OVERCOMING CHALLENGES ASSOCIATED WITH IMPLEMENTING ODOR CONTROL IMPROVEMENTS – A CASE STUDY

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ABSTRACT

The 1.8 MGD (ADWF) Sausalito-Marin City Sanitary District (SMCSD) wastewater treatment plant is situated on a small (approximately 2.5-acre), constrained site on the San Francisco Bay. The plant has numerous odor sources that impact nearby residents and cause odor complaints. Spray masking agents installed in 2003 and liquid phase treatment systems have been marginally effective in controlling offsite odors. Customer surveys determined that odor control from the 50 year-old treatment plant was an important community goal and SMCSD Board of Directors authorized funding and implementation of state of the art odor control measures.

An odor study was completed in 2004 that identified the major odor sources at the plant and made recommendations for odor control improvements. The SMCSD initiated an odor control improvements project immediately thereafter for addressing and controlling plant fugitive odor emissions. The initial concept design phase selected biotechnology as the preferred odor control technology based primarily on performance, safety, and ease of operation.

During the detailed design phase several significant challenges surfaced, including the extremely limited footprint available at the site for new odor control facilities. This challenge was met by selecting small footprint bioscrubbers that would be installed on the roof of an existing control building. This decision triggered a seismic analysis of the existing control building (completed in 1986), since local seismic criteria had since changed significantly since it was constructed. Structural roof improvements were implemented, coupled with the selection of multiple light-weight bioscrubbers (to spread the load). Roof weight limitation, equipment comparative performance assessment, and schedule issues drove the project to procure the bioscrubbers via a sole-source arrangement. Ongoing plant improvements that were impacting detailed odor control design had to be carefully coordinated.

Two major design changes produced a significant cost savings for the project. First, a decision was made to reduce the primary clarifier cover to a launder-only cover. This accomplished a desire of plant staff to minimize confined spaces (for ease of maintenance and renewal and replacement efforts). In addition, there was an expected benefit that planned ferric chloride addition to plant influent would have on both primary clarifier performance and reduction of hydrogen sulfide (H_2S) related odors. Second, the design team reversed the fixed film reactor air flow (air flow was changed to a vertical downward direction)_in order to delete the requirement for a fixed film reactor cover from the project (the downward flow pattern was expected to

reduce fugitive emissions from the open top). These cover cost savings alone were realized at over $300,000 for the overall $1.5 million dollar project.

During the construction phase of this project additional challenges surfaced, including an accelerated deteriorating vehicle access causeway that required the contractor to adjust construction work approaches. In addition, due to limitations related to access at the plant, an ocean barge and crane was used via San Francisco Bay to hoist the bioscrubber equipment onto the roof of the existing control building. Finally, more stringent plant effluent permit requirements imposed by the local water board required that treated plant effluent, designed to be utilized for bioscrubber irrigation, be chlorinated to greater than 5 parts per million (ppm) Cl-, a level exceeding that recommended by the bioscrubber manufacturer. This required that a separate non-chlorinated pumped irrigation system (secondary effluent) be implemented as both an irrigation and nutrient source.

The various challenges encountered during implementation of the odor control improvements at the SMCSD were met with ingenuity, creativity and perseverance by both plant staff and the engineering consultant. This allowed the project to move forward, meeting both schedule and budget constraints, and accomplish the project goal of mitigating offsite odors while building community trust and demonstrating that SMCSD is acting as a good neighbor.

KEYWORDS

Odor; Hydrogen sulfide; Biotechnology; Biotowers; Bioscrubbers; Procurement strategies; Selection criteria; Removal performance

INTRODUCTION

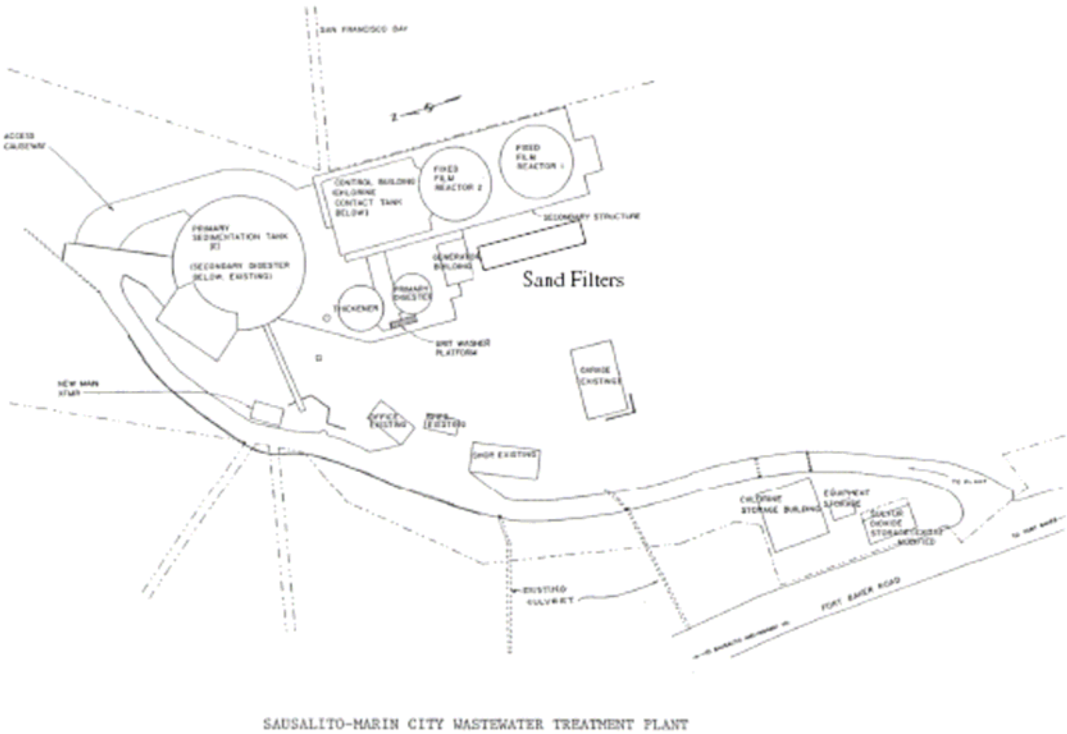
The Sausalito-Marin City Sanitary District (SMCSD) wastewater treatment plant has a design ADWF (average dry weather flow) of 1.8 MGD (million gallons per day). The plant, originally built more than 50 years ago, is situated on a small 2.5-acre constrained site on the San Francisco Bay and serves about 18,000 customers located in Sausalito, Marin City and Tamalpais Valley, California.

