

21 YEARS OF O&M EXPERIENCE WITH HYBRID ANAEROBIC TREATMENT

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ABSTRACT

In 1983, the NutraSweet Company (NSC) commissioned a hybrid anaerobic treatment system for treating the high-strength wastewater at the site. The anaerobic treatment system has operated continuously from start-up in 1984. The anaerobic treatment facility consists of two upflow reactors with an open or suspended-growth zone in the lower section of the reactor and structural media in the upper part of the reactor. In 2002, a study showed that the hydraulic retention time in both anaerobic reactors had declined significantly. In 2003, NSC decided to remove an anaerobic reactor from service to enable it to be inspected and rehabilitated. The rehabilitation consisted of removing and replacing the media, removing and dewatering sludge, replacing the internal piping, and reseeded the reactor. The project required approximately five months to complete. The rehabilitation of the anaerobic reactor improved the COD removal from 63% observed before the shutdown to 93% observed after start-up of the rehabilitated reactor.

KEYWORDS

Anaerobic, industrial, wastewater, COD, BOD₅, digester, hybrid, media, chemical, high-strength.

INTRODUCTION

NSC in Augusta, Georgia owns and operates a plant that manufactures the sweetener, Aspartame. The manufacturing is a two step process consisting of a fermentation process and a chemical coupling step. The following types of process wastewater are generated:

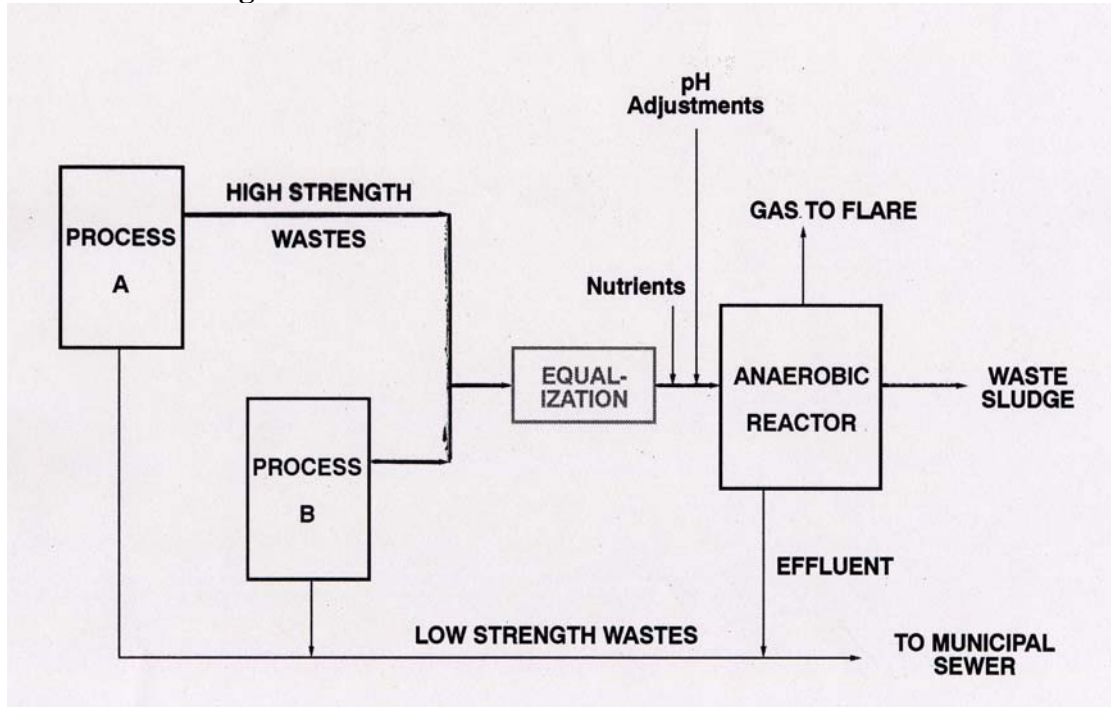
- Spent fermentation cells,
- High-strength (COD) wastewater,
- Low-strength (COD) wastewater.

