Columbus Discovers a Greener Odor Control Approach

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ABSTRACT

To reduce overflows of untreated wastewater into area waterways, the City of Columbus constructed a large capacity sewer (13-foot diameter) to provide up to 60 million gallons of storage (equivalent to the projected wet weather flow from a 1-year storm event) and connected it to a new headworks facility at the Southerly Wastewater Treatment Plant that was designed to pump and treat over 400-mgd. To address the anticipated high hydrogen sulfide and odor concentrations from the collection system, the new headworks required a proven and effective odor control technology that would reduce any nuisance odors from being perceived off-site. The goals established by the City regarding the odor control system were:

- No odors at the plant fenceline
- Design odor control for the health and safety of the facility operators
- Apply a proven odor control technology
- Provide redundancy to preclude odor control system down-time

The odor control challenges were characterizing the sewer and new headworks odor potentials and selecting the most cost-viable technology to comply with these goals.

Odor assessment investigations were conducted to characterize odor conditions in the collection system and at the pre-existing headworks area of the WWTP. As a result of the collection system being redesigned to handle and store wet weather flows, it was anticipated the potential for hydrogen sulfide generation and release, due to this greater detention time and deposition of solids, would be increased. Site measurements showed a range of hydrogen sulfide concentrations from 1 to 160-ppm_v. Field measurements and office calculations were used to establish the overall odor control system design average and peak concentrations of hydrogen sulfide as 3.5 and 33-ppm_v, respectively. Other reduced sulfur compounds were present, but at considerably lower levels. The volume of air required, to provide effective capture and containment of the odors, was approximately 100,000 cfm.

Four odor control technologies were evaluated (wet scrubbing, carbon adsorption, biofiltration, and biotrickling filter) and biotrickling filters were selected based on:

- lower operating costs
- no chemicals used/stored/handled
- no hazardous residuals
- greener, sustainable operation
- less maintenance labor
- effective treatment of design odor loads

Once selected, the City of Columbus installed the largest stand-alone biotrickling filter system (provided by Bioway) for odor treatment in North America. The system was designed to treat 96,000 cfm of odorous air.

The biotrickling odor control system consists of ten towers fed by a central fan system. The fan system pulls the odorous air through a carefully designed combination of main and branch ducts and pushes it through the ten towers. The treated air is exhausted through a stack at the top of each of the towers. The multiple towers were designed to manage the varying hydrogen sulfide concentrations and other reduced sulfur compounds associated with raw influent wastewater.

Extensive process performance trials were conducted and the biotrickling filter system was found to have exceeded its design performance requirements. The system demonstrated 96% removal of odors, taking the average exhaust odor concentration to less than 300 odor units. The odor control system has proved to be robust and has coped well with the varying seasonal odor loads experienced in central Ohio over the past nearly two years of operation (the new headworks building with odor control system was placed into operation in March 2008).

This paper will present the odor control technologies that were evaluated, review the bio-trickling filter system and present performance data.

KEYWORDS

Headworks, bio-trickling filter, hydrogen sulfide, odor concentration, dilution-to-threshold

INTRODUCTION

Continued population growth in the City of Columbus (Ohio) Metropolitan Area (City) necessitated the expansion of the Southerly Wastewater Treatment Plant. The former headworks did not have the hydraulic capacity to support plant expansion, and also had design, operation, and maintenance limitations which made expansion of the original facilities unfeasible. Inadequate grit removal facilities and equipment failures due to the corrosive atmosphere caused by the stripping of odorous gases, notably hydrogen sulfide from the raw sewage were two key problems with the headworks. The decision was made to replace the headworks with a new facility located just north of the treatment plant.

The new headworks was designed for an ultimate capacity of 600 million gallons per day – mgd with an initial installed equipment capacity of 440 mgd. To minimize the number of unscreened wastewater bypass events, which the plant had suffered from in the past, in addition to an equipment capacity of 300-mgd, a new interceptor sewer storage capacity of 60-mg was designed and constructed. To allow the collection system wastewater to flow by gravity and avoid maintaining an existing off-site pumping station, the new headworks facility was designed at a depth of four to five stories deep.

Together with improvements to the management of influent wastewater and process equipment, the City recognized that the capture, containment and treatment of nuisance and corrosive odors were also key components to the success of the new headworks facility. Past corrosive infrastructure damage and odor complaints, combined with the aggravated odor potential associated with the interceptor storage capacity of 60-mg, made the City understand that odor control was a critical element in the planning and design of a new headworks facility.