The SMCSD wastewater collection system consists of one main interceptor that alternates between gravity and force main, various small to medium sized pump stations, and vacuum breakers at grade breaks between force main and gravity sections. At the Marin City and Bell Lane Pump Stations calcium nitrate (Bioxide®) is injected into the pump station wet wells to control odors in the conveyance system leading to the treatment plant, some six to seven miles away. In general, however, odor complaints along the collection system have been infrequent. Thus, the general focus of this case study is on odor related issues associated with the plant only.

Figure 1 herein provides plan view of the SMCSD plant. The plant is a secondary treatment plant that includes the following potentially odorous treatment processes:

1. Primary Clarifier: A 55-foot diameter above-grade tank, this facility receives wastewater directly from the collection system (there is no headworks process at the SMCSD plant).

Figure 1 – Sausalito WWTP Site Plan



Effluent passes over weirs and through a launderer, then through a screen just downstream of the clarifier.

2. Fixed Film Reactors (FFR’s): Two 40-foot diameter 34-foot tall vessels provide biological conversion of organic material in the wastewater as it flows over the surface of interior media. Only one vessel was typically operated, but plant performance issues and stricter regulatory requirements involving the reduction of peak wet weather flow ‘blending” events required that the second vessel be placed in routine operation.

3. Secondary Sedimentation Tanks: Two tanks are located beneath the fixed film reactors. These 20-ft x 88-ft tanks provide final clarification of the FFR effluent. These unit processes are only marginally odorous and therefore are not considered primary odor sources.

4. Grit Cyclone: Sludge from the primary and secondary sedimentation tanks is conveyed to a grit cyclone where up to 90% of the sand is removed. The grit cyclone is planned to be replaced with a package headworks facility sometime in the future.

5. Gravity Sludge Thickener: Following the grit cyclone, sludge is then conveyed to and thickened in a gravity thickener.

6. Dewatering Belt Filter Press: From the secondary digester, sludge is sent to a belt filter press for dewatering. The dewatering building is a two-story structure with the belt filter press on

the upper level. SMCSD is planning to replace the belt filter press with a screw press by the summer of 2008. The screw press will be located on an elevated platform currently supporting the grit cyclone. The lower level of the dewatering building houses a truck loadout bay. Dewatered solids are trucked to a landfill.

7. Primary Digester and Digester Gas Flare: The primary anaerobic digester is fully enclosed and therefore does not represent a significant odor source. Digester gas that is not used for digester heating is combusted using a small flare. The flare burns year round, and could be a fugitive odor source if the flame does not produce complete combustion or if the iron sponge is not maintained. However, currently, this unit process is not considered a primary odor source.

These odor sources were impacting nearby residents and causing odor complaints. Preliminary findings from a site visit in 2003 identified the fixed-film reactors, primary clarifier, gravity sludge thickener, and belt filter press to be primary odor sources.

Past and Current Plant Odor Control

SMCSD previously installed the piping and equipment to spray masking agents around the perimeter of the primary clarifier, fixed film reactors, and sludge thickener tanks, using a 55-gallon drum of concentrate and water. It was found that the masking agent spray system was only marginally effective in controlling offsite odors and also made the area foggy. Spraying of masking agents is currently employed at SMCSD only on an interim basis around the fixed film reactors and dewatered biosolids truck loading station. Once the planned ferric chloride storage facility and the new sludge screw press/sludge loading area have been constructed, the use of masking agents is planned to be ceased.

An iron sponge for scrubbing digester gas is installed at the plant. The plant staff monitors the effectiveness of this device by monitoring H_2S in and out of the scrubber using sorbent tubes.

BACKGROUND

Customer surveys conducted in 2002 determined that odor control from the 50 year-old treatment plant was an important community goal and the SMCSD Board of Directors authorized funding and implementation of state-of-the-art odor control measures.

Field odor surveys were conducted in December 2002, June 2003, and August 2003 in order to quantify and prioritize odor sources at the plant. A summary of findings is presented in Table 1 for the summer 2003 survey, for which H_2S and ammonia (NH_3) were measured.

Even though measured H_2S levels at the fixed film reactor were low, field observations revealed the likelihood of the presence of other more complex odors, likely methyl mercaptan, a reduced sulfur compound. It should be noted that the field sampling data presented in Table 1 helped "ground truth" assumptions for anticipated loading rates but tended to under-estimate odor levels based on the following inherent grab sample uncertainties.

