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Ammonia Stripping and Integrated Fixed-Film Activated Sludge At the Keystone Sanitary Landfill Leachate Treatment Plant

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INTRODUCTION

The Keystone Sanitary Landfill (KSL) is located at the Keystone Industrial Park in Dunmore and Throop Boroughs, Pennsylvania. The 618 acre landfill site was originally permitted for 5,000 tons of trash per day, and recently received a permit to develop more cells to extend the operation for another 25 years at 5,000 tons per day. Landfill leachate, an inevitable by-product of landfilling, is collected in two 5.5 million gallon holding basins that are mechanically aerated to keep solids in suspension and to prevent odors. These basins serve as "equalization tanks" to smooth out precipitation-induced high flows from the landfill prior to discharge to the leachate treatment plant (LTP). Pretreated effluent is discharged to the Scranton Wastewater Treatment Plant owned and operated by the Scranton Sewer Authority, with the Authority administering the pretreatment program and enforcement of industrial dischargers permitted limits.

Existing Leachate Treatment Plant

The LTP was commissioned in 1989. The plant was rated for an average flow of 35,000 gpd at an influent biochemical oxygen demand (BOD_5) concentration of 3,000 mg/L and ammonia (NH_3-N) concentration of 350 mg/L. Hydraulically, the rated peak flow was 70,000 gpd for the treatment units. The LTP was supplied by the Met-Pro Corporation (Met-Pro) and is comprised of the following treatment units that are listed in order from influent to effluent. All process systems are located within the Leachate Treatment Building.

- Primary Treatment: Physical/chemical treatment for metals precipitation and settling. Caustic soda (sodium hydroxide) is added to raise the pH to around 9 to 10 for metal-hydroxides formation and settling. The primary treatment skid consists of a rapid mix tank, flocculation tank, 14-feet diameter clarifier, and pH neutralization mix tank where sulfuric acid is added to lower the pH. An effluent pump discharges flow to the anaerobic treatment process.
- Heat Exchanger Skid: This plate-type heat-exchanger was to raise the primary effluent temperature prior to anaerobic treatment. However, it clogged shortly after commissioning because of precipitate build-up. A hot water tubing-coil was added in the pH neutralization tank by plant operators to attain some heating of the influent to the anaerobic reactors that should operate at 90ºF to 95ºF for effective treatment.
- Anaerobic Treatment Reactors: These two 24 feet long by 12 feet wide by 7.5 feet sidewater depth tanks each have two 12 feet by 12 feet compartments with a down-flow, 3.0 Hp mixer in each of the two compartments. Each 16,200 gallon tank anaerobically converts biodegradable COD (BDCOD) to biogas to reduce BOD_5 loading to the aerobic reactors. A unique process feature of these anaerobic reactors is that each compartment includes 768 ft^3 (about 70% fill volume) of rigid PVC plastic media modules similar to that used in plastic-media trickling filters. The media in compartment no. 1 of each tank has a specific surface area of 30 ft^2/ft^3, and in compartment no. 2 of each tank there are 42 ft^2/ft^3 media modules. Met-Pro called this the "Matrix Biological Film" (MBF) process. The media, which is supported by a structural framework in the compartments, provides a high surface area for attached biofilm growth. The framing arrangement allows for an "open zone" in the compartment's center for the mixer draft tube and impeller, and supports the media to create an open area at the floor (plenum area). The idea is that the down-pumping mixer circulates the liquid to the plenum area beneath the media modules such that the flow pattern is outward and upward through the flutes

of the plastic media modules stacked together in the tank. Figure 1 from the Met-Pro operating manual illustrates this media and mixer arrangement.