The spent fermentation cells, which are rich in nitrogen and phosphorus, are land applied to farm lands in the area. The low-strength wastewater is pH neutralized and discharged to the City of Augusta POTW. The high-strength wastewater is treated by an on-site anaerobic treatment system and discharged along with the low-strength wastewater to the POTW. In 2003, the wastewater flow from the site averaged 3,900 m³/d (1.0 mgd). The portion of high-strength wastewater volume was approximately 17% of the total wastewater volume.

The anaerobic treatment system was placed into service in the fall of 1984. The treatment system consists of equalization, pH control, temperature control and two hybrid-type anaerobic reactors. The equalization tank has a volume of 1,900 m³ (500,000 gpd). The tank is mixed by

three side-mounted, 15-HP agitators. The pH control consists of caustic addition that is used to maintain alkalinity in the anaerobic reactors. Trace nutrients are added. The temperature control is accomplished by direct steam injection to the influent wastewater.

Figure 1 – Schematic of Anaerobic Treatment Plant



The two anaerobic reactors are upflow, hybrid type systems. The suspended growth zone is located from the floor to 2.4 m (8 ft) above the tank floor. The attached growth zone is located between 2.4 m (8 ft) to 7.3 m (24 ft). The attached-growth zone is filled with cross-flow media. There is a 1 m (3 ft) liquid zone above the media. This zone provides quiescent conditions for settling. Located from 8.2 m to 9.1 m (27 to 30 ft) above the reactor floor is the headspace for gas collection. The physical dimensions of each reactor are:

- Length = 25.6 m (84 ft),
- Width = 9.1 m (30 ft),
- Side Water Depth = 8.2 m (27 ft),
- Liquid Volume (Each Reactor)= 1,930 m³ (509,000 gallons),
- Number of Anaerobic Reactors = 2, and
- Total Liquid Volume = 3860 m³ (1,017,000 gallons).

The influent pipe enters the reactor via one entry nozzle. Inside each reactor, the piping is distributed in a grid system consisting of 10 droplegs and 20 outlet nozzles. The influent nozzles are approximately 0.31 m (1 ft) above the floor of the reactor and discharge horizontally. Also located at the bottom of each anaerobic reactor is the recycle piping. The recycle pipe enters the reactor via one entry nozzle. Inside each reactor, the piping is distributed in a grid system consisting of 10 drop legs and 20 outlet nozzles. The recycle nozzles are approximately 0.31 (2 ft) above the floor of the reactor and discharge horizontally. Installed immediately above

the cross-flow media is the effluent collection trough. The trough bisects the reactor along the length and is supported from the ceiling by cross-braces. The trough, which has a depth of 0.64 m (2.1 ft), has small holes in the bottom to reduce the buoyancy forces.

The effluent, which is collected in the trough, discharges to a standpipe that prevents gases from exiting with the reactor. The standpipe consists of an inverted weir. Effluent flows under the weir and then over the discharge weir. The suction for the recycle pumps is located near the bottom of the standpipe. The discharge from the standpipe flows by gravity to effluent monitoring station.

The cross-flow media was manufactured by B. F. Goodrich. The media has a surface area of $98 \text{ m}^2/\text{m}^3$ ($30 \text{ ft}^2/\text{ft}^3$). The media was manufactured in 0.61 m by 0.61 m by 1.2 m (2 x 2 x 4 ft) sections. Eight rows of media were placed in each anaerobic reactor. The lowest row of media was placed on slats that were supported by concrete beams. Each row or course of media was placed in a brick-like manner. The orientation of the each course was alternated. That is, a north-south orientation of the media was placed between east-west orientations of the media. Installing the media in this manner resulted in the media being interlocked.