Table 1 – June 2003 Field Survey Findings

Location or Process Unit	H_2S (ppm)	NH_3 (ppm)
Primary Sedimentation Tank (center of tank at inlet – turbulent flow)	4.0	N/S
Chlorine Contact Tanks (probe placed through opening in wall)	0.001	N/S
Fixed Film Reactor 1 (Probe held above the media and above the rotating arms)	0.007	N/S
Sludge Degritter (Top of Process Unit)	0.5	1
Sludge Degritter (Grit in Bin)	0.007	1
Sludge Thickener (Middle of Tank)	0.17	1
Sludge Thickener (Effluent Weir)	0.67	N/S
Filter Building (Belt Press Off)	N/S	N/S
Dewatered Biosolids in Truck	N/S	10.5
Belt Filter Press Filtrate	N/S	8
Notes: 1. N/S = Not Surveyed		

- External Effects: Sampling uncertainties include natural ventilation effects, process anomalies, etc. that are difficult to account for or are unknown.

- Diurnal Effects: Grab samples represent one-time sample events as opposed to on-line continuous data loggers that capture diurnal fluctuations.

- Seasonal Factors: Summer months tend to result in higher odor levels.

Emissions Modeling and Source Rankings

In 2003, emissions modeling was performed to prioritize and rank odor sources at the plant based on associated offsite odor impacts. All emission rates from SMCSD plant process units used to determine source rankings were estimated using one of the following two methods:

1. The Bay Area Sewage Treatment Emissions (BASTE) model, which estimates odor production from liquid-phase process units

2. Conversion of gas-phase field measurements of hydrogen sulfide and ammonia near the process units directly to emission rates, using process characteristics and a compound emissions formula

The BASTE model is an EPA-approved model that was developed by a consortium of public utility agencies in Northern California to estimate hazardous air pollution emissions from wastewater treatment processes. BASTE modeling was completed to produce emission rates for hydrogen sulfide and ammonia during what is referred in the modeling to be an “average odor event”. Results were “ground-truthed” and correlated with actual complaints by nearby residents.

BASTE emissions modeling is limited to the analysis of liquid-phase processes only, and not solids processes. Therefore, direct calculations of emission rates for solids processes were required, and were based on sampling of H_2S and NH_3 at the plant. Results of both the BASTE model and calculation of emissions rates at solids processes provided a basis for ranking odor sources at the plant. A summary of predicted odor rankings are provided in Table 2 below.

Table 2 – Source Rankings at Plant Based on Emission Modeling

Process	Odor Emissions Rank	H_2S Emissions (kg/day)	NH_3 Emissions (kg/day)	NH_3 Emissions (kg/day as H_2S)[1]	Total Odor Emissions (kg/day as H_2S
Fixed Film Reactor # 2	1	5.6	4.3	0.0033	5.6
Belt Press Room	2	5.0	4.4	0.0033	5.0
Dewatered Biosolids (on truck)	3	2.4	1.9	0.0015	2.4
Primary Sedimentation Tank	4	1.8	4.4	0.0034	1.8
Sludge Thickener	5	0.2	0.0	0.0000	0.2
Sludge Grit Removal	6	0.1	0.0	0.0000	0.1

[1] NH_3 concentration converted to H_2S equivalents of D/T by multiplying by 0.000762 This conversion factor is based upon mathematical manipulation of the detection thresholds of hydrogen sulfide (0.86 ppbv) and ammonia (2.28 ppmv) along with their respective molecular weights as follows:.

0.00086/2.28 x 34/17 = 0.000762

Source rankings in Table 2 are reflective of emissions only and do not take into account meteorological dispersion off-site. Dispersion modeling was completed but output data was unrealistic and not acceptable in predicting odor dispersion from the SMCSD plant, as odor contours (based on H_2S equivalency) extended for miles outside the site, which does not correlate sufficiently with the history of odor complaints. Unrealistic results were caused by having to use overly conservative screening input data since site-specific meteorological data were not available at the time.

The odor study recommended that the primary clarifier, sludge thickener, and one fixed film reactor be covered and ventilated to an odor control system. Although H_2S sample data (see Table 1) revealed relatively low odor levels, the anticipated inlet H_2S levels to be treated were set at 15 ppmV (average) and 30 ppmV (peak) in order to take into account inherent grab sample uncertainties and better align with odor levels experienced at similar facilities. Various vapor phase technologies were evaluated based upon a number of criteria including odor removal effectiveness, ease of operation, initial and operating cost, and safety. Chemical packed tower scrubbers, carbon adsorption, biofilters, and thermal oxidation were evaluated. Wet scrubbers have limited effectiveness on some organic-based odor causing compounds expected to be emitted from the SMCSD plant processes, are more difficult to operate, and require handling of toxic chemicals. Carbon adsorption could have been an appropriate technology had odor levels at the SMCSD plant been low enough to make it cost-effective. However, carbon technology is typically not cost effective at inlet loadings greater than 5 ppm H_2S due to accelerated odor breakthrough and subsequent frequent media change-outs. Thermal oxidizers exhibit higher first (capital) cost and operating cost, especially for the smaller expected SMCSD odor treatment system. Biofilters are very effective at treating a wide variety of odors, are easy and safe to operate, represent a "green" approach to odor control, and are cost effective. Thus, biofilters were the recommended odor treatment solution at the SMCSD plant.

