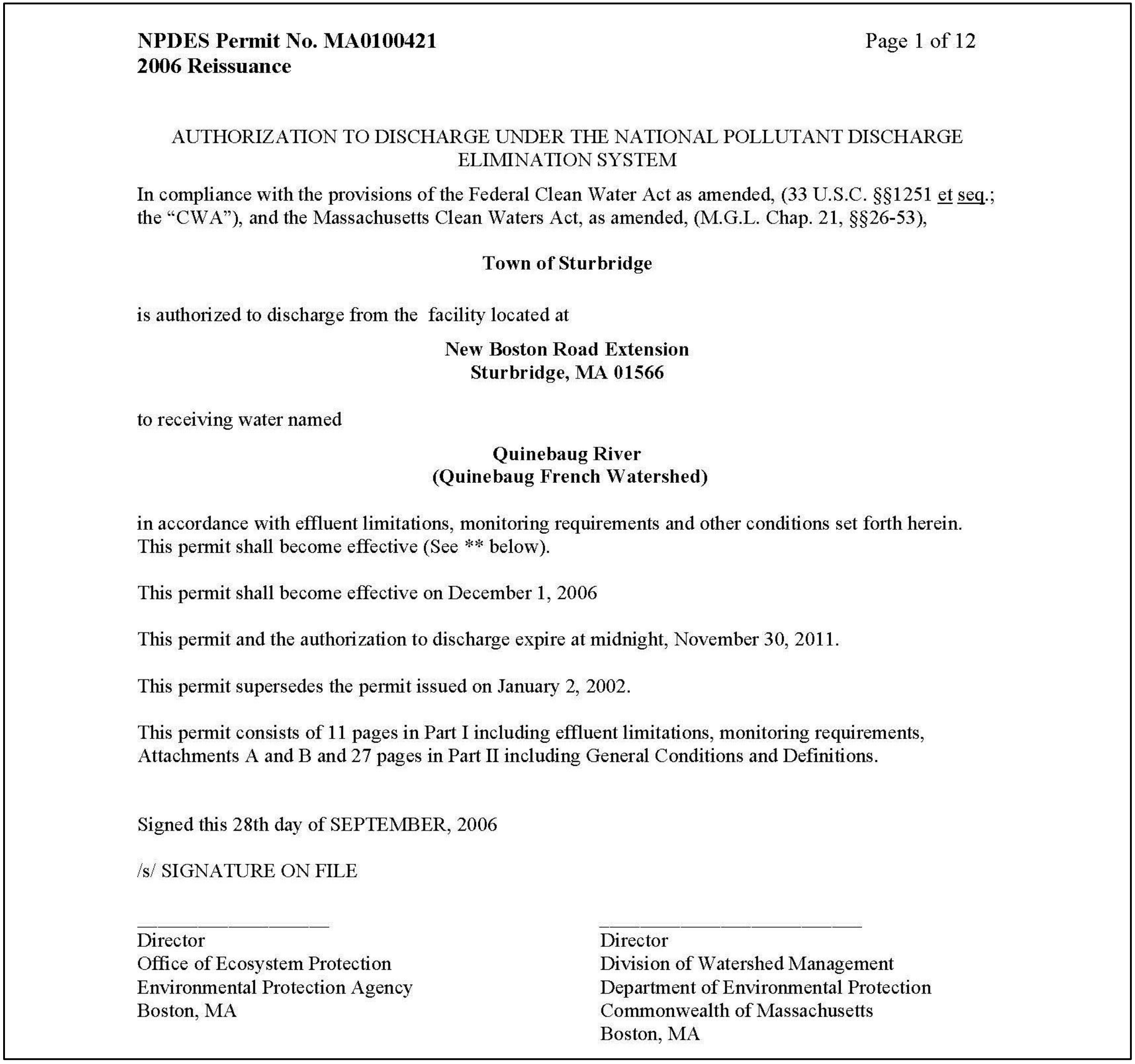
Viessman, W., & Hammer, M.J. (1998). *Water Supply and Pollution Control*. Menlo Park, CA: Addison Wesley.

Appendix A: Sturbridge Wastewater Treatment Plant

A.1: Pre-Upgrade Plant Conditions

Effluent Limitations

The current NPDES permit was issued December 1, 2006 and expires November 30, 2011. As of February 2012, the Sturbridge WWTP continues to use the November 30, 2011 NPDES permit. In the summer, the plant has a seasonal limit on ammonia and lower TSS and BOD limits. The current NPDES permit is located below.



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2006 Reissuance

AUTHORIZATION TO DISCHARGE UNDER THE NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM

In compliance with the provisions of the Federal Clean Water Act as amended, (33 U.S.C. §§1251 et seq.; the "CWA"), and the Massachusetts Clean Waters Act, as amended, (M.G.L. Chap. 21, §§26-53),

Town of Sturbridge

is authorized to discharge from the facility located at

New Boston Road Extension
Sturbridge, MA 01566

to receiving water named

Quinebaug River
(Quinebaug French Watershed)

in accordance with effluent limitations, monitoring requirements and other conditions set forth herein. This permit shall become effective (See ** below).

This permit shall become effective on December 1, 2006

This permit and the authorization to discharge expire at midnight, November 30, 2011.

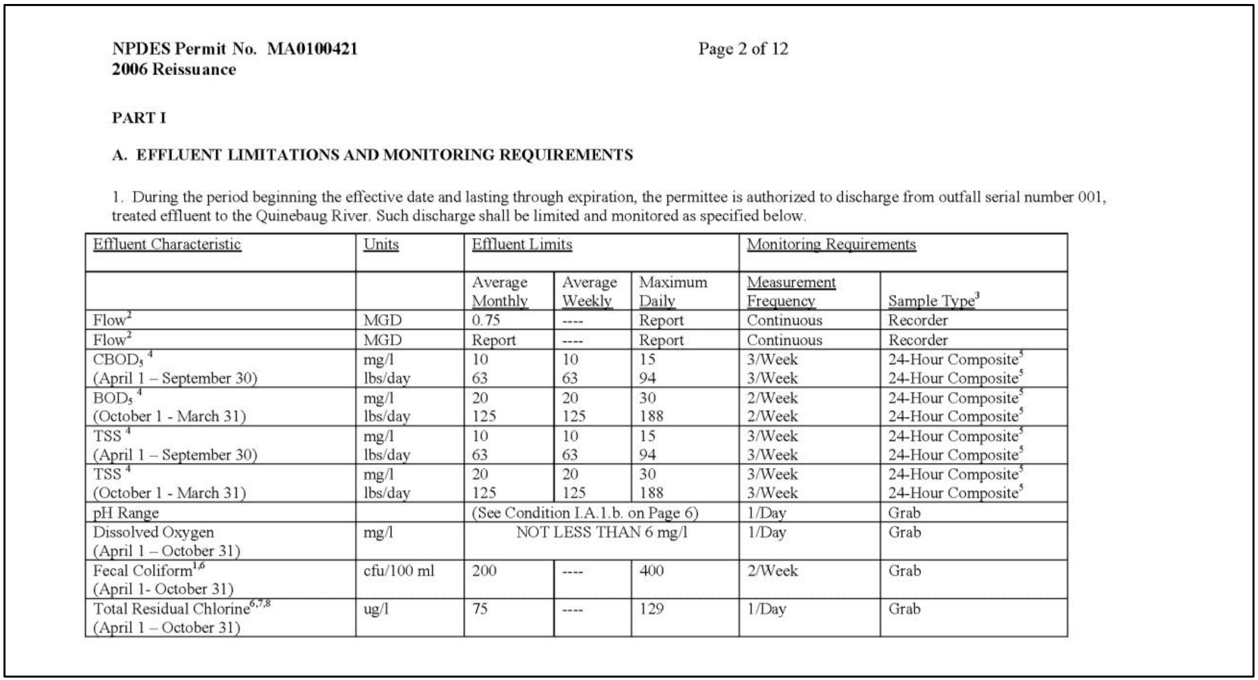
This permit supersedes the permit issued on January 2, 2002.

