Paper Mill Primary Clarifier Odor Control with Increased BOD Removal

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Primary clarifiers are often the culprit for sulfide formation and the subsequent release of Hydrogen Sulfide (H_2S) odors. While the wastewater sits in the settling tank for several hours, any available dissolved oxygen is consumed and BOD degrading bacteria then use sulfates as an oxygen source, producing dissolved sulfides. As the primary clarifier is intended to be a quiescent basin to aid in the settling process, there is little to no opportunity for natural or induced re-aeration of oxygen directly from the air. When the water flows over the effluent weirs, the turbulence strips out H_2S, resulting in odor and potential corrosion to the primary clarifier and nearby structures.

Odor control in a primary clarifier can be achieved in various ways. The clarifier can be covered and gases underneath the cover can be removed and treated. In addition to the cost of covering the primary clarifier, consideration must be given to how to treat the off-gases. The malodorous air must be conveyed to a carbon unit, wet chemical scrubber, or biofilter for further treatment. Furthermore, corrosion will still be active underneath the cover. Corrosion in covered primary clarifiers can become so severe that the covers have to be replaced. If the clarifier is fully covered it may become classified as a “confined space” with significant safety issues that must be addressed before personnel can enter for inspection and maintenance operations. Since the major zone of H_2S stripping from the primary clarifier is the cascade over the effluent weirs, an annular ring cover over the effluent weirs is also possible, but again, the off-gases must be captured and treated. The “cover and scrub” odor control method may be the most common approach to primary clarifier odor control.

A second possibility is to use chemical addition to either precipitate the H_2S out of solution using iron or to induce chemical oxidation of existing H_2S. Other chemicals, such as nitrate, will allow for microbial oxidation of the existing H_2S, but may or may not prevent additional formation within the primary clarifier itself. These methods can increase solids loading or affect other processes within the treatment plant.

A third option for primary clarifier odor control is to establish aerobic conditions using dissolved oxygen (D.O.). If wastewater can be maintained in an aerobic condition, not only is H_2S generation stopped, but any dissolved hydrogen sulfide is readily chemically and microbially oxidized.

Odor prevention in the primary clarifier using oxygen depends upon sufficient influent D.O. increase to a concentration in excess of that which is consumed in the primary clarifier.

Achievement of these concentrations using pure oxygen will preclude H_2S generation in the bulk water and allow bacterial oxidation of H_2S flux from the sludge layer into the bulk water. A side benefit is then that a comparable reduction in oxygen needed in the aeration tank is in proportion to the oxygen consumed in the primary clarifier.

The Anson-Madison Sanitary District (AMSD) Wastewater Treatment Facility (WWTF), operated by Woodard & Curran, desired to control odors generated in the primary clarifier to eliminate odor complaints. The treatment facility is located in close proximity to neighbors and had experienced odor issues for many years. Wastewater entering the treatment facility is oxygen deficient and the BOD degrading microorganisms were using sulfates as an oxygen source, forming high levels of hydrogen sulfide (H_2S) gas. H_2S levels had been recorded at 150 ppm average with spikes of up to 800 ppm as shown in Figure 1.