Due to lack of available footprint at the plant, retrofitting the idle fixed film reactor (FFR No. 2) into a biofilter was considered. However, this concept was ultimately screened out for the following two reasons: (1) The tower would have been well oversized for the estimated foul air flow rate, and (2) Removing the FFR from the treatment scheme meant no redundancy in secondary treatment in case FFR No. 1 needed to be taken off line.

Once the preferred vapor phase odor treatment technology was selected along with the recommended covering of specific unit process areas, SMCSD initiated the conceptual and detailed design phase of the project. During the initial conceptual design phase, additional odor sampling was performed to better quantify complex odors emitted from the primary clarifier, fixed film reactor, and sludge thickener. A vacuum pump was utilized for gathering bag samples for laboratory analysis using the ASTM Testing Standard D5504-01, titled Standard Test Method for Determination of Sulfur Compounds in Natural Gas and Gaseous Fuels by Gas Chromatography and Chemiluminescence. Samples were gathered in late September 2004 and were analyzed for 20 sulfur compounds.

Several observations were made as a result of reviewing the lab analysis reports:

- The fixed film reactor was clearly the most odorous process unit at the plant based on both H_2S and other reduced organic sulfur compounds
- The fixed film reactor emitted high amounts of methyl mercaptan: 81 parts per billion by volume (ppbV), or 162 times its detection threshold concentration of 0.5 ppbV
- Sludge thickener samples exhibited twice the H_2S levels as the samples taken from the primary clarifier
- Hydrogen sulfide was the predominant odorous compound being emitted from the primary clarifier

As a result of these findings, a two-stage vapor phase treatment system was considered. The first stage system would be a biotower for treating the higher predominantly H_2S odor levels emitted from the fixed film reactor, sludge thickener, and grit cyclone. The second stage system would be a carbon adsorption polishing stage for treating any remaining H_2S and complex organic odors from the first stage as well as expected lower odor levels from the primary clarifier, primary effluent screening box, dewatering equipment, and the discharge from the first stage biotower. The second stage polishing system was proposed to be located in the existing dewatering building since the existing belt filter press was slotted to be replaced with smaller footprint centrifuges or remote screw presses in the near term; freeing up available space for the second stage system.

Due to budget considerations, indecision on the preferred dewatering improvements approach, and significant structural corrosion issues related to the dewatering building, SMCSD decided to pursue a single-stage biotower solution initially followed in the future by a second stage system if deemed necessary. The system proposed was an 8,000 cubic feet per minute (cfm) facility with expansion to 10,000 cfm in the future. General design criteria pertaining to the proposed system is summarized in Table 3 below.

Table 3 – Vapor Phase Odor Control System Design Criteria

Biotower Performance	
Capacity	8,000 CFM (initial), 10,000 CFM (future)
Inlet Loadings, H_2S	15 ppm (average) 30 ppm (peak)
Minimum Guaranteed Odor Removal Rate, H_2S	For inlet concentrations > 10 ppmV, 99% removal (up to 150 ppmV)
	For inlet concentrations < 10 ppmV, outlet concentration ≤ 500 ppbV
Estimated Odor Unit (D/T) Removal Rate	65% (based on past experience)
Empty Bed Gas Residence Time (EBGRT)	> 9 seconds
Unit Processes Served & Corresponding Ventilation Rates	
Primary Clarifier	1,000 CFM (12 ACH)
Sludge Thickener	500 CFM (12 ACH)
Grit Cyclone	200 CFM (20 ACH)
FFR No. 2	5,000 CFM
Primary Effluent Screen Box	200 CFM (20 ACH)
Sample Sump	50 CFM (20 ACH)
Belt Filter Press Room	1,400 CFM (12 ACH)[1]
Truck Loadout	1,500 CFM (15 ACH) (future)[1]
Ductwork	
Material:	
Exposed to Tide Related Impact Loads	HDPE Pressure Pipe
Above Ground (all sizes)	Vinyl Ester FRP
Odorous Air Exhaust Fans	
Number of Units	1
Type	FRP Centrifugal
Capacity	8,000 cfm (initial), 10,000 cfm (future) @ 10” WC
Motor Size & Type	30 hp, TEFC (Class 1, Div. 2)
Drive Type & Control	Belt Driven, Variable Speed Drive. Speed Control: Suction Side Pressure

Accessories	Acoustical housing (stainless steel or FRP)

[1] Due to major structural corrosion issues related to the solids building as well as potential relocation of dewatering equipment, SMCSD decided to not connect permanent ductwork to this space. As such, temporary ductwork and an air stream shutoff damper was installed, which allowed foul air scrubbing of the building only during the time the belt press was in operation. With this reduction in foul airflow, the foul air system has the ability treat odors from two operating FFR's; albeit at a reduced (4,000 CFM) capacity.

Abbreviations:
CFM = cubic feet per minute
ACH = air changes per hour
EBGRT = empty bed gas residence time
HDPE = high density polyethylene
FRP = fiberglass reinforced plastic
TEFC = totally enclosed fan cooled

DESIGN CHALLENGES

It became apparent early on in the design phase that several key challenges having profound impacts on the odor control design had to be addressed. These included limited available footprint, seismic code issues, ongoing plant process optimization, and budget constraints.

Limited Available Footprint and Seismic Code Issues

The SMCSD wastewater treatment plant is situated on a small (approximately 2.5-acre), constrained site on the San Francisco Bay. Figure 1 indicates the overall plant layout but does not show the extreme topographical profile of the plant. The entire west side of the main unit process area is bordered by a steep hillside, making this area very difficult for siting of an odor control system. Various locations were considered. However, all but one were ultimately determined to be non-viable due to limited space, limited accessibility, or higher cost to implement. Thus, it was decided to pursue locating the single stage biotower system on the roof of the existing control building.