This permit consists of 11 pages in Part I including effluent limitations, monitoring requirements, Attachments A and B and 27 pages in Part II including General Conditions and Definitions.

Signed this 28th day of SEPTEMBER, 2006

/s/ SIGNATURE ON FILE

Director Office of Ecosystem Protection Environmental Protection Agency Boston, MA	Director Division of Watershed Management Department of Environmental Protection Commonwealth of Massachusetts Boston, MA



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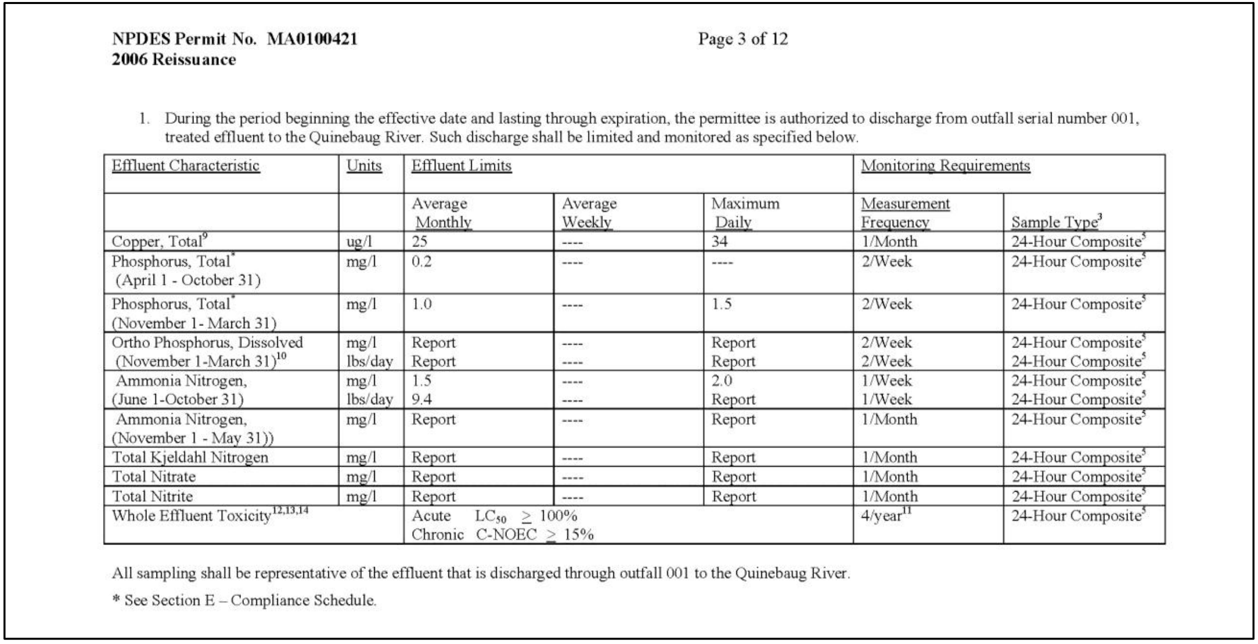
PART I

A. EFFLUENT LIMITATIONS AND MONITORING REQUIREMENTS

1. During the period beginning the effective date and lasting through expiration, the permittee is authorized to discharge from outfall serial number 001, treated effluent to the Quinebaug River. Such discharge shall be limited and monitored as specified below.

Effluent Characteristic	Units	Effluent Limits			Monitoring Requirements	
		Average Monthly	Average Weekly	Maximum Daily	Measurement Frequency	Sample Type[3]
Flow[2]	MGD	0.75	----	Report	Continuous	Recorder
Flow[2]	MGD	Report	----	Report	Continuous	Recorder
CBOD$_5$ [4] (April 1 – September 30)	mg/l lbs/day	10 63	10 63	15 94	3/Week 3/Week	24-Hour Composite[5] 24-Hour Composite[5]
BOD$_5$ [4] (October 1 - March 31)	mg/l lbs/day	20 125	20 125	30 188	2/Week 2/Week	24-Hour Composite[5] 24-Hour Composite[5]
TSS [4] (April 1 – September 30)	mg/l lbs/day	10 63	10 63	15 94	3/Week 3/Week	24-Hour Composite[5] 24-Hour Composite[5]
TSS [4] (October 1 - March 31)	mg/l lbs/day	20 125	20 125	30 188	3/Week 3/Week	24-Hour Composite[5] 24-Hour Composite[5]
pH Range		(See Condition I.A.1.b. on Page 6)			1/Day	Grab
Dissolved Oxygen (April 1 – October 31)	mg/l	NOT LESS THAN 6 mg/l			1/Day	Grab
Fecal Coliform[1,6] (April 1- October 31)	cfu/100 ml	200	----	400	2/Week	Grab
Total Residual Chlorine[6,7,8] (April 1 – October 31)	ug/l	75	----	129	1/Day	Grab



NPDES Permit No. MA0100421 Page 3 of 12
2006 Reissuance

1. During the period beginning the effective date and lasting through expiration, the permittee is authorized to discharge from outfall serial number 001, treated effluent to the Quinebaug River. Such discharge shall be limited and monitored as specified below.

Effluent Characteristic	Units	Effluent Limits			Monitoring Requirements	
		Average Monthly	Average Weekly	Maximum Daily	Measurement Frequency	Sample Type[3]
Copper, Total[9]	ug/l	25	----	34	1/Month	24-Hour Composite[5]
Phosphorus, Total* (April 1 - October 31)	mg/l	0.2	----	----	2/Week	24-Hour Composite[5]
Phosphorus, Total* (November 1- March 31)	mg/l	1.0	----	1.5	2/Week	24-Hour Composite[5]
Ortho Phosphorus, Dissolved (November 1-March 31)[10]	mg/l lbs/day	Report Report	---- ----	Report Report	2/Week 2/Week	24-Hour Composite[5] 24-Hour Composite[5]
Ammonia Nitrogen, (June 1-October 31)	mg/l lbs/day	1.5 9.4	---- ----	2.0 Report	1/Week 1/Week	24-Hour Composite[5] 24-Hour Composite[5]
Ammonia Nitrogen, (November 1 - May 31))	mg/l	Report	----	Report	1/Month	24-Hour Composite[5]
Total Kjeldahl Nitrogen	mg/l	Report	----	Report	1/Month	24-Hour Composite[5]
Total Nitrate	mg/l	Report	----	Report	1/Month	24-Hour Composite[5]
Total Nitrite	mg/l	Report	----	Report	1/Month	24-Hour Composite[5]
Whole Effluent Toxicity[12,13,14]		Acute LC$_{50}$ $\geq$ 100% Chronic C-NOEC $\geq$ 15%			4/year[11]	24-Hour Composite[5]

All sampling shall be representative of the effluent that is discharged through outfall 001 to the Quinebaug River.

* See Section E – Compliance Schedule.