The following odor goals were applied as the basis of design for the headworks odor control system:

- "No odors" at the plant fenceline.
- Control technologies to be considered must have a proven track record of success.
- Equipment redundancy must be incorporated into the design in order to minimize any potential odor control down time.
- The odor control system layout must result in a good/safe working environment to reduce risk to the operators.
- The odor control system design must comply with the guidelines presented in the National Fire Protection Association (NFPA) Code 820 dealing with wastewater treatment plants.

The new headworks odor control system must provide the following coverage for unit operations, in flow sequence:

- <u>Bar racks</u> were installed in channels immediately upstream of the plant pump wet wells, these four heavy duty coarse bar racks remove large debris entering the new headworks and provide protection to the downstream pumps.
- An innovative, self-clearing trench-type wet well design reduces odors and enhances personnel safety. This deep and narrow wet well design reduces solids deposition on the floor and reduces the surface area exposed to the room air over which odors can be stripped out of the wastewater.
- <u>Fine screens</u> remove material of 6-mm in size and larger on perforated screens. The removed material is washed and compacted before being conveyed to containers for final disposal.
- Grit is removed from the influent wastewater flow in four 24-foot diameter vortex grit tanks. The grit slurry collected is concentrated and classified before being placed in containers for final disposal.

- Collection, storage and load-out of the grit and screenings removed from the plant influent flow are accomplished at ground level within the new headworks building. A system of belt and screw conveyors discharges the grit and screenings material into 20-cubic yard containers.

DESIGN AIR FLOW RATES AND ODOR SOURCES

The volume of air from the headworks to be treated was determined using two different criteria: for areas that would not be occupied by plant personnel, an air change rate of 4 air changes per hour was used; for areas where maintenance would be conducted and is in contact with raw sewage, an air change rate of 12 air changes per hour was used, consistent with the Standard for Fire Protection in Wastewater Treatment and Collection Facilities, referred to as the National Fire Protection Association (NFPA) 820. Additionally, an air change rate of 30 air changes per hour was used for when personnel enters the plant's wet well for maintenance purposes. NFPA 820 provides minimum requirements for protection against fires and explosion by recommending ventilation rates and area electrical classification. It has not been formally accepted by states but is used as a design standard by wastewater and air pollution control industries. Table 1 lists the areas being odor controlled and the corresponding exhaust air flow rate. The total exhaust air flow rate was determined to be 96,000 cfm.

Table 1 – Odor Control Air flow Rates

Location	Air flow Rate (cfm)
Raw Sewage Pump Building	
Influent Chamber	800
West Wet Well	3,000
East Wet Well	3,000
Emergency Bypass Channel	1,100
West Bar Rack Chamber	1,900
East Bar Rack Chamber	1,900
Bar Rack Channels	1,500
Bar Rack Room	13,000
Bar Rack Container Room	1,800
Raw Sewage Pump Building Subtotal	**28,000**
Screen and Grit Building	
Pump Discharge Channel	600
Screen Channels	600
Screen and Grit Room	35,200
Grit Tank Influent Distribution Channel	500
Screen and Grit Container Room	23,100
Grit Tank Influent Channels	300
Grit Tanks	600
Grit Tank Effluent Channels	300
Grit Tank Effluent Chamber	400
Wet Weather Bypass Chambers	2,500
Screen and Grit Building Subtotal	**64,100**
Influent Junction Chamber	
Influent Junction Chamber Subtotal	**3,900**
TOTAL AIR FLOW RATE	**96,000**

Hydrogen sulfide monitoring had been conducted in the existing plant's headworks over 4 years (1998 to 2001) in the screen room and within the influent channel. Measurements were made using a Crowcon Gas Detection Instruments which uses an electrochemical sensing technology. Hydrogen sulfide readings were made approximately every 10 minutes. Average and maximum hydrogen sulfide results are given in Table 2 for this time period.

Table 2 – Measured Hydrogen Sulfide Concentrations (1998-2001) in parts per million by volume (ppm_v)

Location	Annual Average	Annual Average of Maximum Values
Screen Room	1.1 - 1.2	27 – 29
Influent Channels	1.7 – 33	102 - 160

Samples were collected and analyzed for twenty reduced sulfur compounds (ASTM D5504-98) at the start of the headworks upgrade project and are presented in Table 3.