The control building is a cast-in-place concrete structure constructed in the mid-1980's. One unique aspect of the structure, which underscores the extreme space limitations at the plant, is the fact that the building was constructed directly above and integral to the chlorine contact structure below. The control building houses a small lab, electrical room, chlorine/sulfur dioxide feeder room, and administration spaces. As such, the roof of the control building was found to include various roof mounted components including roof exhaust fans, ventilation exhaust hoods, roof access hatch, large access to diversion tank below, and plumbing vents. Figure 2 herein reveals the limited available space for placing odor control equipment on the control building roof due to the various roof obstructions.

In addition to roof space constraints, there was concern regarding the structural capacity of the structure for housing odor control equipment. Thus, the roof was structurally analyzed for the anticipated loads associated with the additional odor control system. Various biofilter and biotower venders were contacted and specific operating weights were received as follows:

- Conventional Biofilter: 30 feet x 25 feet x 8 feet tall (low center of gravity). Would require the entire roof area. Load = 300,000 pounds.

Figure 2 – Control Building Roof Perspective

- Single Biotower Vessel with Lava Rock Media: 16-foot diameter x 28 feet tall vessel (high center of gravity). Load = 200,000 pounds.

- Multiple Small Biotower Vessels with Synthetic or Foam Media: Four 8-foot diameter x 15 feet tall (medium center of gravity). Load = 28,000 pounds.

The following conclusions were made after the building was structurally analyzed:

- The total building dead load was calculated at 2,000 kilopounds (kips).

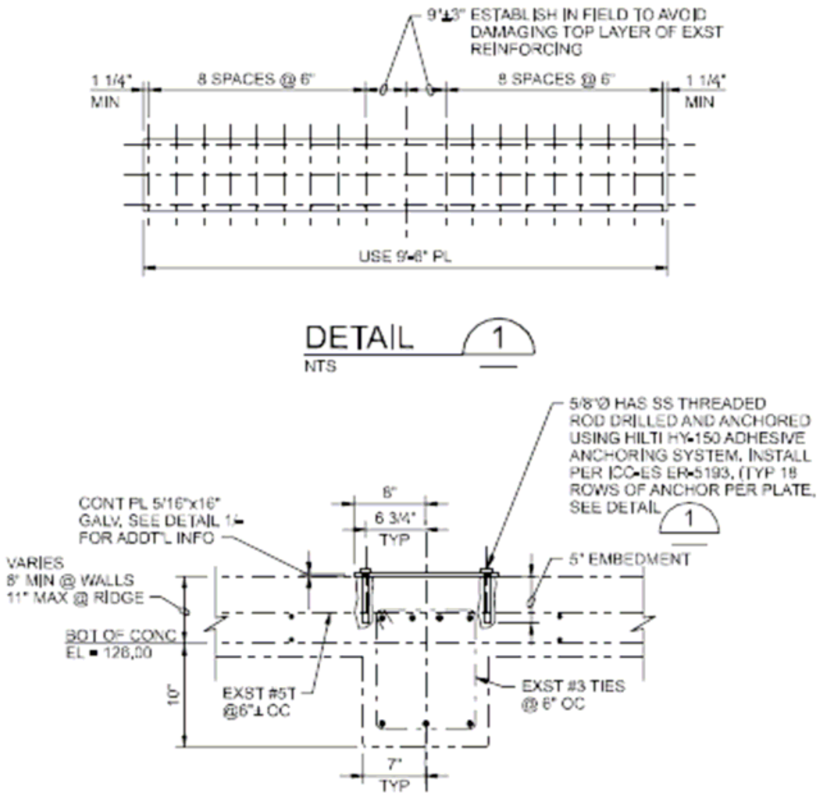
- 5% of 2,000 kips allowed for another 100 kips of additional load before triggers would potentially require major structural redesign.

- The proposed multiple small biotower option, even with ductwork, fan, acoustic enclosure, and ancillary equipment loads included, was the only option falling below the 100 kip trigger point for major structural rework.

The multiple small biotower option was selected for the following reasons: (1) Lowest overall operating weight of the system, (2) Lower center of gravity, and (3) Load spread out due to multiple units. Even with this proposed arrangement, it was found that undersized concrete roof beams required that continuous 5/16-inch by 16-inch wide steel plates be anchored to the top of the beams. A detail of this structural modification is provided in Figure 3 herein.

Roof structural improvements required that the existing built-up roofing system with gravel ballast be removed for installation of the reinforcing plates. In addition, while completing a desktop evaluation of the existing roof system for demolition, it was found that existing roof flashing material contained asbestos fibered asphalt, triggering specialized ACRM (Asbestos

Figure 3 – Roof Beam Plate Detail



Containing Roofing Materials) removal techniques complying with 29 CFR 1926 (OSHA Construction Standards) and EM 385-1-1 (Safety and Health Requirements). Due to the extreme weight limitation requirements, even concrete housekeeping pads had to be minimized with height restraints, making roof tapered insulation and flashing systems more challenging.

It should be noted that synthetic structured media and foam media were the only media types that met the weight limitation criteria. Even so, foam media was excluded from the project, due primarily to media performance issues observed in past installations, including longevity, compression, and channeling of airflow.