Historical Flows and Loads

Historical flow data are critical in the determination of influent flow and load variations at the plant. Tighe & Bond, Inc. recorded maximum monthly, maximum weekly, and maximum daily peak hourly conditions from April 1, 2004 through April 30, 2006. These data were analyzed by Tighe & Bond to determine the plant capacity and system performance. The results of the analysis performed by Tighe & Bond, Inc. are summarized in Table A.1.

Table A.1: Flows, BOD, and TSS Loading, 2004-2006 (Tighe & Bond, CWMP)

	Total Flow (MGD)	BOD (lbs/day)	BOD (mg/l)	TSS (lb/day)	TSS (mg/l)
Average[1]	0.68	1,388	245	1,307	230
Maximum Monthly	0.85	1,873	264	2,037	287
Maximum Weekly	0.99	2,226	269	2,691	326
Maximum Daily	1.1	2,582	281	3,305	360
Peak Hourly	1.44[2]	--	--	--	--
Minimum Monthly	0.51	933	219	675	159

[1] Equivalent concentrations calculated based on corresponding flow and load. The maximum month and maximum day pollutant concentrations may not actually correspond to actual flow conditions.

[2] Maximum capacity of flow meter. Actual peak flows may exceed meter capacity.

The flows presented in Table A.1 are significantly higher than flows recorded in prior years. Comparing the flows recorded in the 2002 report and flows observed at the plant from 2004 to 2006, indicates a 40% increase in average daily flows over the last five years.

A.2: Pre-Upgrade Treatment Facilities

The following subsections describe each major unit processes utilized at the Sturbridge WWTP before the upgrade was started. The condition and estimated capacity of each system is described in the following sections.

Activated Sludge System

This system is described in Section 2.6 and is not repeated here.

Sand Filter

Wastewater from the three PTU clarifiers flows by gravity to a centralized manhole and then to a Parshall Flume, a form of a venturi flume that measures flow, before being piped to the sand filter unit. The sand filter unit consists of a 9.5’ wide by 32’ long steel tank. The active filter area of approximately 300 square feet removes suspended solids that were not captured by the three PTUs. The unit serves as a final step in refining the effluent; it is not meant to frequently capture large amounts of solids. The filter is currently adequate for existing flow and permit conditions. The wastewater flows by gravity from the sand filter to the chlorine contact chambers adjacent to the filter building.

Chlorine Contact Chamber

The chlorine contact chamber consists of two parallel concrete basins which comprise a combined volume of approximately 25,000 gallons. This volume provides a theoretical retention time of 25 minutes during existing peak hourly flow of 1.44 MGD. If one basin is taken off line for cleaning or maintenance, the theoretical retention time is cut in half; therefore the contact chamber currently cannot provide adequate retention time for the plant.

The chlorine contact chamber utilizes sodium hypochlorite for effluent disinfection. The sodium hypochlorite is added just upstream of the chlorine contact chamber for disinfection of microorganisms prior to effluent discharge into the Quinebaug River. Metabisulfite is added in the last portion of the chamber to remove remaining chlorine prior to discharge.

Belt Filter Press

The existing belt filter press, which is housed in the south room of the main wastewater treatment plant building, is not currently in operation. If put back in operation, the belt filter press can potentially be used to thicken waste sludge so it can be sent to a landfill rather than another facility for dewatering. The Sturbridge WWTP chooses not to bring the belt filter press back into operation as it is not believed to be cost effective.

Septage Receiving Facilities

The existing septage receiving facility includes a bar rack, septage holding tank, and septage pumps. It is located on the east side of the main wastewater treatment facility building. A septage truck can be backed in and pump the septage into a holding tank. The septage is then pumped to the distribution box at the headworks of the wastewater treatment process. The septage holding tank lacks a septage flow meter. The bar rack is located below water level and is very difficult for an operator to clean.

Residuals Disposals

The raw sludge produced from the treatment process is currently hauled via truck to Cranston, RI to be dewatered and incinerated. Trucking the un-thickened sludge over 50 miles to Cranston, RI is not cost effective. Thickening the sludge and/or hauling it to a closer facility may potentially reduce residual disposal costs for the plant.

A.3: Future Pollutant Loading Projections

Past WWTP records were used in the analysis of historic influent pollutant loadings. Projected influent pollutant loadings were estimated in the CWMP for BOD, TSS, ammonium, and total phosphorus, and are summarized in Table A.2 and Table A.3 (Tighe & Bond, 2008).

Table A.2: Projected Influent BOD and TSS Loads

Time Frame	BOD Loading		TSS Loading	
	(mg/L)	(lb/day)	(mg/L)	(lb/day)
Average	245	2,654	230	2,495
Maximum Monthly	264	3,552	287	3,861
Maximum Weekly	269	4,209	326	5,093
Maximum Daily	281	5,065	360	6,483

Historic influent nitrogen and phosphorus concentration records were not available. Projected nutrient loadings were estimated using the typical ratio between BOD, total Kjeldahl nitrogen (TKN), and total phosphorus of 220:40:8. TKN is used in the ratio in lieu of ammonia to estimate influent nitrogen because it represents a complete measure of ammonia and organic nitrogen. Projected influent nutrient loading is presented in Table A.3 (Tighe & Bond, 2008).

Table A.3: Projected Influent Nutrient Loading

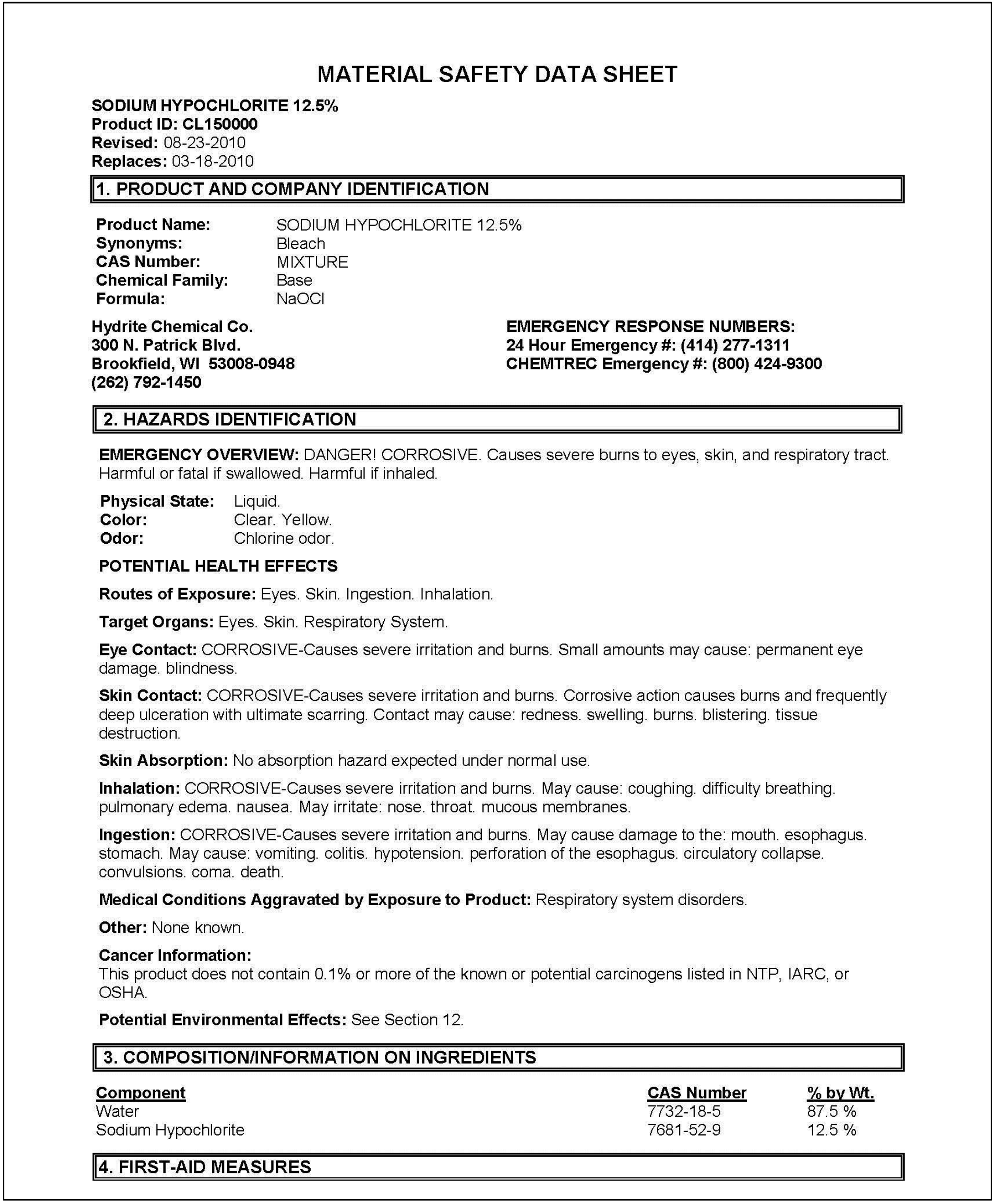
Time Frame	Flow	Total Kjeldahl Nitrogen		Total Phosphorous	
	(MGD)	(mg/L)	(lb/day)	(mg/L)	(lb/day)
Average	1.30	45	488.2	8.9	96.5
Maximum Monthly	1.62	48	648.9	9.6	129.8
Maximum Weekly	1.87	49	764.6	9.8	
Maximum Daily	2.16	51	919.2	10.2	183.8