The biogas piping collects gases from the headspace of each anaerobic reactor and each effluent standpipe. The biogas equipment installed consisted of flame arresters, flow measurement and flame arresters. A 36.5 m (120 ft) high flare is used to combust the biogas.

METHODOLOGY

The anaerobic system has operated continuously from start-up in 1984 until one of the reactors was taken out of service for inspection and rehabilitation in 2003. This section summarizes 19 years of operating experience and the problems observed after 19 years of continuous operation.

Summary of 19 Years of Operation

Anaerobic treatment of NSC's high-strength wastewater has been very effective in terms of BOD and COD removal. The COD loading to the two anaerobic reactors has ranged from approximately 2.1 to 4.1 $\text{kg}/\text{m}^3/\text{d}$ on an annual basis for the past 19-years of operation. During this time, the COD removal efficiency has varied from 70 to 80 percent. The BOD_5 removal has generally been in excess of 90%. The greatest difficulty with the anaerobic treatment system was the length of the start-up. It took approximately 300 days to achieve a COD removal of 80%. Part of the delay was likely caused by seeding the anaerobic reactor with anaerobic sludge from a municipal digester.

A major advantage of anaerobic treatment is the low power consumption. The 19-year operating experience of NSC has shown low power consumption. The operating power load is less than 150 KJoules-seconds (200 HP). Assuming an energy cost of \$0.06/KW-hr, the power cost is approximately \$0.02 per kilogram of COD removed.

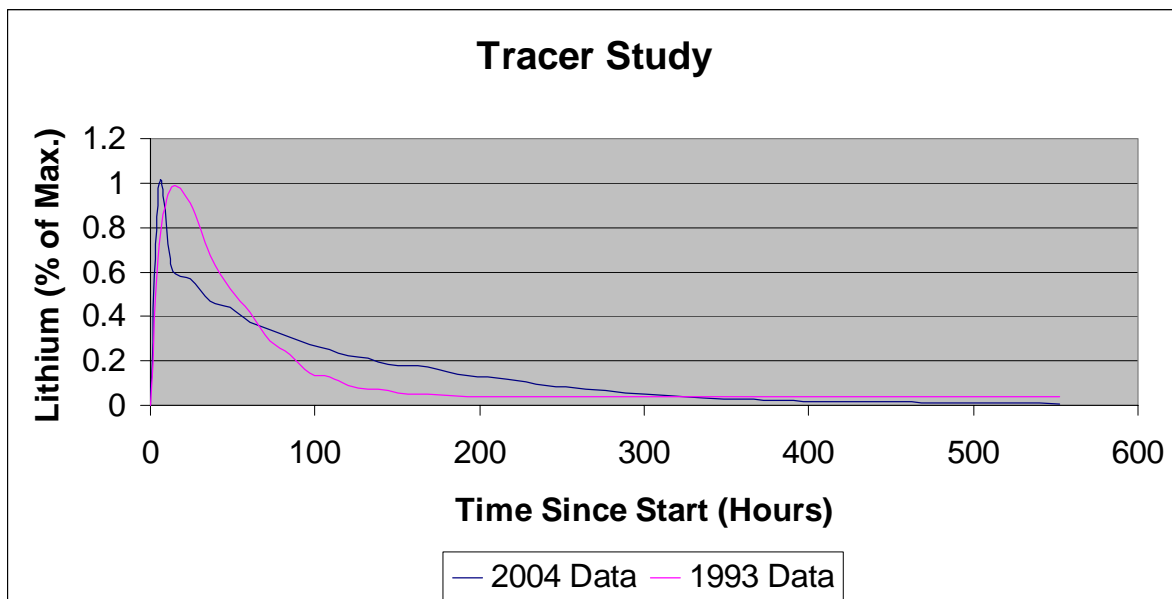
Another advantage of the anaerobic treatment is the low sludge generation rate. The operating experience of NSC has proven this to be true. The solids yield is estimated to be less than 0.10 kg-TSS/kg-COD removed. The sloughing of solids occurs continuously and does not vary significantly from day to day. The biological solids present in the anaerobic treatment plant effluent are discharged to the POTW. Since the effluent TSS concentration is typically greater than 250 mg/L, NSC pays a surcharge to the POTW.