Table 3 – Reduced Sulfur Compound Concentration, parts per billion by volume (ppb_v)

Compound	Results					
	Screen Bldg, East, AM	Influent Channel, AM	Influent Flow Splitter, AM	Screen Bldg, East, PM	Influent Channel, PM	Influent Flow Splitter, PM
Hydrogen Sulfide	931	12,300	31,700	202	2,760	11,500
Carbonyl Sulfide	9.25	71.9	34.4	ND	57	23.9
Methyl Mercaptan	19.4	233	191	3.86	87.5	163
Dimethyl Sulfide	4.94	41.5	16.0	ND	28.7	9.16
Carbon Disulfide	2.92	16.1	3.57	ND	14.6	4.53

Carbon dioxide is an acid gas like hydrogen sulfide and is absorbed in wet scrubbers operated at elevated pH. Samples were collected and analyzed for carbon dioxide in order to be able to account for the alkali demand that would be exerted by this gas in a wet scrubber system. Samples were analyzed by EPA Method 25C. The measured carbon dioxide is summarized in Table 4.

Table 4 – Carbon Dioxide Concentrations, parts per million by volume (ppm_v)

Location	Concentration
Screen Room	700
Influent Channel	6,400
Flow Splitter	1,800

Using the measured hydrogen sulfide concentrations and the design exhaust air flow rates for each of the areas to be odor controlled, mass balance calculations were conducted and average and maximum design inlet concentrations to the odor control system were developed. The average of the maximum measured screen room concentrations were assigned to open areas in contact with sewage, and the measured influent channel concentration were assigned to closed spaces such as the wet well and bar rack channels.

The design basis for the odor control system is summarized in Table 5.

Table 5 – Odor Control System Inlet Air Characterization

Parameter	Value
Air Flow Rate, cfm	96,000
Inlet Hydrogen Sulfide Concentration	
Maximum, ppm_v	33
Average, ppm_v	3.5
Inlet Carbon Dioxide Concentration, ppm_v	1,400

TECHNOLOGY EVALUATION

The technology evaluation was conducted in two phases. Initially a screening evaluation was conducted where the following three technologies were considered: wet scrubbing, carbon adsorption and biofiltration. Process designs and order-of-magnitude cost estimates were developed for each. The basis for evaluating these technologies was:

- "No odors" at the plant fenceline
- Proven track record of success
- Constructability
- Ease of operations & maintenance and safety aspects
- Dispersion characteristics
- Cost

The second evaluation phase considered two forms of biological odor control: biofiltration and bio-trickling filtration.

Wet Scrubbing

The leading odor control technology over the last 25 years has been wet scrubbing. It has proven to be an effective method for controlling traditional odors associated with wastewater operations. Wet scrubbing consists of a physical-chemical process that removes odorous compounds from an air stream. A chemical scrubbant solution is distributed over a bed of plastic media. The scrubbant is typically water to which sodium hydroxide and sodium hypochlorite is added. The odorous compounds are removed from the air by absorption into the scrubbant. The key odorous constituent normally associated with wastewater operations is hydrogen sulfide. Hydrogen sulfide is very soluble in high pH solutions. By raising the pH of the scrubbant solution by adding sodium hydroxide, the hydrogen sulfide and other soluble odor compounds are absorbed into the scrubbant solution. To maintain a strong mass transfer driving force, sodium hypochlorite is also added to the scrubbant. The sodium hypochlorite converts the absorbed hydrogen sulfide into sulfate and prevents it from being re-stripped from the liquid phase either in the scrubber, or after the liquid is drained from the scrubber and the pH drops as it combines with other lower pH plant drain waters.

The wet scrubbing system would consist of two scrubbers operating in parallel. The wet scrubbing system would include recirculation pumps for each stage; chemical storage tanks and chemical feed pumps for sodium hydroxide and sodium hypochlorite feed to each scrubber; and a control system that would control chemical feed to the wet scrubbers. Sodium hydroxide feed would be based on pH, and sodium hypochlorite feed would be based on the oxidation-reduction-potential of the scrubbant solution. Table 6 is a design summary of the wet scrubber system.

A 50-year present worth cost estimate was developed for the wet scrubber system which assumed the wet scrubbers would be replaced in 25 yrs. These costs are presented in Table 9.