During the design it was found that a site-specific seismic report specifying unique seismic parameters above and beyond the enforced 2001 California Building Code (CBC) was applicable to the project. Therefore, equipment specifications were tailored to include these seismic criteria to ensure the overall seismic (and functional) rigidity of the entire system. Specifications included testing and design for seismic and wind forces in addition to the required equipment anchorage.

The challenge associated with the various roof obstructions was met by carefully laying out the four 8-foot diameter vessels along with water control panels, an exhaust fan, drain piping, and irrigation piping such that conflicts were avoided while maintaining adequate access to all new and existing equipment. This proved to be a formidable challenge. In addition, a roof expansion joint further limited viable equipment locations and required that adequate expansion joints be placed in ductwork routed across the roof expansion joint .

Biotower Sole-Source Procurement Arrangement

The number of viable biotower suppliers was limited by the following requirements: (1) Roof weight limitations, (2) Additional stringent seismic requirements specified in the site-specific seismic report, and (3) Design criteria such as experience, media characteristics, and published performance data.

The limited number of sufficient biotower suppliers, coupled with a preferred shortened implementation schedule in order to achieve system start-up prior to the following summer odor season, triggered the evaluation of several equipment procurement approaches. These included the following:

- Traditional Design-Bid Approach: Biotower system specifications would be included as part of the installation contract documents; requiring the potential general contractor to obtain bids from vendors. Due to specific critical design criteria including weight limitations, performance requirements, and experience, a "tight" specification would be written in an attempt to preclude non-complying suppliers from bidding. This approach was deemed unfavorable for the following reasons:
  - Quality Assurance Concerns: This approach is not always successful at precluding non-complying suppliers. A “tight” specification is difficult to make “iron-clad”.
  - Scheduling Concerns: This approach would require a total estimated time from contract award to substantial completion of 15 to 17 weeks (which was considered fairly optimistic). Based upon the expected contract award date, it was estimated that the system would not be operational until midway through the summer; not a favorable outcome for SMCSD with summer conditions representing the greatest odor potential.
- Separate Procurement Package Approach: This approach would consist of a separate competitive bid package just for the biotower equipment. The overall schedule reduction when compared to the traditional design-bid approach was estimated at only 2 to 4 weeks and also required additional engineering costs for putting the package together. Therefore, this approach was considered unfavorable.
- Sole-Source Approach: This approach would require that SMCSD purchase the equipment under a sole-source approach. The “Owner-Furnished” equipment would be stored offsite for the installation contractor to pick up and deliver to the site for installation. It was determined that this approach could potentially reduce overall construction schedule by approximately two months when compared to the traditional design-bid approach, allowing for system start-up prior to the summer odor season. In addition, this approach would allow the engineer to select the best suited supplier based on the various critical criteria. However, due to legal requirements, sufficient technical criteria were required to justify sole-sourcing of this equipment. These criteria, consisting of weight, odor reduction performance, experience, and

reasonableness of bioreactor equipment cost was presented to the SMCSD attorney and found to be legally supportable for allowing the SMCSD Board of Directors to approve the sole sourcing approach.

Ongoing Plant Improvements

Ongoing plant improvements that were impacting detailed odor control design had to be carefully coordinated. These improvements included the following:

- Sludge Dewatering Improvements: During the initial design phase, the odor control system was designed to ventilate and collect odors from the existing solids building, which housed a belt filter press. However, during the design, SMCSD was considering alternative sludge dewatering methods including replacing the existing belt filter press with a screw press. Additionally, an alternate use of the existing solids building for the planned packaged headworks was considered, meaning the new sludge dewatering equipment would be sited in a different location. These possible modifications made it economically risky to design extensive ductwork and containment features into a facility likely to be either demolished or significantly altered. Ultimately, it was decided to simply install temporary ducting and a damper to the proposed duct branch serving this facility as an interim measure.

- FFR Operational Modifications: The odor control system was initially designed based on the operation of only one FFR. Due to plant hydraulics and loadings, at the onset of design only FFR No. 1 was being operated with FFR No. 2 maintained in an idle standby condition. However, late in the design phase it was decided that in order to improve plant process performance and flexibility, both FFRs should be operated on a regular basis. Therefore, the odor control system design was changed to accommodate foul air flows from either FFR or both simultaneously. This required ductwork modifications and reworking system foul air flow criteria under a two FFR operation mode.

- Sludge Thickening Improvements: The odor control design criteria included collecting and treating odors from the existing gravity sludge thickener tank. This required covering the tank and ventilating it at an appropriate rate that would prevent fugitive odors and minimize interior corrosion. However, as part of an Operations Audit performed concurrently with the odor control design, consideration was given to replacing the gravity sludge thickener in the future with a rotary drum thickener. Since a decision regarding this process change was unlikely to occur for quite some time, ultimately it was decided to keep the design unchanged and further to ensure that the thickener cover was designed to be removable and equipped with appropriate access hatches.

- Causeway Improvements: A cast-in-place causeway serving as a major access road into the plant was severely deteriorated due to corrosion. As a result, a design was underway to make structural improvements to the causeway. Due to site limitations, as part of the odor control design, a major foul air header was to be routed below the causeway. In order to accommodate future causeway construction activities, ductwork was designed with appropriate flanges and expansion joints for ease of removal and replacement. Ultimately, it was decided to delay installation of the foul air header until the causeway could be rehabilitated, several months later.

Operations Criteria, Future Plant Improvements, and Project Budget Reductions

During the design phase, SMCSD plant staff voiced concern with covering the primary clarifier and FFR due to confined space issues related to maintenance activities. In addition, planned plant performance improvements, consisting of the regular addition of ferric chloride and polymer to improve suspended solids removal in the primary clarifier would have a dual benefit of reducing hydrogen sulfide emissions, thereby making the covering of the entire tank potentially not necessary.