The anaerobic reactor has been a safe system. Part of the outstanding safety record is due to NSC's emphasis on safety during project planning and execution. The dedication to safety is evident in the design of the anaerobic treatment system. The design incorporates a 36 m (120 ft) high flare to reduce the risk of exposure to biogases in the event that the flare does not light. There are several levels of safety regarding the reactor pressure relief valves. NSC's excellent safety program was exemplified by the fact that there were no injuries or lost time incidents during the entire reactor rehabilitation project.

Problems after 19 Years of Operation

In 2002, NSC observed a decline in the COD removal of the anaerobic treatment system. To identify possible causes, NSC conducted a lithium tracer study. The study showed that the actual hydraulic retention time (HRT) was 0.8 days. The theoretical HRT was 4.4 days. A previous tracer study was performed in 1993 (Figure 2). The 1993 study showed that the actual HRT was 3.6 days. In 20002, it was concluded that the anaerobic reactors were short-circuiting. The suspected causes of the short-circuiting were 1) media plugging or 2) channeling of flow through the reactor. Plugging of the cross-flow media would be caused by either biological solids or powdered activated carbon used in the manufacturing operations.

Figure 2 – Anaerobic Reactor Tracer Study (1993 and 2003)



Based upon the fact that the anaerobic reactor was short-circuiting and the COD removal performance had decreased to less than 70%, it was decided to inspect and rehabilitate one of the two anaerobic reactors. Inspection of the anaerobic reactor is not an easy undertaking for several reasons. First, the reactor is gas tight and has limited access. It was estimated that the reactor would have to be out of service for three months to allow the vessel to be emptied of the hazardous gases, water, sludge and media and rehabilitated. Start-up of the system would require another one to three months. At the beginning of 2003, NSC decided to undertake the anaerobic reactor rehabilitation project.

RESULTS

In January of 2003, NSC began planning the rehabilitation project. NSC scheduled the project during the traditionally low-production period, summer, of 2003. The project was divided into the following phases:

- Planning,
- Reactor Shutdown,
- Media and Sludge Removal,
- Reactor Inspection and Rehabilitation, and
- Reactor Start-up.

Planning

The first step of the project was to develop a method for emptying the reactor of the hazardous gas, wastewater, sludge and media. Once the plan was prepared, a schedule and budget estimate was developed for the project. The schedule showed that the reactor would be out of service for approximately 3 months. Additionally, a one to two month start-up was planned after the reactor was rehabilitated.

During the planning phase, the safety issues associated with the project were reviewed and discussed. Since the reactor was a confined space. The reactor was vented continuously. All personnel working in the reactor had life lines and self contained breathing. A three-person rescue crew was assigned to the project whenever personnel were in the reactor. The work was performed in the evenings and at night to reduce the effects of heat. The work crews in the reactor were rotated after 2 hours to reduce the risk of fatigue and heat-related illnesses.

Reactor Shutdown

Before taking the reactor out of service for rehabilitation, it was necessary to shut it down. The first step was to stop the flow of influent into the reactor. The influent was directed to the second reactor. The recycle pumps were operated until the gas production in the reactor ceased. Next, caustic was added to increase the pH to 10.5 to stop biological activity. After the pH was increased, the reactor was purged with nitrogen gas to remove methane and hydrogen sulfide. Next, the two 76 cm (30 inch) access manholes and a 2.4 m by 3.0 m (8 ft by 10 ft) hatch on the top of the reactor were removed. Portable fans were installed to purge the nitrogen from the reactor. After venting the reactor, personnel entered the confined space to begin the work of removing the digester media.