Table 6 – Wet Scrubber System Design Parameters

Parameter	Value
Air Flow Rate	96,000
Quantity	2
Scrubber diameter, ft	13
Packing Depth, ft	10
Recirculation rate per scrubber, gpm	1,200
Sodium hydroxide, lbs/d	810
Sodium hypochlorite, lbs/d	340
Makeup water per scrubber, gpm	25

Carbon Adsorption

Carbon adsorption is a proven technology for the removal of hydrogen sulfide and other odorous compounds. Contaminants adsorb onto (or “attach to”) active sites on the surface of the carbon. Activated carbon has a high surface-to-volume ratio; thus, a large surface area is available for adsorption in a relatively small volume.

Carbon life is dependent on the mass loading of hydrogen sulfide and other compounds in the air stream being treated. Carbon will continue to adsorb compounds until active sites for the compounds being adsorbed are occupied, and then compounds in the inlet stream will begin to pass through the carbon and be present in the exhaust air. This is referred to as “breakthrough.” When the wave front of compounds passes out of the bed and the exhaust concentration equals the inlet, then “saturation” of the carbon exists. The life of the carbon bed is dependent on the acceptable breakthrough level. The amount of compounds adsorbed is dependent on the properties of the compounds, in addition to their concentration in the bulk gas, system temperature, pressure and humidity. Different compounds have different affinities for adsorption on carbon.

The carbon adsorption system would consist of eight 12-ft diameter dual bed carbon adsorbers. There would be a grease filter/mist eliminator located upstream of each adsorber to remove moisture and particulate that could blind the carbon. The quantity and size of adsorbers were designed so that one could be taken offline and the remaining adsorbers would have the capacity the treat the odorous air stream. The use of regenerable carbon was assumed and that it could be regenerated three times before its replacement was required. Table 7 is a design summary of the carbon adsorption system.

Table 7 – Carbon Adsorption System Design Summary

Parameter	Value
Air Flow Rate, cfm	96,000
Design Superficial Velocity, fpm	55
Number of 12-ft diameter dual bed vessels	8
Air Flow Rate per vessel	11,500
Carbon Mass, lbs	163,000
Carbon Usage Rates, lbs/d	131

A 50-year present worth cost estimate was developed for the carbon adsorption system which assumed the carbon adsorbers would be replaced in 25 yrs. These costs are presented in Table 9.

Biofiltration

Biofilters utilize an organic substrate material such as wood chips, bark, and compost, or an inorganic material such as lava rock, or other proprietary materials. Similar to a wet scrubber, the biofilter relies on the ability of the odorous compounds to be absorbed into the liquid film that coats the biofilter media. Microorganisms within the liquid film convert the odorous compounds to non-odorous gases and other by-products. This odor removal process takes place without having to add hazardous chemicals, thereby precluding the storage, handling and health and safety issues associated with them. The biofilter also utilizes sorption as a removal mechanism. This process aids in removing compounds that are more difficult to absorb into water such as organic reduced sulfur compounds. As a result of these two mechanisms, absorption and sorption, biofilters are highly efficient treating air streams containing hydrogen sulfide and organic reduced sulfur compounds.

The microorganisms that address the key odor constituent, hydrogen sulfide, are called autotrophic. Autotrophic bacteria use inorganic compounds as an energy source and obtain their carbon for cell growth from carbon dioxide. Autotrophs consume inorganic compounds for energy such as hydrogen sulfide and other sulfur based compounds. Some autotrophic organisms can also degrade some low molecular weight organic compounds such as carbon disulfide, methyl mercaptan, and ethyl mercaptan. Once inside the cell wall, biological processes act on these compounds to extract the energy for use by the bacteria. After the energy is extracted through their particular metabolic process, a converted and oxidized byproduct of the compound is released. The main microorganism responsible for removing hydrogen sulfide is Thiobacillus. Thiobacillus consumes hydrogen sulfide gas and releases sulfuric acid.

Maintaining the media at adequate moisture content, typically 50 to 60% depending on the media, is key to sustaining the health of the microorganisms. To achieve this, the inlet air to the biofilter is saturated with water by passing it through a humidification chamber. Supplemental water is sometimes added to the media through irrigation conduits in the media bed or through the use of surface sprinkler systems.

The biofilter would be constructed of concrete with a polyethylene perforated floor-plate system and would utilize an organic media (wood chips). The inlet air to the biofilter would pass through a humidification chamber in order to saturate the air. During the winter the air would be heated by heating the water used to humidify the air. The concrete would be coated with a corrosion resistant coating in order to protect it from corrosion from leachate containing sulfuric acid. Table 8 is a design summary for the biofilter.