As mentioned, the NPDES permit for the Sturbridge WWTP has limits for BOD_5, TSS, nutrients and metals. The plant has seasonal limits for ammonia and phosphorous. Limitations in the summer months in regard to phosphorous are more stringent and thus were used in the design of the upgrade. Table A.4 presents the summer future NPDES permit limits for the WWTP.

Table A.4: Future NPDES Permit Limits

Parameter	Average Monthly Concentration	Average Weekly Concentration	Maximum Daily Concentration
Flow	1.3 MGD		
Summer Permit Limits			
$CBOD_5$	5.8 mg/l	5.8 mg/l	8.7 mg/l
TSS	5.8 mg/l	5.8 mg/l	8.7 mg/l
Total Phosphorous	0.1 mg/l	NA	NA
Ammonia	0.9 mg/l	NA	1.2 mg/l
Year Round Permit Limits			
Total Copper	14.4 ug/l	NA	19.5 ug/l

Appendix B: Material Safety and Data Sheet (MSDS) for Sodium Hypochlorite



MATERIAL SAFETY DATA SHEET

SODIUM HYPOCHLORITE 12.5%
Product ID: CL150000
Revised: 08-23-2010
Replaces: 03-18-2010

1. PRODUCT AND COMPANY IDENTIFICATION

Product Name:	SODIUM HYPOCHLORITE 12.5%
Synonyms:	Bleach
CAS Number:	MIXTURE
Chemical Family:	Base
Formula:	NaOCl

Hydrite Chemical Co.
300 N. Patrick Blvd.
Brookfield, WI 53008-0948
(262) 792-1450

EMERGENCY RESPONSE NUMBERS:
24 Hour Emergency #: (414) 277-1311
CHEMTREC Emergency #: (800) 424-9300

2. HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW: DANGER! CORROSIVE. Causes severe burns to eyes, skin, and respiratory tract. Harmful or fatal if swallowed. Harmful if inhaled.

Physical State:	Liquid.
Color:	Clear. Yellow.
Odor:	Chlorine odor.

POTENTIAL HEALTH EFFECTS

Routes of Exposure: Eyes. Skin. Ingestion. Inhalation.

Target Organs: Eyes. Skin. Respiratory System.

Eye Contact: CORROSIVE-Causes severe irritation and burns. Small amounts may cause: permanent eye damage. blindness.

Skin Contact: CORROSIVE-Causes severe irritation and burns. Corrosive action causes burns and frequently deep ulceration with ultimate scarring. Contact may cause: redness. swelling. burns. blistering. tissue destruction.

Skin Absorption: No absorption hazard expected under normal use.

Inhalation: CORROSIVE-Causes severe irritation and burns. May cause: coughing. difficulty breathing. pulmonary edema. nausea. May irritate: nose. throat. mucous membranes.

Ingestion: CORROSIVE-Causes severe irritation and burns. May cause damage to the: mouth. esophagus. stomach. May cause: vomiting. colitis. hypotension. perforation of the esophagus. circulatory collapse. convulsions. coma. death.

Medical Conditions Aggravated by Exposure to Product: Respiratory system disorders.

Other: None known.

Cancer Information:
This product does not contain 0.1% or more of the known or potential carcinogens listed in NTP, IARC, or OSHA.

Potential Environmental Effects: See Section 12.

3. COMPOSITION/INFORMATION ON INGREDIENTS

Component	CAS Number	% by Wt.
Water	7732-18-5	87.5 %
Sodium Hypochlorite	7681-52-9	12.5 %

4. FIRST-AID MEASURES

Eye Contact: Immediately flush eyes with plenty of water for at least 15 minutes while holding eyelids open. Tilt head to avoid contaminating unaffected eye. Get immediate medical attention.

Skin Contact: Immediately flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. Get medical attention immediately. Do not reuse clothing and shoes until cleaned. Do not apply oils or ointments unless ordered by the physician.

Inhalation: Remove to fresh air. If breathing is difficult, administer oxygen. If not breathing, give artificial respiration, preferably mouth-to-mouth. GET MEDICAL ATTENTION IMMEDIATELY.

Ingestion: If fully conscious, drink a quart of water. DO NOT induce vomiting. CALL A PHYSICIAN IMMEDIATELY. If unconscious or in convulsions, take immediately to a hospital or a physician. NEVER induce vomiting or give anything by mouth to an unconscious victim. If vomiting occurs spontaneously, keep head below hips to prevent aspiration of liquid into the lungs.

Note to Physicians:
Do not administer acidic antidotes or Sodium Bicarbonate following overexposure. An ounce of 1% Sodium Thiosulfate or milk of magnesia may be helpful.

5. FIRE FIGHTING MEASURES

Extinguishing Media: For fires in area use appropriate media. For example: Water spray. Dry chemical. Carbon dioxide. Alcohol foam.

Fire Fighting Methods: Evacuate area of unprotected personnel. Wear protective clothing including NIOSH-approved self-contained breathing apparatus. Remain upwind of fire to avoid hazardous vapors and decomposition products. Use water spray to cool fire-exposed containers and disperse vapors.

Fire and Explosion Hazards: May generate potentially explosive oxygen.

Hazardous Combustion Products: Chlorine-containing gases.

6. ACCIDENTAL RELEASE MEASURES

Spill Clean-Up Procedures: CORROSIVE MATERIAL. Evacuate unprotected personnel from area. Maintain adequate ventilation. Follow personal protective equipment recommendations found in Section 8. Never exceed any occupational exposure limit. Contain spill, place into drums for proper disposal. Flush remaining area with water to remove trace residue and dispose of properly. Avoid direct discharge to sewers and surface waters. Notify authorities if entry occurs.