Reduced cover scope for the primary clarifier and the FFRs also produced the benefit of reduced project costs. The following design modifications were considered:

- Primary Clarifier Launder Cover: In lieu of fully covering the primary clarifier, consideration was given to providing a cover over the effluent launder only with appropriate hatches for maintenance activities. A submerged launder cover can successfully contain and capture most odors emitted from a primary clarifier since the launders represent a turbulent zone where greater hydrogen sulfide emissions are likely to occur. The remaining quiescent liquid surface area is less likely to emit strong odors, especially with the planned addition of ferric chloride. The launder only covers also will keep plant staff from having to meet confined space requirements when the tank is taken down for maintenance.

- FFR Cover: During an Operations Audit workshop the possibility of changing the airflow direction through the FFR's from up-flow to down-flow was considered. Further evaluation of this approach concluded that FFR performance would not be significantly altered following a reversal of the air flow. There were two main advantages to this approach: (1) The life of the distributor could be improved by less corrosive air exposure, and (2) An expensive domed cover could be avoided.

  One concern with this approach was that the existing FFR supply fans pulled air from the lower level secondary basin head space, thereby maintaining a slight negative pressure at this process and preventing fugitive odors. The proposed reverse flow approach would pull air from the top of the FFR, resulting in zero mechanical ventilation from the lower secondary sedimentation basin and the possibility of fugitive odors. It was decided that this condition was not significant because odors from secondary sedimentation basins are normally very low, and the lower level secondary sedimentation basin would still be contained with a checker plate, minimizing odor migration.

  Another concern was the effectiveness of odor capture by modifying the operation to a reverse flow approach and not installing a cover. The down-flow arrangement meant a capture velocity of only 4 feet per minute (fpm) at the top surface of the FFR media. Normally, for effective odor containment for moderate odor sources under low wind speeds a capture velocity of 1 meter per second (m/s) (192 fpm) is considered adequate to prevent the escape of odors [2]. The low capture velocity would mean that odors generated near the top of the fixed film reactor could escape due to wind effects. However, it was determined during design that any odors generated within the media bed would be concealed from the wind and drawn downward (parallel with the liquid) into the odor control system. If future wind effects are proved to contribute to significant fugitive odors than installation of covers would be considered.

- Miscellaneous Cost Cuts: Other cost cutting measures considered included substituting PVC for FRP ductwork, painted galvanized steel instead of stainless steel for duct supports, elimination of the fan sound enclosure, and reducing the number of biotowers from four to three.

It was decided to proceed with launder only covers at the primary clarifier and the down-flow (reverse-flow) approach at FFR's without covers. The other miscellaneous cost cutting options were not carried forward. Cover cost savings alone were realized at over $300,000 for the overall $1.5 million dollar project. A photo of the completed primary clarifier launder cover is shown in Figure 4.

Figure 4 – Primary Clarifier Launder Cover

CONSTRUCTION RELATED CHALLENGES

Various construction-related challenges surfaced that required close attention and innovative solutions to resolve. These included a badly deteriorated causeway, limited crane access, and changed plant effluent characteristics used for biotower irrigation.

Badly Deteriorated Access Causeway

During the design phase, SMCSD made the engineer aware of the fact that a major plant access causeway extending over San Francisco Bay was badly deteriorated. It was determined that its load bearing capacity was reduced to approximately 70% of its original design load. The original designer was contacted and confirmed that the causeway was originally designed for H-15 loading (a truck with two axles, having a 6,000 lb front axle and a 24,000 lb rear axle load). A full concrete truck weighs approximately 55,000 lbs. Thus, load restrictions were included in the contract documents excluding concrete trucks and requiring specific approval from SMCSD regarding proposed vehicular loadings. As a result, once the contract was awarded the contractor chose to place a small concrete mixer on the roof of the control building and hoist individual concrete bags onto the roof. This method was approved by SMCSD.

During the early phases of construction it became apparent that the causeway was significantly more deteriorated than originally estimated. A 100-foot square portion of the underside of the causeway broke off, revealing exposed, severely corroded rebar. Thus, for safety reasons the causeway was completely blocked off, requiring the contractor to adjust work approaches significantly. In addition, the causeway-rehabilitation project was accelerated by emergency declaration by the SMCSD Board of Directors exempting the project from public bidding requirements, and the odor control project contractor was awarded this work since the odor control project contractor was already mobilized.

Limited Crane Access

Extreme plant space limitations coupled with a deteriorated access causeway required that the four biotower vessels be placed onto the existing control building roof using alternative methods. It was anticipated that unloading of the biotowers would likely require an ocean barge and crane via San Francisco Bay. The contractor opted to use a barge supported, 5 ton tracked crane capable of hoisting the 4,000 lb reactor a horizontal distance of about 70 feet. Care had to be exercised to not damage SMCSD's submerged outfall pipeline, which was located in close vicinity of where the barge was set up to hoist the reactors. Figure 5 herein shows the biotowers being readied to be placed onto the roof of the existing control building.

Changed Plant Effluent Characteristics

During the construction phase a change in plant effluent permit requirements was imposed by the local water board that required treated plant effluent to be chlorinated to a concentration greater than 5 ppm chloride (Cl^-). Reclaimed water (pumped plant effluent) had been designed to be the primary irrigation and nutrient source for the biotowers in order to take advantage of available nitrogen and phosphorous nutrients in lieu of installation of a separate costly nutrient feed system. At the time the permit change was mandated, biotower water control panels had already been installed and plumbed to the reclaimed water system and the odor control system was going through its acclimation period.