Table 8 – Biofilter Design Summary

Parameter	Value
Air flow rate, cfm	96,000
Number of cells	5
Air flow rate per cell, cfm	19,320
Cell dimensions, ft	50 X 125
Media depth, ft	4
Media volume, ft^3	125,000
Contact time, sec	78

A 50-year present worth cost estimate was developed for the biofilter system which assumed the media would be replaced every 3 years. These costs are presented in Table 9.

Table 9 – Odor Control Technology Screening Level Cost Comparison

Technology	Capital Cost	Annual Operations & Maintenance	Present Worth Operation & Maintenance	Total Present Worth
Wet Scrubbing	$5,680,000	$312,000	$5,700,000	$11,400,000
Carbon Adsorption	$7,200,000	$387,000	$7,070,000	$14,270,000
Biofiltration	$4,470,000	$349,000	$6,390,000	$10,900,000

On the basis of the above analysis, biofiltration was selected for the Headworks Building control technology. Subsequently, another form of biological odor control was evaluated, referred to as bio-trickling filtration. This technology is similar to biofiltration except that the microorganisms reside on a media located in a column very similar to the type of vessel used for wet scrubbing. Air passes upward through the media. Irrigation water is fed to the top of the media and in some cases intermediate points within the media, and cascades downward through it. The irrigation water usually contains a low concentration of nutrients that serve to sustain the microorganisms.

Preliminary designs and cost estimates were prepared for a biofilter and bio-trickling filter odor control systems. The bio-trickling filter system was based on bio-reactors and a design provided by Bioway. The results of a 50-year present worth cost analysis indicated approximately a $900,000 savings with a Bioway system. On this basis, the City of Columbus selected the Bioway system as the basis of design, which included ten Purspring™ reactor vessels, including two control panels with programmable logic controllers, a water panel containing irrigation water control valves for each reactor and two recirculation tanks. Also included, was startup services, performance testing, personnel training, and a 4-year annual service agreement. The cost for this hardware and services was $2.73 million.

HEADWORKS ODOR CONTROL SYSTEM DESCRIPTION

Odorous air from the sources described above is normally pulled by four radial blade wheel fans that discharge into a header which feeds ten bio-trickling filter units operating in parallel. Under normal operating conditions the bio-trickling filters treat 96,000 cfm. Periodically, the bio-trickling filters treat an additional 50,000 cfm from the plant's wet well (less than 24 times per year). This occurs when the wet well is inspected and is exhausted at a rate of 30 air changes per hour. Two fans are designated for this purpose. There is an additional fan which serves as a standby/swing fan which can pull air either from odor sources serviced by the main header or from the wet well.

The use of a fan inlet box, inlet box damper, and magnetic adjustable speed drives on the fan motors resulted in the successful balancing of the ducting and fan system and all air flow rates were consistent with the design.