7. HANDLING AND STORAGE

Handling: Avoid contact with eyes, skin, and clothing. Use with adequate ventilation. Do not swallow. Avoid breathing vapors, mists, or dust. Do not eat, drink, or smoke in work area. Wash thoroughly after handling. Empty containers retain product residue (vapor, dust, or liquid) and can be dangerous. DO NOT pressurize, cut, weld, braze, solder, drill, grind, or expose such containers to heat, flame, sparks, static electricity, or other source of ignition. They may explode and cause injury or death.

Storage: CORROSIVE MATERIAL. Store in a cool, well ventilated area, out of direct sunlight. Store in a dry location away from heat. Keep away from incompatible materials. Keep containers tightly closed. Do not store in unlabeled or mislabeled containers. Relieve pressure in containers weekly. Do not freeze. Avoid temperatures greater than 70 Deg. F. Product degrades more rapidly with increasing temperature.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

OSHA Exposure Guidelines:

Component	Limits
No components found.	

ACGIH Exposure Guidelines:

Component	Limits
No components found.	

Note:
*Exposure Limit for Chlorine: 1 ppm Ceiling; 3 mg/m3 Ceiling (OSHA); 0.5 ppm TWA; 1 ppm STEL (ACGIH).

Engineering Controls: Local exhaust ventilation, process enclosures, or other engineering controls are required when handling or using this product to avoid overexposure. Keep levels below exposure limits. To determine exposure levels, monitoring should be performed regularly.

Eye/Face Protection: Wear chemical safety goggles and a full face shield while handling this product. Do not wear contact lenses.

Skin Protection: Prevent contact with this product. Wear gloves and protective clothing depending on condition of use. Protective gloves: Rubber (latex). Polyvinyl chloride. Neoprene.

Respiratory Protection: If vapors or mists are present, wear: NIOSH-Approved respirator. NIOSH-Approved self-contained breathing apparatus. DO NOT exceed limits established by the respirator manufacturer. All respiratory protection programs must comply with OSHA 29 CFR 1910.134 and ANSI Z88.2 requirements and must be followed whenever workplace conditions require a respirator's use.

Other Protective Equipment: Eye-wash station. Safety shower. Rubber apron. Chemical safety shoes. Protective clothing.

General Hygiene Conditions: Wash with soap and water before meal times and at the end of each work shift. Good manufacturing practices require gross amounts of any chemical be removed from skin as soon as practical, especially before eating or smoking.

9. PHYSICAL AND CHEMICAL PROPERTIES

Physical State: Liquid.
Color: Clear. Yellow.
Odor: Chlorine odor.
Boiling Point (deg. F): Not Estab.
Freezing Point (deg. F): ~ -10
Melting Point (deg. F): N.D.
Vapor Pressure (mm Hg): Not Estab.
Vapor Density (air=1): > 1
Solubility in Water: Complete
pH: > 12
Specific Gravity: 1.210 @ 25C
% Volatile (wt%): 100
Evaporation Rate (nBuAc = 1): N.D.
VOC (wt%): 0
VOC (lbs/gal): 0
Viscosity: N.D.
Flash Point: None.
Flash Point Method: N.A.
Lower Explosion Limit: N.A.
Upper Explosion Limit: N.A.
Autoignition Temperature: No Data
Fire Point: N.D.

10. STABILITY AND REACTIVITY

Stability: Stable under normal conditions.

Conditions to Avoid: Avoid exposure to light. Avoid temperatures greater than 70 Deg. F. Product degrades more rapidly with increasing temperature.

Incompatible Materials: Ammonia. Organic materials. Acids. Amines. Ammonium salts. Aziridine. Methanol. Reducing agents. Oxidizing agents. Iron. Copper. Bisulfates. Phenyl acetonitrile. Cellulose. Ethyleneimine. Oxidizable metals. Soaps.

Hazardous Decomposition Products: Chlorine-containing gases. Reacts with acids to release poisonous chlorine gas. Sodium oxide.

Possibility of Hazardous Reactions: Hazardous polymerization will not occur under normal conditions.

11. TOXICOLOGICAL INFORMATION

Component	Oral LD50	Dermal LD50	Inhalation LC50
Sodium Hypochlorite	Rat: 8200 mg/kg	Rabbit: > 10000 mg/kg	No Data

Other Information

Inhalation LC50:	Rat: 293 ppm/1 H (Chlorine)

12. ECOLOGICAL INFORMATION

Ecotoxicological Information: DATA PROVIDED ARE FOR SODIUM HYPOCHLORITE-

Freshwater Fish Toxicity:
LC50 clupea harengus 0.033 - 0.097 mg//l/96 hr, flow through bioassay (pH: 8)
LC50 cymatogaster aggregata 0.045 - 0.098 mg/l/96 hr, flow through bioassay (pH: 8)
LC50 gasterosteus aculeatus 0.141 - 0.193 mg/l/96 hr, flow through bioassay (pH: 8)
LC50 oncorhynchus gorbuscha 0.023 - 0.052 mg/l/96 hr, flow through bioassay (pH: 8)
LC50 oncorhynchus kisutch 0.026 - 0.038 mg/l/96 hr, flow through bioassay (pH: 8)
LC50 oncorhynchus mykiss: 0.05-0.771 mg/L/96 hr, flow through
LC50 oncorhynchus mykiss: >0.03-<0.19 mg/L/96 hr, semi-static
LC50 oncorhynchus mykiss: 0.18-0.22 mg/L/96 hr, static
LC50 parophrys vetulus 0.044 - 0.144 mg/l/96 hr, flow through bioassay (pH: 8)
LC50 pimephales promelas 0.22 - 0.62 mg/l/96 hr, flow through bioassay (pH: 7)
LC50 pimephales promelas: 4.5-7.6 mg/L/96 hr, static
LC50 lepomis macrochirus: 0.4-0.8 mg/L/96 hr, static
LC50 lepomis macrochirus: 0.28-1 mg/L/96 hr, flow through

Invertebrate Toxicity:
EC50 ceriodaphnia sp. 0.006 mg/l/24 hr
EC50 daphnia magna 0.07 - 0.7 mg/l/24 hr
EC50 daphnia magna 2.1mg/l/96 hr
EC50 gammarus fasciatus 4 mg/l/96 hr
EC50 nitocra spinipes 40 mg/l/96 hr
EC50 palaemonetes pugio 52 mg/l/96 hr

Other Toxicity:
Algae:
ErC50 dunaliella sp. 0.6 mg/l/24 hr
ErC50 dunaliella tertiolecta 0.11 mg/l/24 hr
ErC50 skeletonema costatum 0.095 mg/l/24 hr

Chemical Fate Information: BIODEGRADATION: This material is inorganic and not subject to biodegradation.
PERSISTENCE: This material is believed not to persist in the environment.
BIOCONCENTRATION: This material is not expected to bioconcentrate in organisms.

13. DISPOSAL CONSIDERATIONS

Hazardous Waste Number: D002
Disposal Method: Dispose of in a permitted hazardous waste management facility following all local, state and federal regulations. If approved, flush to sewer with large quantities of water.

14. TRANSPORTATION INFORMATION

DOT (Department of Transportation):

Identification Number:	UN1791
Proper Shipping Name:	HYPOCHLORITE SOLUTION

Hazard Class:	8
Packing Group:	III
Label Required:	CORROSIVE
Reportable Quantity (RQ):	100# (Sodium Hypochlorite)

15. REGULATORY INFORMATION

TSCA Inventory Status: All components of this product are on the TSCA Inventory or are exempt from TSCA Inventory requirements.