- Aerobic Treatment Units: Four aerobic tanks are installed, each with three 12 feet long by 12 feet wide by 7.5 feet sidewater depth compartments, similar to the anaerobic tanks. Each 36 feet long by 12 feet wide tank has a capacity of 24,300 gallons and is a "MBF reactor" like the anaerobic tanks. Figure 2 from the Met-Pro shop drawing illustrates the aerobic tanks configuration. Compartment no. 1 and no. 2 used 30 ft^2/ft^3 plastic media modules and compartment no. 3 used 42 ft^2/ft^3 plastic media modules. Each of the three compartments per tank used a 7.5 Hp, two-speed, down-draft-tube mixer similar to the arrangement in the anaerobic tanks compartments. The mixers were to induce aeration by downward pumping of the liquid contents and oxygen transfer to the circulating liquid from the air in the tank headspace. A single 150 cfm, 15 Hp air blower was provided for the four tanks to supply air to the "aerobic process" headspace.
- Secondary Treatment (Final Clarifier) Skid: This package includes a pH adjustment mix tank, flocculant aid mix tank, 14-feet diameter final clarifier, and pH neutralization mix tank.
- Gravity Sludge Thickener: 14-feet diameter, picket-rake thickener.
- Sludge Holding Tank: 7.5-feet diameter, 4,000 gallon holding tank.
- Filter Press: Plate and frame dewatering press.

An annotated general arrangement drawing from the Met-Pro operating manual is included as Figure 3 to illustrate the layout of the treatment units in the Leachate Treatment Building.

Pretreatment Limits Issues

In late 2002, the leachate ammonia concentration increased significantly and remains relatively high. Ammonia discharge concentration from the LTP was averaging around 300 mg/L, far in excess of the 23 mg/L pretreatment limit. The Scranton Sewer Authority's plant was not meeting its NPDES ammonia limit, and it advised KSL that its pretreated effluent ammonia concentration must comply with its pretreatment permit limit. An effective and fast solution needed to be defined. KSL's consulting engineers, CECO Associates, Inc. (CECO) retained Gannett Fleming, Inc. (GF) in July of 2003 to assist in evaluating the existing leachate treatment plant, and design and implement a fast-track ammonia removal technology.

Landfill Expansion Permit Application

At the same time as the excess ammonia discharge was occurring, KSL and CECO were working through PADEP to permit the landfill for expansion. The future total leachate flow was defined at 100,800 gpd. Prior to GF's involvement, CECO had requested proposals for new treatment facilities in conjunction with the landfill expansion permit application work. The proposals were based on providing treatment systems capable of treating 80,000 gpd, with the existing plant derated to 20,800 gpd to achieve the overall design flow of 100,800 gpd.

Technical and equipment cost proposals that were received from the manufacturers are summarized in the following:

- U.S. Filter: Powdered activated carbon (PAC) activated sludge process; $1.66 million
- Pall Corp.: Reverse osmosis membrane process; $1.73 million
- Shaw/Emcon/OWT Inc.: Leachate drying process; $3.69 million.

GF was requested to review CECO's proposals evaluation package that recommended the U.S. Filter PAC process. After the review, and following our evaluation of the existing leachate treatment plant data and physical facilities, we recommended that an ammonia stripping process be implemented for immediate removal of ammonia, and that one of the aerobic bioreactors be piloted based on an integrated-fixed-film activated sludge (IFAS) process. Our preliminary process calculations indicated that, given a target 70 percent ammonia removal by high-pH stripping, the existing aerobic reactors had sufficient capacity, if high-rated by IFAS carrier media and application of an efficient diffused aeration system, to satisfy the future treatment flows and constituents removals. This bold approach was favorably considered by KSL in that it could potentially save a million dollars based on not requiring the proposed new treatment facilities.

EXISTING LTP DATA ANALYSIS

Table 1 summarizes the inter-unit treatment process performance. As indicated by primary treatment influent and effluent concentrations for total suspended solids (TSS) and for BOD_5, the high pH, metals precipitation/settling system removes about 80% of the TSS, whereas $CBOD_5$ effluent generally equals influent. That relationship illustrates that the biodegradable carbonaceous material is nearly all soluble. Although ammonia removal was minimal through the high-pH primary treatment process, the removal that did occur was most likely due to the high pH of the treated leachate that resulted in conversion of ammonium ions (NH_4-N) to free ammonia (NH_3-N) and release from the liquid phase..…an ammonia odor is normally present around the primary treatment skid.