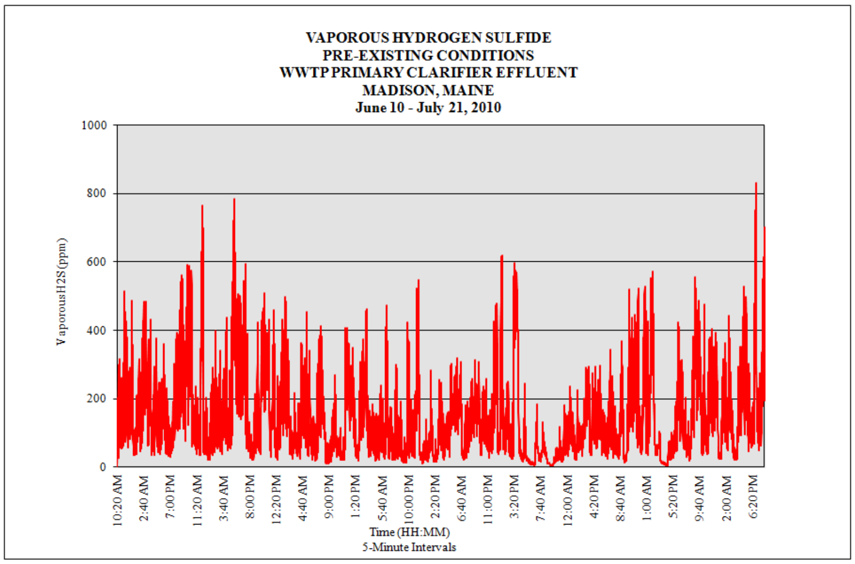

Figure 1: Untreated H_2S Levels at the AMSD Primary Clarifier

AMSD initially controlled odors from the primary clarifier by adding calcium nitrate (Bioxide®) to the wastewater. The average daily calcium nitrate dosage was equivalent to ~318 kg/day (700 lbs/day) of pure oxygen and cost ~$500 per day resulting in an annual budget of approximately $183,000. This level of treatment reduced the odor levels, but did not eliminate the complaints. To reduce the operating cost of the current odor control system, Woodard & Curran considered replacing the chemical dosing system with a pure oxygen dosing system.

Determining Oxygen Requirements

The goal of using oxygen for odor control is to establish and then maintain aerobic conditions so that additional H_2S is not formed. Any dissolved sulfides present in wastewater containing positive D.O. levels will quickly be chemically and microbially consumed as dissolved sulfide is readily oxidized by bacteria. So, for effective odor control, the correct amount of oxygen must be added to the primary clarifier to maintain aerobic conditions over the entire Hydraulic Retention Time (HRT) of the settling basin.

Average flow conditions for the WWTF are ~15,140 m^3/day (4.0 MGD), with 88% coming from the UPM-Madison Paper mill and the remaining coming as municipal wastewater from the local communities of Anson and Madison, Maine. As such, the BOD loading is highly dependent on the paper mill's current operation and varies greatly throughout the day. An average BOD for the WWTF is 500-600 mg/L at 28-30℃. At average flow conditions, the resulting HRT is approximately 3.5 hours.

In order to size the oxygenation system, a worse case condition was developed where the low, average, and peak flow rates were evaluated against a worse case OUR of 10 mg/L/hr. An additional oxygen requirement exists for any dissolved sulfides present in the incoming wastewater. For every 1 mg/L of dissolved sulfides present, 2 mg/L of D.O. is allotted for removal. Assuming worse case conditions of 2 mg/L results in an additional 60 kg/day (130 lbs/day) of oxygen required resulting in a total design requirement of 590 kg O_2/day (1,300 lbs O_2/day).

In order to validate the total design requirement, the calcium nitrate dosage was increased as the budgeted dose was not providing adequate odor control. The original dose rate of calcium nitrate was 0.8 m^3/day (200 gpd) which is equivalent to approximately 320 kg/day (700 lbs/day) of oxygen. The calcium nitrate dosage was increased to 1.35 m^3/day (356 gpd) before the desired results were achieved. This new dosage rate would require AMSD to nearly double their chemical budget to $325,000 per year.

System Sizing and Layout

A SuperOxygentation system using a Speece Cone is designed considering the required amount of oxygen as well as the available pressure. As pressure in a system increases, the saturation point of oxygen increases as well. In a primary clarifier, the goal is to add oxygen as D.O. so there are no bubbles to impact settling. As such, the influent should not be supersaturated with oxygen to avoid a risk of effervescence or otherwise contain bubbles that would impact settling.

Oxygen Supply

The design oxygen transfer efficiency of the Speece Cone is 90%. Considering the oxygen uptake rate sampling data and calcium nitrate dosage testing, the design flow of oxygen was established to be 590 kg O_2/day (1,300 lbs O_2/day). Due to high transportation costs of bulk liquid oxygen to the remote site, Woodard & Curran opted to pursue the use of on-site oxygen generation. AMSD opted to purchase two (2) Vacuum Swing Adsorption (VSA) on-site oxygen generators. The flexibility of two equal sized oxygen generators would allow for the WWTF to better handle the BOD load variations as well as provide for energy savings at lower BOD loading periods. Each of these generators can produce 381 kg/day (840 lbs/day) of oxygen for a combined 762 kg/day (1,680 lbs/day) total capacity. The units are self contained and are equipped with variable frequency drives (VFDs) which automatically control the operation of the units to produce oxygen at the design flow and pressure.