SARA Title III Section 311/312 Category Hazards:

Immediate (Acute)	Delayed (Chronic)	Fire Hazard	Pressure Release	Reactive
Yes	No	Yes	No	No

Regulated Components:

Component	CAS Number	CERCLA RQ	SARA EHS	SARA 313	U.S. HAP	WI HAP	Prop 65
Sodium Hypochlorite	7681-52-9	Yes	No	No	No	No	No

***Prop 65 - May Contain the Following Trace Components**
No data available.

NSF/ANSI Standard 60 Maximum Use Level: 84 mg/L.

16. ADDITIONAL INFORMATION

Hazard Rating System

Health:	3
Flammability:	0
Reactivity:	1

* = Chronic Health Hazard

NFPA Rating System

Health:	3
Flammability:	0
Reactivity:	1
Special Hazard:	OX

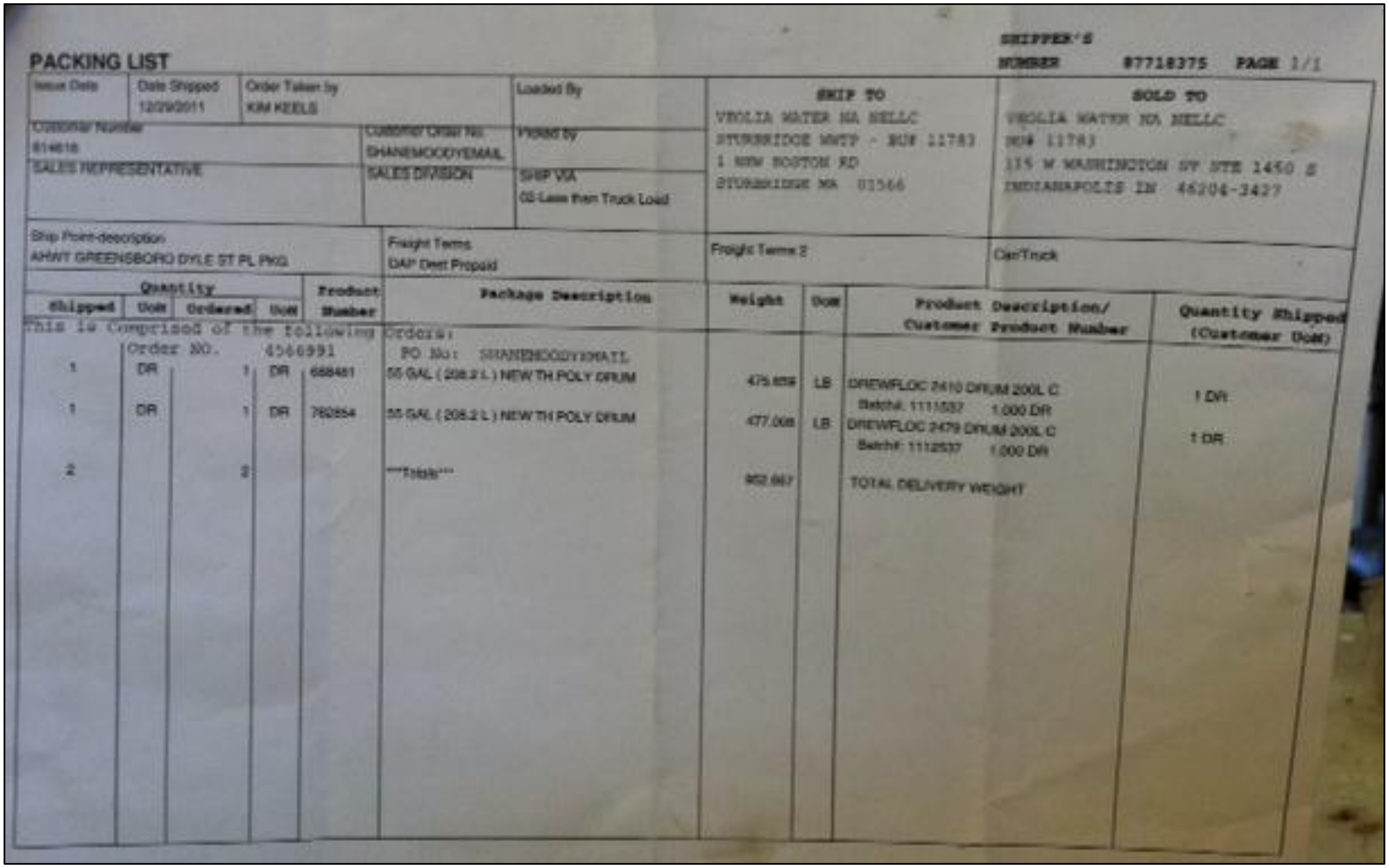
MSDS Abbreviations
N.A. = Not Applicable
N.D. = Not Determined
HAP = Hazardous Air Pollutant
VOC = Volatile Organic Compound
C = Ceiling Limit
N.E./Not Estab. = Not Established

MSDS Prepared by: JAK

Reason for Revision: Change(s) made in Section 12.

The data in this Material Safety Data Sheet relates to the specific material designated and does not relate to its use in combination with any other material or process. The data contained is believed to be correct. However, since conditions of use are outside our control it should not be taken as warranty or representation for which HYDRITE CHEMICAL CO. assumes legal responsibility. This information is provided solely for your consideration, investigation, and verification.

Appendix C: ESP FC 435 Defoamer Order



PACKING LIST

SHIPPER'S NUMBER 87718375 PAGE 1/1

Issue Date
Date Shipped 12/29/2011
Order Taken by KIM KEELS
Loaded By
Customer Number 614618
Customer Order No. SHANEMOODYEMAIL
Picked by
SALES REPRESENTATIVE
SALES DIVISION
SHIP VIA 03-Less than Truck Load

SHIP TO
VEOLIA WATER NA NELLC
STURBRIDGE WWTP - BU# 11783
1 NEW BOSTON RD
STURBRIDGE MA 01566

SOLD TO
VEOLIA WATER NA NELLC
BU# 11783
115 W WASHINGTON ST STE 1450 S
INDIANAPOLIS IN 46204-3427

Ship Point-description AHWT GREENSBORO DYLE ST PL PKG
Freight Terms DAP Dest Prepaid
Freight Terms 2
Car/Truck

This is Comprised of the following Orders:
Order NO. 4566991 PO No: SHANEMOODYEMAIL

Quantity Shipped	UoM	Quantity Ordered	UoM	Product Number	Package Description	Weight	UoM	Product Description/ Customer Product Number	Quantity Shipped (Customer UoM)
1	DR	1	DR	688481	55 GAL (208.2 L) NEW TH POLY DRUM	475.859	LB	DREWFLOC 2410 DRUM 200L C Batch#: 1111537 1.000 DR	1 DR
1	DR	1	DR	782854	55 GAL (208.2 L) NEW TH POLY DRUM	477.008	LB	DREWFLOC 2479 DRUM 200L C Batch#: 1112537 1.000 DR	1 DR
2		2			***Totals***	952.867		TOTAL DELIVERY WEIGHT	