Media and Sludge Removal

The media were found to be nearly completely filled with solids. The media modules weighed between 180 kg and 270 kg (400 and 600 pounds) and were wedged into the matrix. The modules could not be lifted directly up with a crane because of the concrete roof. The modules had to be pulled a spot below the hatch. A bundle of four modules was tied together and lifted from the reactor. Outside the reactor, the media modules were stacked on a containment pad. From the containment pad, the modules were transported to a sanitary landfill for final disposal.

Figure 3 – Photo of Media Modules Removed from Anaerobic Reactor



The sludge in the reactor was pumped into a Baker Tank before dewatering. A belt filter press was utilized to dewater the sludge. Polymer was added as a conditioning compound. The sludge dewatered readily and passed the paint filter test. The dewatered sludge was transported and disposed at a sanitary landfill.

The concrete reactor was inspected thoroughly after 19 years of continuous operation. The only damage to the vessel occurred along the joint between the center wall and the roof. The damage was caused by the uplift from the gas pressure in the anaerobic reactor. This damage was repaired by pressure grouting the joint.

The hold-down rods for the media modules had failed due to the buoyancy forces of the gas. The buoyancy forces caused the media to rise approximately 0.6 m (2 ft) as a monolithic matrix. The flume that bisected the reactor lengthwise had also failed.

No noticeable signs of large ‘channeling’ were observed in the media. The short-circuiting that had been observed was likely caused by the plugged media rather than large voids in the media matrix.

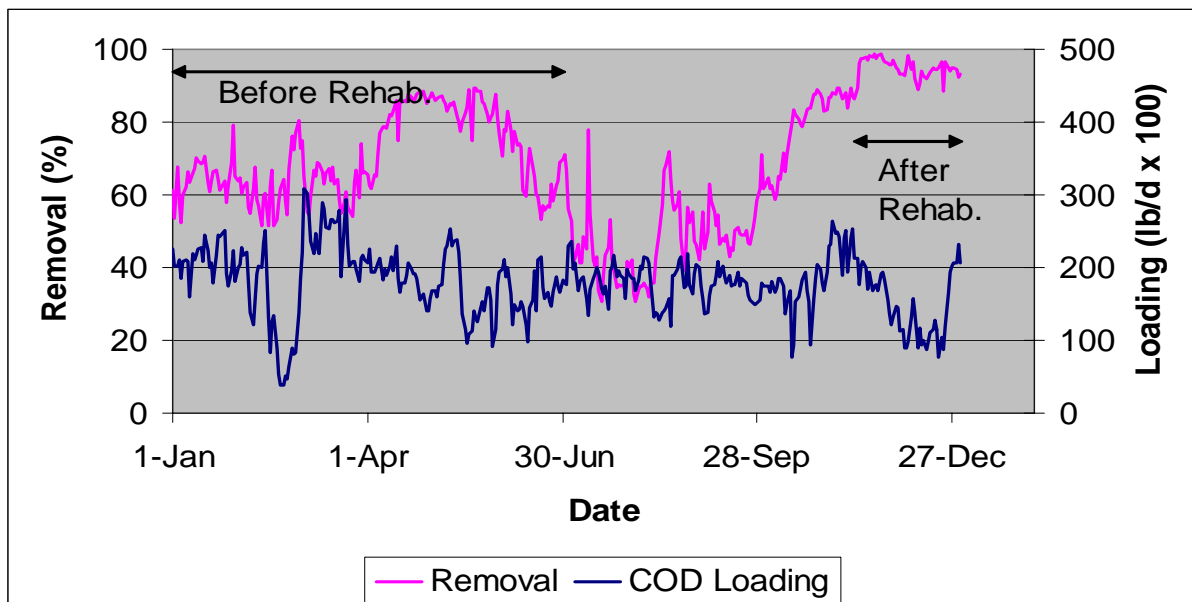
The internal (influent and recycle) piping located in the lower zone of the reactor was found to be broken and plugged with solids. Because some of the last two courses of media fell to the floor before they could be lifted from the reactor, the falling media may have broken the piping. Part of the plugging problem was caused by operating at flow rates that were much less than the design flow rates. Additionally, powdered activated carbon (PAC) had occasionally been discharged to the reactor during the 19-year operating period. It appeared that PAC was a primary cause for the plugging of the pipeline.