The SuperOxygenation system was placed into operation in March of 2012. The system was operated at varying primary clarifier influent flow rates and oxygen feeds and a mass balance was calculated to verify system efficiency as shown in Table 1.

Table 1: Efficiency Testing

Influent Flow (m^3/day(MGD))	**Oxygen Input (kg/day(lbs/day))**	**Theoretical D.O. @ 100% Transfer (mg/L)**	**Actual D.O. (mg/L)**	**Transfer Efficiency**
10,978 (2.9)	762(1,680)	65.1	62	95.2%
11,735 (3.1)	620(1,365)	50.2	48	95.6%
11,735(3.1)	715(1,575)	57.9	56	96.7%
12,870 (3.4)	572(1,260)	42.2	41	97.2%

The efficiency testing was conducted on the discharge of the Speece Cone. Additional measurements were taken at the primary clarifier weir. Figure 2 shows the sensor locations as well as corresponding readings. These values are reflective of the system operating at maximum oxygen addition capacity.

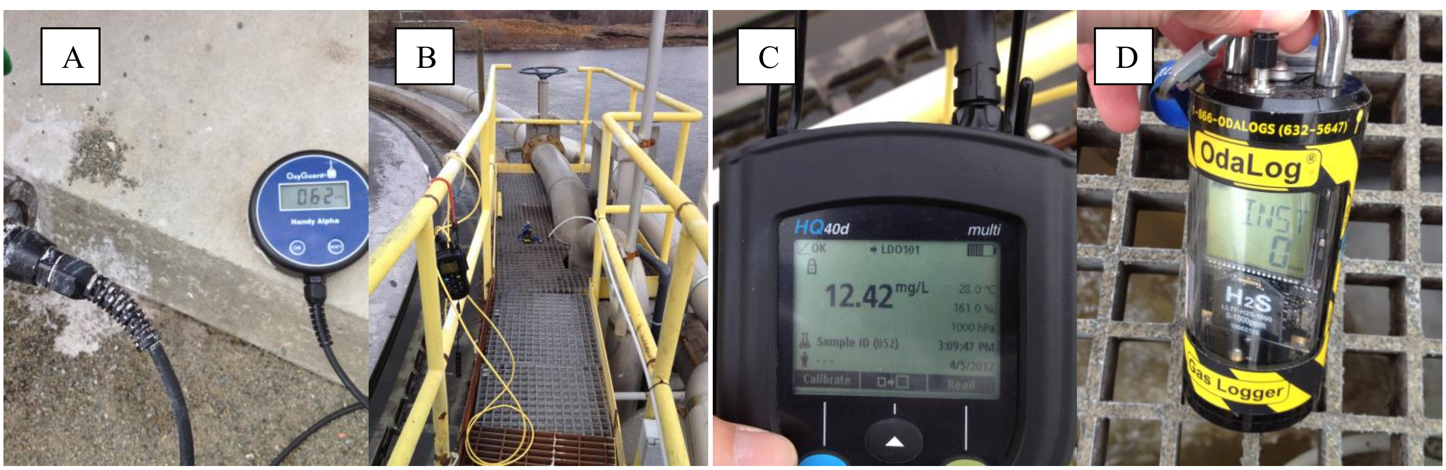

Figure 2: (A) D.O. level at Speece Cone discharge, (B) Sensors over primary weir, (C) D.O. reading at primary weir, (D) H_2S reading at primary weir

Project Economics

A secondary goal to odor control in the primary clarifier was to incur cost savings to the odor control process. Table 2 summarizes the cost savings of using oxygen over calcium nitrate and considers the capital and operating cost of the SuperOxygenation system installed by AMSD.