The anaerobic treatment reactors significantly reduce the biodegradable organic material, from about 3,500 mg/L to 1,000 mg/L, for an average of around 70% conversion of biodegradable COD to biogas. The anaerobic reactors biogas is discharged to the landfill biogas collection system. As expected, ammonia input pretty much equals ammonia output from the anaerobic reactors, with about 400 mg/L NH_3-N discharged to the aerobic treatment process. Overall, the existing four aerobic reactors/final clarification process reduced $CBOD_5$ to around 120 mg/L, well below the 330 mg/L pretreatment limit. However, the TSS removal through the clarifier is marginal, with an effluent average of about 230 mg/L. For a final effluent around 120 mg/L $CBOD_5$ and 230 mg/L TSS, the inference is that most of the solids are not biologically active. This is a reasonable observation considering that the “aerobic reactors” are very oxygen-transfer limited as expected for the Met-Pro aeration concept employed. In fact, it is hypothesized that the $CBOD_5$ removal through the “aerobic reactors” is a continuation of anaerobic degradation, or at least “facultative degradation”, through this process. Any ammonia reduction is probably from biosynthesis nitrogen requirements for the biomass assimilation of the carbonaceous material. This is suggested by the Total Kjeldahl Nitrogen (TKN) effluent concentration that includes ammonia nitrogen and organic nitrogen, with the organic nitrogen comprised of biodegradable and non-biodegradable nitrogen compounds.

Recognizing that the existing aerobic reactors are minimally aerobic because of the inefficient oxygen-transfer system, high-rating the reactors by increasing the active aerobic biomass inventory and satisfying the associated high oxygen demand for carbonaceous material oxidation and ammonia oxidation was a key goal. This constituted the approach for retrofitting one of the aerobic reactors to IFAS and running a pilot study to gather performance data.

AMMONIA STRIPPING PROCESS

The design of the ammonia stripping process (ASP) was initiated in July 2003 after the review meeting with KSL and CECO regarding our recommendations. Table 5 presents the design basis parameters for the ASP. The ASP physical facilities design and construction delivery approach started out as a design/procure/contractor build idea, but soon transformed into a GF design/GF advise KSL what to buy/KSL personnel build approach. Effectively, we prepared equipment and products scope documents, communicated directly with vendors, negotiated prices, and forwarded the final quote information to KSL for procurement. The major equipment included:

- FRP ammonia stripper tower and fan
- Carbon adsorber for off-gas VOC removal
- Carbon adsorber inlet air heat exchanger
- FRP discharge stack
- Stripper influent wet well and stripper influent pump system
- Stripper effluent wet well and stripper effluent pump system
- Stripper recirculation flow control valve
- Aerobic influent heat exchanger
- Caustic soda feed system
- Sulfuric acid feed system
- Piping; instrumentation; and a PLC-based process monitoring and control system with touch screen operator interface.

GF design drawing P-1 showing the general arrangement of the ammonia stripping process facilities, and P&ID drawings I2 and I3 illustrating the piping and instrumentation, are appended to the end of this paper for reference. Also appended with those drawings is a detailed description of the ammonia stripping process and controls to understand the operation.