Appendix D: Design Calculations

- **Determine the concentration of Cl_2** in the 12.5% bleach
  - $\frac{12.5\ g\ NaOCl}{100mL\ Bleach} = \frac{125\ g\ NaOCl}{1\ L\ bleach} \times \frac{1000mg}{1\ g} = 125{,}000\ mg\ NaOCl\ in\ 1\ L\ of\ bleach$
  - Bleach is formed by reacting sodium hydroxide with chlorine gas to make sodium hypochlorite, sodium chloride and water.
  - $2\ NaOH\ (aq) + Cl_2\ (g) \rightarrow NaOCl\ (aq) + NaCl\ (aq) + H_2O\ (l)$
    - Stoichiometric relationship between NaOCl and Cl_2 is 1:1
    - Molecular Weight NaOCl = 74.4 g/mol
    - Molecular Weight Cl_2 = 70.9 g/mol
  - $\frac{125\ g\ NaOCl}{1\ L\ of\ bleach} \times \frac{1\ mole\ NaOCl}{74.4\ g\ NaOCl} \times \frac{1\ mole\ Cl_2}{1\ mole\ NaOCl} \times \frac{70.9\ g\ Cl_2}{1\ mole\ Cl_2} \times \frac{1000\ mg}{1\ g} = \frac{119120\ mg\ Cl_2}{1\ L\ bleach}$
  - Concentration of Chlorine in bleach = 119120 mg/L

- **Find time to surface waste 24,000 gpd** through SMH (30 gpm from PTUs to SMH)
  - 24,000 gpd of surface waste needed to maintain MLSS 10,000 mg/L
  - Flow from PTUs to SMH is 30 gpm
    - $\frac{30gal}{min} \times \frac{60\ min}{1\ hr} \times \frac{24\ hr}{1\ day} = 43200\ gpd$
  - $24000gal \div \frac{43200\ gal}{1\ day} = 0.5556\ days$
    - $0.5556\ days\ \times \frac{24\ hr}{1\ day} \times \frac{60\ min}{1\ hr} = 800\ minutes\ needed\ to\ waste$

- The pressure at the plant hydrant is at 75 psig. It was recommended by Tighe & Bond, Inc. to maintain a flow rate of 1 gpm of hydrant water through the eductor (motive fluid), mix with the suction fluid and then discharge into the scum manhole. The value of 1 gpm was chosen because the pressure of 75 psig can sustain that flow rate easily though the eductor. Also, after a run time of 800 mins, 800 gallons of chlorinated water will be processed through the system, which is only 3.2% of the total liquid being processed through surface wasting.

- **Find total amount of chlorine needed to maintain a 50 mg/L applied dose** to the 30 gpm surface waste flow and 1 gpm hydrant flow over 800 minutes of wasting.
  - Surface waste being processed per day (given before)
    - $(30\ gpm \times 800\ min) + (1gpm \times 800\ \text{min}) = 24800\ gallons\ processed$
  - For 50 mg/L dose, find equivalent to <u>X</u> mg per volume of 24800 gallons (find the X to make the concentration of mass/volume 50 mg/L)
    - Convert 24800 gallons to liters
      - $24800gal\ \times \frac{3.7854\ Liters}{1gal} = 93878\ Liters$
    - Use a proportion to find mass of hypochlorite needed to have a 50 mg/L concentration
      - $\frac{50\ mg}{1\ Liter} = \frac{X}{93878\ Liter}$
      - $\frac{50\ mg \times 93878\ \cancel{Liter}}{1\ \cancel{Liter}} = x$

                - $x = 4{,}693{,}896\ mg = mass\ of\ Cl_2\ needed\ per\ surface\ waste = volume\ processed\ over\ 800 mins$ (24800 gallons)

- **Find how much bleach needs to be suctioned into the eductor** to achieve 4,693,896 mg of chlorine to the SMH over an 800 min run time (0.56 day)
    - Get concentration of bleach in units of mg OCl^-/gal bleach
        - $\frac{119120\ mg\ Cl_2}{L\ bleach} \times \frac{3.7854\ L\ bleach}{1\ gal\ bleach} = \frac{450915\ mg\ Cl_2}{1\ gal\ bleach}$
    - Use a ratio to determine the volume of bleach needed; place over run time of 800 min for flow rate in gpm, and over 0.556 days for flow rate in gpm of bleach suction into the eductor.
        - $\frac{450915\ mg}{1\ gal} = \frac{4693896\ mg}{X}$
        - $X = \frac{4693896\ \cancel{mg} \times 1\ gal}{450915\ \cancel{mg}}$
        - $X = 10.41\ gal$
            - $Flow\ rate\ in\ gpm\ (Q_{bleach}) = \frac{10.41\ gal}{800\ min} = 0.013\ gpm$
            - $Flow\ rate\ in\ gpd\ (Q_{bleach}) = \frac{10.41\ gal}{0.5556\ day} = 18.7 gpd$

- **Sizing Venturi Eductor** from Fox Venturi
    - Motive Liquid Parameters
        - Water
        - Specific Gravity = 1
        - Temp 40 deg F (outside)
        - Flow = 1 gpm (800 gpd)
        - Pressure = 75 psig
    - Suction Fluid Parameters
        - 12.5% Sodium Hypochlorite (bleach) NaOCl
        - Specific Gravity = 1.17
        - Temp 40 deg F (outside)
        - Flow = 0.013 gpm (18.7 gpd)
        - Lift = 3ft
    - Discharge Conditions
        - Pressure = atmospheric (10 psig to be safe and design up)

Appendix E: Materials and Design Schematic

Table E.1: Materials Required for Chlorination System Design

Material	Manufacturer	Quantity	Unit Cost ($)	Total Cost ($)
Venturi Eductor (Designed for 1 gpm)	FOX	1	$245	$245
Male Tee PVC Splitter (1.5" diam.)	Spears	1	$1.50	$1.50
90^{o} PVC Fitting (0.25" diam.)	Lasco	3	$0.20	$0.60
Straight PVC Fitting (0.25" diam.)	Lasco	4	$0.15	$0.60
PVC Pipe (0.25" diam., 10' length)	Harvel Plastics	3	$0.55 per foot	$16.50
PVC Pipe (1/8" diam., 5' length)	Harvel Plastics	1	$0.45 per foot	$2.25
PVC Female Adapter (0.25" diam.) [For eductor]	Lasco	1	$0.70	$0.70
PVC Male Adapter (1/8" diam.) [For eductor]	Lasco	1	$0.60	$0.60
PVC Male Adapter (0.25" diam.) [For eductor]	Lasco	1	$0.70	$0.70
90^{o} PVC Fitting (0.25" to 0.5")	Spears	1	$0.30	$0.30
Spray Head (0.5" Connection, Q_{max} = 2.5 gallons/minute)	Waterpik (Model No. TRS-529)	1	$19.98	$19.98
Needle Valve (1/4" diam.)	SMC	1	$10.66	$10.66
Needle Valve (1/8" diam.)	SMC	1	$10.66	$10.66
			Total Cost of Materials:	**$310.05**