Table 2: Project Economics

Characteristic	SuperOxygenation Cost	Calcium Nitrate Cost
Chemical Cost		$325,000
Oxygen Cost[1]	$27,250	
Annual Savings	$297,740	
Equipment Capital Cost[2]	$320,000	
Installation Cost[3]	$470,000	
Project Payback Period	2.7	

[1]Power requirement for both oxygen generators operating at full capacity year round. Each generator requires 254 kWhr/day at $0.147/kWhr.
[2]Equipment includes the ECO_2 Speece Cone and (2) oxygen generators.
[3]Installation includes engineering, piping, instrumentation, labor and the construction of an oxygen generator building.

The system has been in operation for over 2 years and has adequately controlled odors at the primary clarifier. H_2S levels are typically under 5 ppm and odor complaints have been eliminated. To further evaluate savings in plant operations, the BOD removal efficiency of the primary clarifier was evaluated. The AMSD plant averages 5,900-6,350 kg BOD/day (13,000-14,000 lbs BOD/day). Before the SuperOxygenation system was installed, 15% removal was achieved by the primary clarifier. After the installation of the SuperOxygenation system with an average daily addition of 454 kg O_2 (1,000 lbs O_2), an additional 272-454 kg BOD (600-1,000 lbs BOD) are being removed by the primary clarifier, raising its removal rate to approximately 20%. This increased BOD removal across the primary clarifier contributes additional plant savings to the odor control system.

After the wastewater exits the primary clarifier, it flows by gravity to an aeration lagoon. The aeration lagoon is equipped with surface aerators to add D.O. for additional BOD removal. In clean water, this type of aerator will achieve 0.61-1.5 kg/kwHr (1-2.5 lb/HP Hr). In wastewater, this transfer rate is typically lower, more on the order of the low end of the transfer rate. At 0.61 kg/kwHr (1 lb/HP Hr) removal, 272 kg (600 lb) of BOD removal (the low end of AMSD's daily savings) would require 446 kWhr. At $0.147/kWhr, this equates to an annual savings of approximately $24,000. Considering the same criteria at the high end BOD removal of 454 kg (1,000 lb) would equate to an annual savings of approximately $40,000. The revised project economics considering actual oxygen usage as well as aeration savings are shown in Table 3.

Table 3: Revised Project Economics

Characteristic	SuperOxygenation Cost	Calcium Nitrate Cost
Chemical Cost		$325,000
Oxygen Cost[1]	$20,700	
Aeration Savings[2]	$24,100	
Annual Savings	$328,400	
Equipment Capital Cost[3]	$320,000	
Installation Cost[4]	$470,000	
Project Payback Period	2.4	

[1]Power requirement for oxygen generators producing 454 kg (1,000 lbs) O_2/day. Each generator requires 193 kWhr/day at $0.147/kWhr.
[2]Considers 272 kg (600 lb) BOD reduction per day.
[3]Equipment includes the ECO_2 Speece Cone and (2) oxygen generators.
[4]Installation includes engineering, piping, instrumentation, labor and the construction of an oxygen generator building.

An aeration basin or lagoon is typically home to a well acclimated bacteria population that has been developed over a period of time. The primary clarifier does not contain the same bacteria population, however it does contain bacteria that will thrive in the presence of oxygen. A 5 per cent increase in BOD removal is not a large increase in process efficiency when compared to typical aeration practices. However, when considering the downstream effect of reduced aeration expenses, this 5 per cent removal results in significant savings to the WWTF's operating budget.

Adding oxygen as dissolved oxygen to the primary clarifier influent is an effective means for odor control. This method is operationally compatible as there is no impact to settling within the primary clarifier as the oxygen is completely dissolved before being introduced to the wastewater. The system is efficient, realizing an average transfer efficiency of over 96%, with the oxygen being added to meet real-time flow demand. Most importantly, the system installed at Anson-Madison has meet the District's needs with near non-detect H_2S levels while realizing a savings of over $300,000 per year over equivalent nitrate costs as well as aeration savings through increased BOD reduction within the primary clarifier.