IFAS AEROBIC REACTOR PILOT

Based on analysis of the plant data, projected design condition leachate characteristics were established for a design flow of 100,800 gpd. Using that information and predicted constituents removals through primary treatment, anaerobic treatment, and ammonia stripping, the process design parameters for retrofitting the aerobic reactors to IFAS were developed as presented in Table 6. Aerobic Reactor No. 4 was selected as the pilot reactor and was retrofitted by KSL personnel in March through April 2004. The three mechanical mixers, plastic media modules, and media support framework were removed. During the demolition work, it was found that the plastic media modules were packed with solids, so the prior assumption that these "aerobic" treatment units were effectively "anaerobic" was valid. Removing nearly 2,300 ft^3 of "constipated plastic media" was an ugly endeavor but successfully completed by the KSL workers. KSL wanted the pilot IFAS reactor on-line as soon as possible to gather data for PADEP relative to the landfill expansion (and leachate treatment) permit application, so KSL directed GF to provide the selected vendor's system equipment and products quotes information to them for procurement, similar to the method used for procuring the ammonia stripping process equipment. Also to expedite the aerobic reactor no. 4 retrofit, KSL advised GF to only provide "installation sketches" for KSL personnel's use to install the pilot IFAS reactor equipment and components, not CADD-drafted drawings. To minimize potential installation conflicts for this fast-track approach, we performed a detailed site survey to accurately identify the location of the aerobic tank no. 4's internal structural support members, to reference the positions of tank openings and piping nozzles, to measure weir elevations and pipe sizes, and to confirm other mechanical and electrical elements characteristics. That information was used to help guide the selection of the diffuser system, blowers, electrical gear, and related components, and to pinpoint their location. A copy of some of the "retrofit sketches" is appended to the end of this paper to illustrate the information GF provided to KSL for its workers to retrofit pilot aerobic reactor no. 4 to IFAS. GF and KSL communicated nearly everyday by phone calls and faxes to address questions, clarifications, provide technical guidance, and make sure the selected equipment and components were delivered and properly installed.

At mid-April 2004, the EDI tubular membrane diffuser system, the Gast regenerative blowers, and the Hydroxyl carrier media were installed and the reactor was successfully wettested to check the air piping and diffuser system for air leaks. Waste activated sludge from the Scranton WWTP was added along with leachate to establish an activated sludge/attached biomass population. Influent and effluent data collection began in May 2004. Influent to pilot IFAS reactor no. 4 was anaerobic treatment effluent because the ammonia stripping process was still under construction. This was good because the ammonia concentration to the pilot IFAS reactor was very high. Constituents concentrations data from the IFAS pilot were for the bioreactor's unsettled effluent. Table 2 presents the influent constituents concentrations, effluent constituents concentrations, and the respective removal percentages. Percent removals were 65% for $CBOD_5$ and 95% for ammonia. As expected, the TSS concentration increased by 46% from biomass production. Alkalinity reduction correlated closely to the stoichiometric amount of 7.14 mg/L alkalinity as $CaCO_3$ consumed per mg of oxidizable nitrogen converted to nitrate (NO_3).

For the May through June 2004 data period, all influent flow was directed to pilot IFAS reactor no. 4 for maximum load testing. Toward the end of the test period, it was discovered that a lot of the Hydroxyl media from compartment no. 1 had been hydraulically transported to compartment no. 2, with minimal media transport from compartment no. 2 to no. 3. This was caused by media flowing over the top of the screened opening in the inter-compartments separation wall. When the existing rectangular weir opening at the top of the separation wall was enlarged to achieve the required flow-through screened area for media retainage, the designed top support member for the screen was located at the same horizontal position as that of the tank's weir opening crest. That media displacement event taught us that for the other reactor retrofits, the screened openings needed to go all the way to the underside of the roof of the tanks. Although the biomass carrier media was disproportionately distributed per compartment, the total media volume remained in the tank, and the treatment performance of the IFAS pilot reactor was excellent. Given that successful demonstration, retrofit of the other aerobic reactors was planned to take place after the ammonia stripper process construction was completed.

AMMONIA STRIPPER AND IFAS REACTOR TREATMENT

The ammonia stripping process went on-line at the end of September 2004. Aerobic reactor no. 3 was retrofitted to IFAS at the same time, so the as-conceptualized process treatment train revision was ready to be run with the stripper and one IFAS reactor in-service. Aerobic reactor nos. 1 and 2 were scheduled to be retrofitted to IFAS, and the media-retainage screens in pilot reactor no. 4 were scheduled to be modified as a result of information attained from its trial operating period.