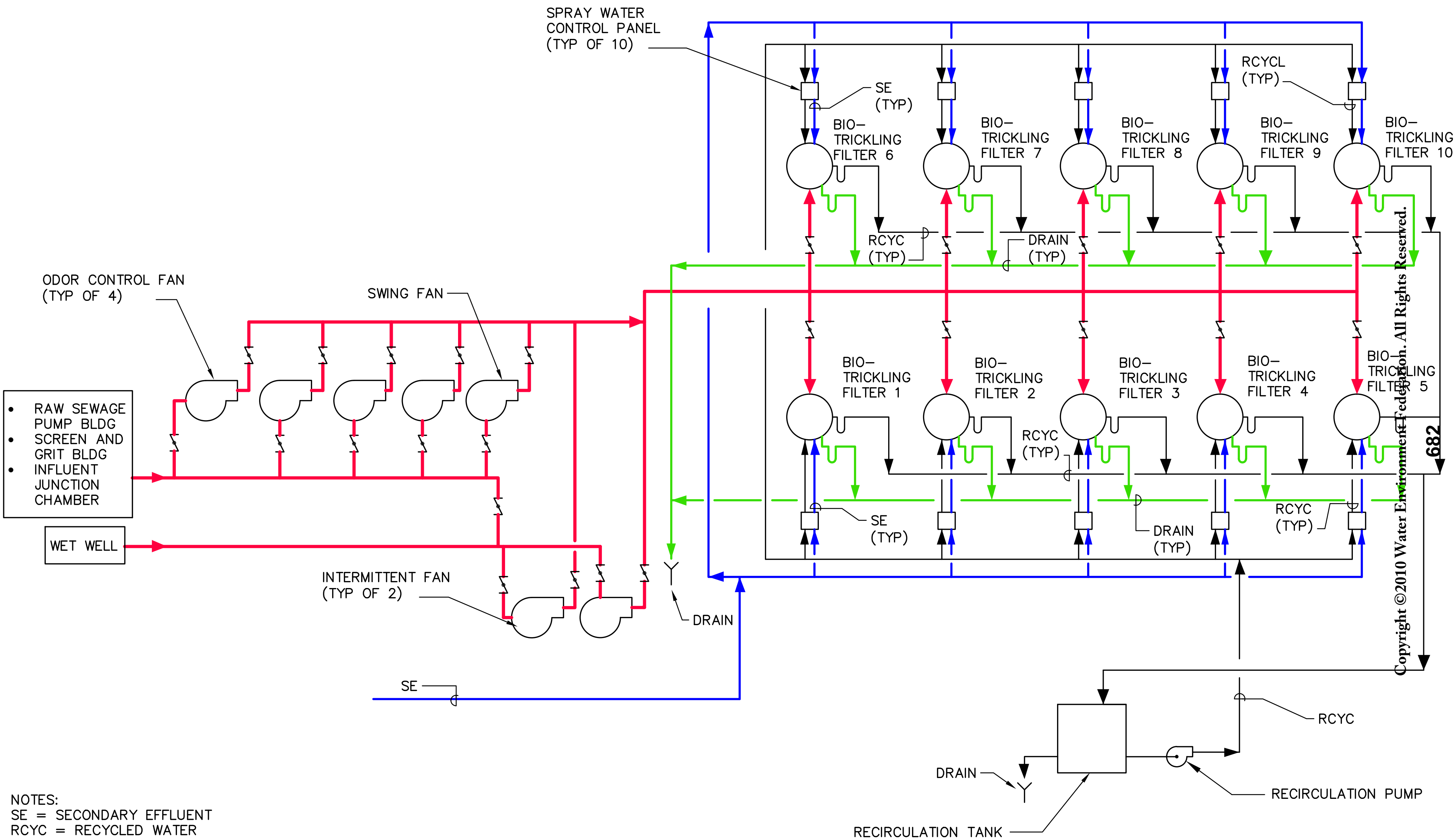
The bio-trickling filters were sized to remove hydrogen sulfide and the other reduced sulfur compounds found to be present. Each bio-trickling filter unit has six media cartridges, each approximately 3.28-feet in depth. Hydrogen sulfide is removed in the lower depth of the media and the reduced sulfur compounds in the upper media levels. The media is patented by Bioway, and is a structured, plastic material.

Secondary effluent is used as irrigation water to help sustain the microorganisms in the bio-trickling filters. This water is introduced at the top of the media and at the two-third level of the media. The benefit of using secondary effluent is its nutrient content and because it is a reused water source. This water is generally not recycled back to the bio-trickling filters, i.e., it is used on a once-through basis. There is a panel containing control valves at each bio-trickling filter which controls the irrigation water feed to each unit. Water usage is approximately 2,500 gallons per day per unit, with an instantaneous water usage rate of approximately 40 gpm for less than one minute. A control system controls the control valves.

During startup, the irrigation water discharged from each unit is collected in a recirculation tank and is recycled back to the units to facilitate development of a microorganism population on the media. Additionally, return activated sludge from the Southerly plant and an external microbial culture that was grown on reduced sulfur compounds was used to seed the population in the bio-trickling filters.

Based on experience with bio-trickling filter operation at other facilities, maintenance is expected to be minimal. The units are filament wound fiber-reinforced-plastic vessels from premium vinyl ester resin which will preclude corrosion problems and promote a long operating life, and the media is provided with a 10-year warrantee. The number and size of the bio-trickling filter units provided were designed so that at least one unit could be taken offline for inspection or maintenance and still provide adequate contact time to meet the design hydrogen sulfide performance of 99% removal. Per Bioway, for the specific media provided and the odor sources being treated, the minimum required contact time is 9-seconds for the design hydrogen sulfide removal. With all units in service a contact time of approximately 13-seconds is provided. With one unit offline the contact time provided is about 11-seconds. The additional contact time provides for removal of the reduced sulfur compounds and other un-identified odorous compounds. These contact times are based on an air flow rate of 96,000-cfm. Ninety-nine percent removal with operation at the higher air flow rate is not required because it is an intermittent and short duration event.