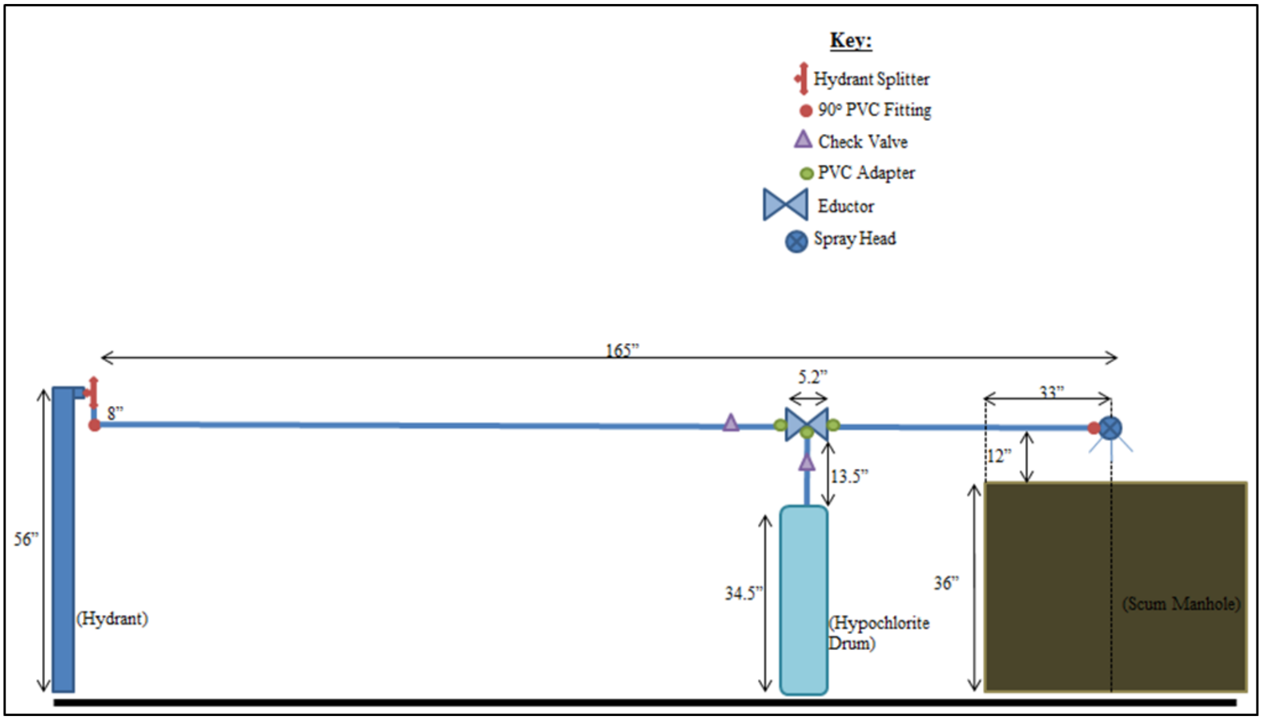
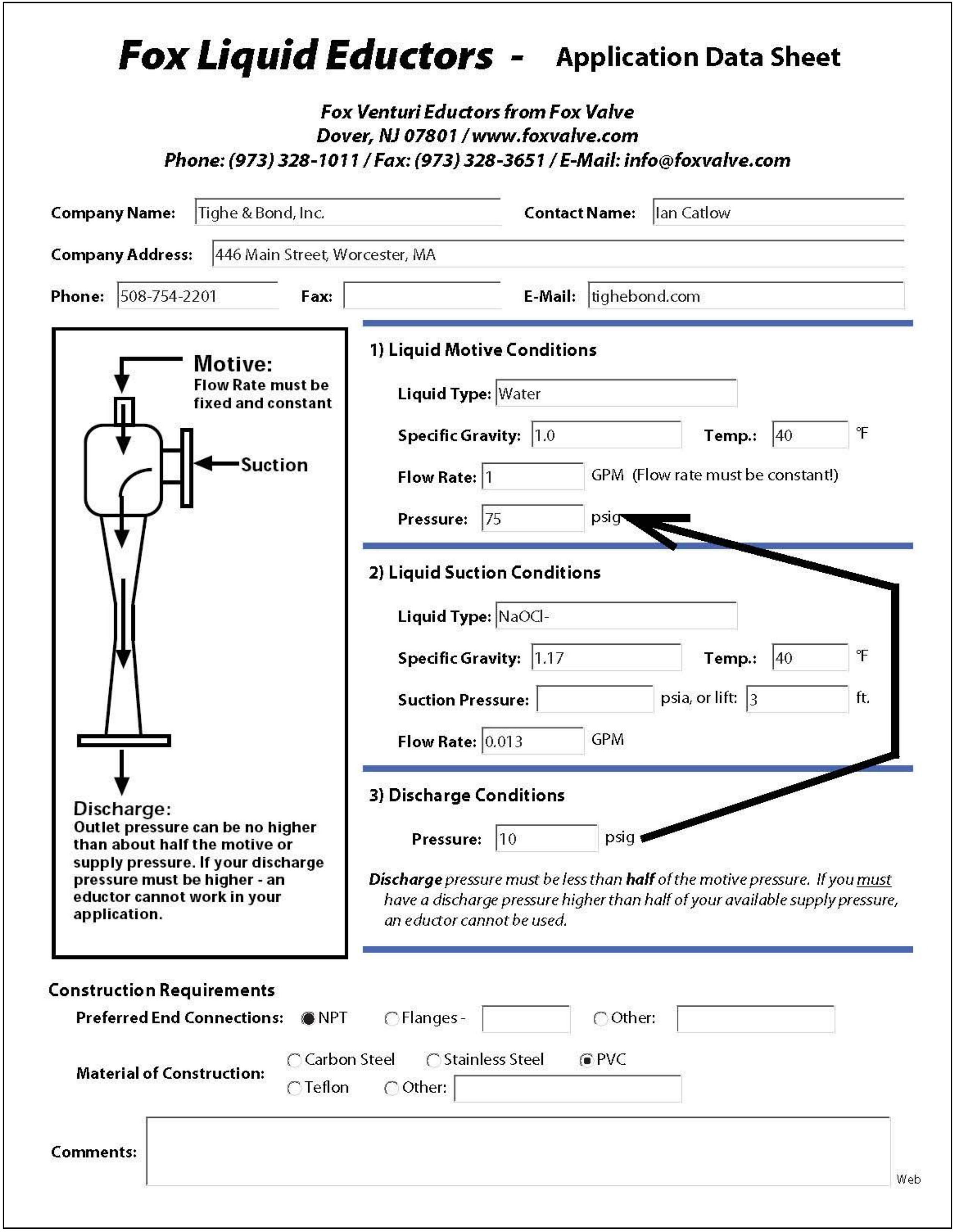


Figure E.1: Design Schematic for Eductor Addition

Appendix F: Fox Eductor Data Sheet



Fox Liquid Eductors - Application Data Sheet

Fox Venturi Eductors from Fox Valve
Dover, NJ 07801 / www.foxvalve.com
Phone: (973) 328-1011 / Fax: (973) 328-3651 / E-Mail: info@foxvalve.com

Company Name: Tighe & Bond, Inc. **Contact Name:** Ian Catlow

Company Address: 446 Main Street, Worcester, MA

Phone: 508-754-2201 **Fax:** **E-Mail:** tighebond.com

Motive:
Flow Rate must be fixed and constant

Suction

Discharge:
Outlet pressure can be no higher than about half the motive or supply pressure. If your discharge pressure must be higher - an eductor cannot work in your application.

1) Liquid Motive Conditions

Liquid Type: Water

Specific Gravity: 1.0 **Temp.:** 40 °F

Flow Rate: 1 GPM (Flow rate must be constant!)

Pressure: 75 psig

2) Liquid Suction Conditions

Liquid Type: NaOCl-

Specific Gravity: 1.17 **Temp.:** 40 °F

Suction Pressure: psia, or lift: 3 ft.

Flow Rate: 0.013 GPM

3) Discharge Conditions

Pressure: 10 psig

Discharge *pressure must be less than* ***half*** *of the motive pressure. If you* *<u>must</u>* *have a discharge pressure higher than half of your available supply pressure, an eductor cannot be used.*

Construction Requirements

Preferred End Connections: ● NPT ○ Flanges - ○ Other:

Material of Construction: ○ Carbon Steel ○ Stainless Steel ● PVC ○ Teflon ○ Other:

Comments:

Web