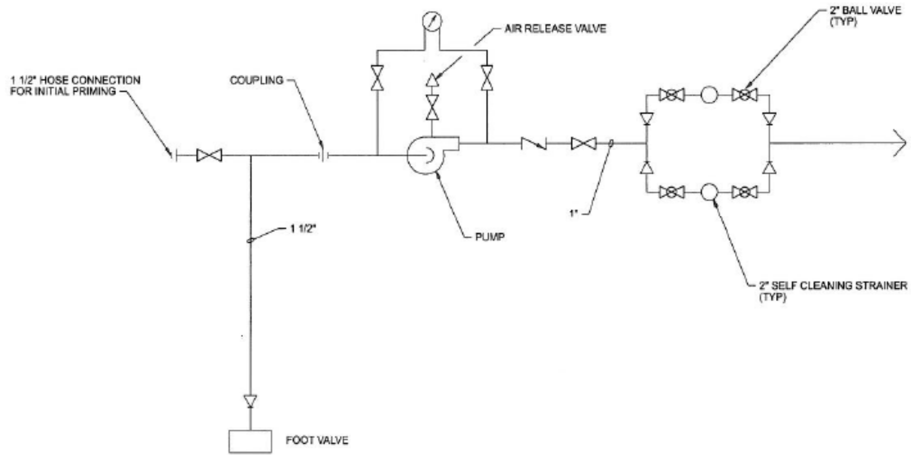
Figure 5 – Placement of Biotowers

The primary work horse in a biotower system is a sulfur reducing bacteria called thiobascillus. In order to keep this bacteria healthy and robust, certain operating parameters must be maintained including temperature, moisture, food source (odorous air), and irrigation water quality. Irrigation water quality must fall within a criteria range for characteristics including nutrients (nitrogen and phosphorous), pH, free chlorine, total suspended solids, and chlorides. The mandated increase in plant effluent free chlorine levels exceeded that recommended by the bioscrubber manufacturer (less than 5 ppm Cl^-). This required a separate non-chlorinated pumped irrigation system (secondary effluent upstream of the chlorine contact basin) be implemented as both an irrigation and nutrient source.

A small pumping system was designed and installed adjacent to the existing secondary effluent screen sump. The system consisted of a 5-horsepower (hp) horizontal end suction centrifugal pump, two self cleaning strainers, suction pipe check valve (for maintaining prime), and ancillary piping and accessories. A schematic of this system is provided in Figure 6.

The SMCSD biotower system irrigation is intermittent. Each of two water control panels is equipped with a solenoid valve for starting and stopping the irrigation cycle for a set of towers. Irrigation cycle time was set up such that tower sprays were activated for 6.5 minutes every half an hour with a 30 second delay between one solenoid stop and the other solenoid start. This would mean that the new irrigation pump would operate under deadhead conditions for approximately 16.5 minutes every half hour, which is not favorable for pump seal life and results in wasted energy consumption. Various control schemes were considered. Ultimately, it was decided to install a pressure switch on the pump discharge line along with time delay relay. When both irrigation solenoid valves are closed (deadhead condition), the pressure in the pump discharge line rises above the pressure switch set-point according to the pump characteristic

Figure 6 – Biotower Irrigation Pumping System



curve and activates a timer relay. This relay automatically de-energizes the pump only after a pressure spike that lasts more than 45 seconds. The pressure set-point was set just below the deadhead pressure of the pump. The time delay relay was installed within the motor starter bucket and wired in series with the pump on/off switch. This set up prevented the pump from being de-energized between the first solenoid valve closure and the second solenoid valve opening; a period of only 30 seconds; allowing the pump to start/stop only twice each hour and preventing motor overheating.

LESSONS LEARNED

The various challenges encountered on the SMCSD odor control project provided opportunities to implement creative and innovative solutions as well as lessons learned for application on future projects. A summary of lessons learned is as follows:

- Physical constraints including limited available footprint can often be overcome with non-traditional equipment layout approaches including roof-top layout and concealed below-causeway duct routing.

- Do not underestimate the design and cost impact of seismically retrofitting an older facility for housing heavy process equipment.

- Depending on project specifics, there are times when technical and performance-related justifications exist for sole-sourcing of odor control equipment.

- Non-traditional cost cutting measures can be viable, including reverse (down) flow of air at fixed film reactor vessels, which results in deletion of costly covers.

- Setting limits and constraints for contractors can result in optimal work products. Contractors can be very savvy in improvising and finding creative ways to complete their work.

- Be prepared to encounter change, both during design and construction, which will require flexibility and creativity in order to still meet project goals and expectations.

CONCLUSIONS

Many challenges were encountered during the implementation of the odor control improvements at the SMCSD, from the early stages of design through the start-up phase of construction. As challenges developed, they were met with ingenuity and creativity by both plant staff and the engineering consultant. Solutions were developed that met project goals and objectives. This allowed the project to move forward, meeting both schedule and budget constraints and accomplishing the overall project goal of mitigating offsite odors while building community trust and presenting SMCSD as a good neighbor. The odor control system is currently performing well, representing a cooperative effort between SMCSD, engineer, contractor, and equipment supplier. Figure 7 shows the completed odor control installation.

Figure 7 – Completed Odor Control System Installation

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