Figure 1 is a process flow diagram of the odor control system. The inlet design parameters and performance requirements for the bio-trickling filter system are summarized in Table 10.



NOTES:
SE = SECONDARY EFFLUENT
RCYC = RECYCLED WATER

MALCOLM PIRNIE	SOUTHERLY WASTEWATER TREATMENT PLANT COLUMBUS, OHIO	HEADWORKS ODOR CONTROL PROCESS FLOW DIAGRAM	MALCOLM PIRNIE, INC. FIGURE 1

Table 10 – Inlet Design and Performance Parameters

Parameter	Value
Continuous Air Flow Rate, cfm	96,000
Intermittent Air Flow Rate, cfm	150,000
Average Inlet Hydrogen Sulfide, ppm	3.5
Maximum Inlet Hydrogen Sulfide, ppm	33
Air Temperature, ºF	59 – 99
Relative Humidity	50 – 100%
Hydrogen Sulfide Removal (@ 96,000 cfm)	99%
Exhaust D/T (@ 96,000 cfm)	600
Maximum Pressure Drop at Intermittent Design Air Flow Rate, inches w.g.	13

The process design summary for the bio-trickling filter is summarized in Table 11.

Table 11 – Bio-trickling Filter Process Design Summary

Parameter	Value
Air Flow Rate, cfm	96,000
No. of Bio-Trickling Filters	10
Diameter, ft	12
Straight-Shell Height, ft	39
Contact time with all units online, secs	12.7
Contact time with one unit offline, secs	11.4
Irrigation water usage per unit, gpd	2,500
Static pressure per bio-trickling filter, inches water	13
No. of Fans	7
Fan motor, HP	150

The cost for the headworks bio-trickling filter odor control system is summarized in Table 12.

Table 12 – Bio-Trickling Filter System Construction Cost

Item	Cost
Bioway Hardware and Services	$2.73
Bioway equipment installation, fans, ducting, concrete, electrical	$1.77
Total	**$4.50 million**

PERFORMANCE

The system was started up in March of 2008 and performance tests were conducted from October through early November 2008. The project specifications required that the units provide 99% removal of hydrogen sulfide and an exhaust odor concentration < 600 dilution-to-threshold (D/T). They also required that the inlet air be augmented with hydrogen sulfide gas if the hydrogen sulfide concentration is less than 3.5-ppm_v. Over the course of the test period the minimum concentration was 8.4-ppm_v, therefore augmentation was not required.

Hydrogen sulfide in the inlet and exhausts were monitored using OdaLog: "0 to 50-ppm_v" and "0 to 2-ppm_v" units, respectively. Five units were tested at a time. The average hydrogen sulfide removal for all ten units was 99.7%. The minimum hydrogen sulfide removal efficiency reported for any unit was 99.25%. Figure 2 presents the inlet and average exhaust concentrations and removal efficiencies for the ten units.

Inlet and exhaust odor concentrations were measured by St. Croix Sensory per ASTM 679-91 and EN 13725 with a presentation air flow rate of 20 liters per minute to the odor panelists. The performance test inlet and exhaust D/T and recognition threshold (R/T) concentrations are summarized in Tables 13 and 14, respectively. Units 1 to 5 were tested on March 7, 2008 and Units 6 to 10 were tested on March 22, 2008, respectively.

Table 13 – Performance Test Inlet and Exhaust D/T Concentrations

Bio-Trickling Filter Units	Inlet (D/T)	Average Exhaust (D/T)	% Removal
1-5	7,800	518	93.4
6-10	12,000	66	99.5
Average	***9,900***	***292***	***96.4%***

Table 14 – Performance Test Inlet and Exhaust R/T Concentrations

Bio-Trickling Filter Units	Inlet (D/T)	Average Exhaust (D/T)	% Removal
1-5	4,500	280	93.8
6-10	8,600	43	99.5
Average	***6,550***	***162***	***96.6%***

In the nearly two years since the start-up of the bio-trickling filter system, there have been no performance problems.

Figures 3 through 5 are photographs of the bio-trickling filters and fans.