Table 3 presents the inter-unit process performance data for the treatment train with the new ammonia stripper and IFAS reactor no. 3 in operation. The stripper achieved an ammonia removal of 71%, and IFAS reactor no. 3 achieved an ammonia oxidation of 93%, with ammonia decreasing from the average primary effluent concentration of 255 mg/L to a final effluent concentration of 5 mg/L. $CBOD_5$ reduction averaged 99%, decreasing from an average primary effluent concentration of 1,212 mg/L to a final effluent concentration of 12 mg/L.

The excellent performance results of the treatment plant additions and alterations project to this point in the implementation scheme speak for themselves. The last part to be completed was retrofitting the other aerobic reactors to IFAS. Given the acceptance by PADEP of the modified plant data report submitted in conjunction with the landfill permit application, and compliance with the Scranton Sewer Authority's pretreatment permit limits, KSL was "off the burner" to finish the job, particularly considering other landfill-related work was rescheduled to get the treatment plant upgraded. Therefore, there was a lag time until the other aerobic reactors were converted to IFAS.

PRIMARY TREATMENT, AMMONIA STRIPPING, AND IFAS

During the period while the remaining aerobic reactors were retrofitted to IFAS, the anaerobic reactors were scheduled to be taken off-line for internal cleaning. This occurred in mid-March 2005 when the four IFAS aerobic reactors were now in-service and the anaerobic reactors were out-of-service. Plant performance data from April 2005 through May 2005 is presented in Table 4 for this treatment train operating condition without the anaerobic treatment process. The main impact related to IFAS reactor loadings for this process operation scheme was the influent $CBOD_5$ concentration that averaged 2,150 mg/L, considerably higher without the biodegradable COD removal typically achieved by the anaerobic treatment process. For this high influent $CBOD_5$ concentration, the IFAS aerobic treatment units averaged 94% $CBOD_5$

removal. A point to note in reviewing the data for this operational condition is the somewhat lower ammonia removal performance through the stripper, which averaged 62% removal compared to the 70% to 73% previously experienced. With the anaerobic reactors off-line, the primary effluent heat exchanger temperature setpoint was lowered. Typically, the anaerobic reactors effluent temperature (ammonia stripper influent temperature) was around 90°F, whereas it averaged 76°F, or about 14°F less, for operation without the anaerobic reactors. This indicates that in addition to a pH in the range of 10 to 11 required for conversion of the ammonium ion to free-ammonia for effective ammonia stripping, water temperature is also important as would be expected for most physical/chemical processes whereby heated reactors typically increase reaction kinetic rates and mass transfer operations. For this data period, the four IFAS aerobic reactors decreased influent ammonia from 103 mg/L to 19 mg/L, for an average ammonia reduction of 82 %.

COMPLETION OF LTP UPGRADE PROJECT

The ammonia stripping process addition, IFAS retrofit of the existing aerobic bioreactors, and equipment automation through the new instrumentation and process monitoring/control system have achieved their design intent and operational expectations. In that KSL is committed to environmental compliance excellence, it has advised CECO/GF to retrofit the primary treatment process and automate it through the new PLC-based PMCS. Also, pursuant to several work sessions related to improving the treatment plant performance, and to ensure the newly permitted design flow of 100,800 gpd can be efficiently treated, the final clarification process is scheduled to be replaced with a dissolved air flotation (DAF) solids separation process. As evidenced from the overall data sets, TSS removal through the final clarifier has been marginal. With the solids tending to remain suspended, a flotation removal process was selected. The new facilities, in conjunction with the above mentioned proposed facilities, will result in a leachate treatment plant capable of treating the leachate from the expanded landfill to effluent concentrations less than pretreatment permit limits.

The overall project cost, that includes the total actual costs for the 2004 additions and alterations project, along with the estimated project cost for the above-mentioned facilities improvements, is $750,000. This is for a treatment plant rated at 100,800 gpd. Comparing that cost to the $1,660,000 capital cost (not project cost, which would likely be 20% more than the capital cost) for the originally proposed PAC treatment alternative (that was rated for 80,000 gpd), the LTP additions and alterations approach that maximized the use of existing facilities was a winning solution.

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