The concrete coating above and below the water level in the reactor was inspected. Except for a few places, the coating was in great shape. The places where most of the damage occurred were around penetrations for the hold-down supports. When these supports pulled away from the wall, they damaged the concrete coating.

Reactor Start-up

The anaerobic reactor was seeded with sludge from a nearby UASB system. Approximately 189 m³ (50,000 gallons) of sludge were added to the reactor. The feed to the reactor was started at a low rate and then increased over a six week period. After six weeks, the loading to the reactor was at 100% of the influent loading.

Figure 4 – COD Removal Before and After Reactor Rehabilitation



DISCUSSION

There were several lessons learned specific to the design and operation of hybrid anaerobic reactors.

Design

Media Design – Cross-flow media with a surface area of $9.1\text{m}^2/\text{m}^3$ provided a service life of nearly 20 years. The media can plug with solids. Thus, it is necessary to provide a means for media removal and replacement. During inspection, none of the cross-flow media failed structurally. Thus, the original structural specification for the media is recommended for hybrid reactors. The original specification required that each module have a minimum bearing capacity of $2,000\text{ kg}/\text{m}^2$ ($400\text{ lb}/\text{ft}^2$) and the media have a design loading of $720\text{ kg}/\text{m}^2$ per m ($45\text{ lb}/\text{ft}^2$ per foot) of media depth.

Uplift Forces – The media will need to be restrained to prevent the media from floating to the water surface. The forces will depend upon the amount of gas produced. Additionally, the supports used below the media must be designed for the system when it contains only media and no liquid. Some of the heavier media modules removed from the reactor weighed approximately $800\text{ kg}/\text{m}^3$ ($50\text{ lb}/\text{ft}^3$).

Inspection Ports – Inspection ports for collecting samples from the attached-growth and suspended-growth zones of the reactor should be provided. If the inspection ports are located on the top of the reactor, they will be easier to flush if plugging should occur.

Internal Piping – The internal piping should be designed to operate at a velocity of 0.6 to 1.2 m/sec (2 to 4 feet/second).–

Operation

Seeding – Seeding anaerobic reactors with an industrial anaerobic sludge is very important to decreasing the start-up duration. When the plant was placed on-line in 1984, there were no anaerobic plants with available sludge. The plant was started-up with municipal sludge. The start-up duration was nearly 300 days. Since that time, many industrial anaerobic facilities have become operational. The start-up of the anaerobic reactor using sludge from an Anheuser Busch UASB facility was 45 days.

COD Removal – The anaerobic treatment system has provided reliable COD removal since the project was started. The COD removal for the 19 years of operation is summarized in the Table 1.

Table 1 – Summary of COD Removal for the past 19 years

Parameter	1st Year	2nd Year	8th Year	10th Year	19th Year (Before Rehab)	19th Year (After Rehab)
Flow (m ³ /d)	1,200	1,300	1,100	870	680	590
COD Loading (kg/m ³ /d)	3.2	2.1	2.9	4.1	2.2	2.0
COD Removal (%)	50	85	78	70	70	93

CONCLUSIONS

The anaerobic treatment system has provided consistent BOD₅ and COD removals from 1984 to the present. The COD removal ranges from 70 to 90% based upon loadings between 2 kg/m³/d. and 4 kg/m³/d. The BOD removal is typically over 90%. The energy consumption for operating the anaerobic system is very low. The energy usage is less than 330 KJoule-sec per kilogram of COD removed. Additionally, the sludge generation is very low. The sludge yield is estimated to be 0.10 kg-TSS/kg-COD removed. The system requires very low maintenance. The tank and reactor were inspected and rehabilitated after the first 19 years of operation. Thus, anaerobic treatment was found to be a very economical method for wastewater pretreatment.