Figure 2
Headworks Bio-Trickling Filter System Performance Test
Southerly Wastewater Treatment Plant
October 15, 2008 - October 16, 2008

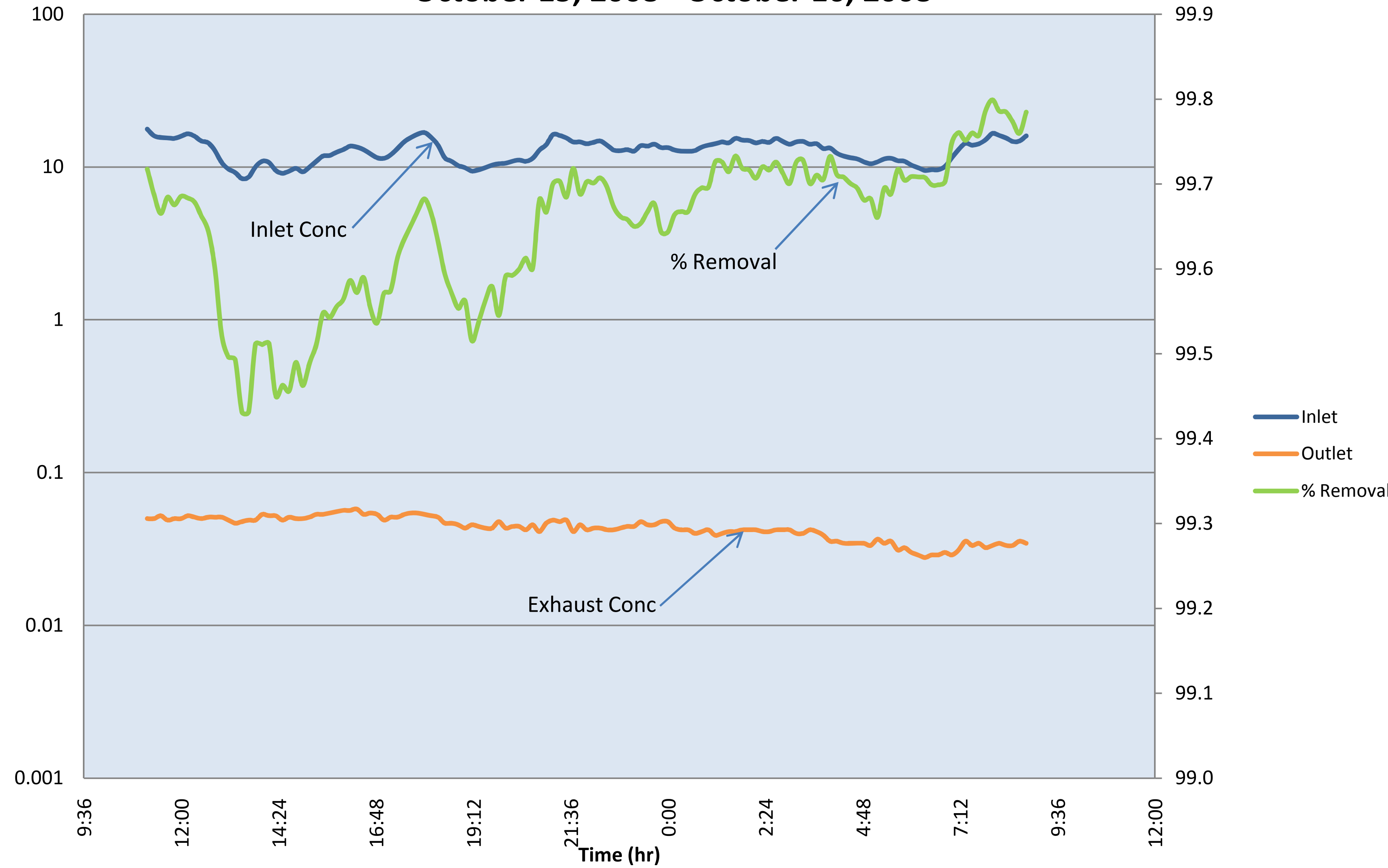


Figure 3 – Bio-trickling Filters

Figure 4 – Bio-trickling Filter Units and Inlet Ducting

Figure 5 – Bio-trickling Filter Odor Control Fans

CONCLUSIONS

1. Bio-trickling filters were determined to be the most cost-effective control technology for treating the exhaust air from the Southerly plant headworks.

2. The selection of bio-trickling filters met the goals of using a control technology that is "green", uses no chemicals, generates no hazardous residuals, has relatively low operating costs, and requires low maintenance.

3. The bio-trickling filters exceeded the hydrogen sulfide and odor removal performance requirements and no odor complaints have been received since startup.

4. The bio-trickling filter units have operated without any significant maintenance or operation issues since start-up.