ABSTRACT
The first North American full scale post aerobic digester (PAD) is successfully operating at the Spokane County Regional Water Reclamation Facility (SCRWRF). The SCRWRF PAD has demonstrated ammonia removals of 90% or above without alkalinity or supplemental carbon addition. When operational controls were optimized for total inorganic nitrogen (TIN) removal, the SCRWRF PAD demonstrated effluent TIN removals of greater than 95%. Data from the SCRWRF PAD also demonstrated an additional 30%-40% volatile solids reduction (VSR) beyond typical anaerobic digester VSR of over 60%, resulting in a total VSR of at least 80% in the SCRWRF digestion system.

The main operational challenge experienced was temperature buildup due to significant biological heat. Proper automation and controls are critical to maintain proper operation.

INTRODUCTION
This paper will present an evaluation of data and costs from North America's first full scale post-aerobic digestion (PAD) system at the Spokane County Regional Water Reclamation Facility (SCRWRF) located in Spokane, Washington, USA. PAD is a recently developed advanced digestion process where aerobic digestion is designed to follow mesophilic anaerobic digestion. The SCRWRF PAD system was placed into service in late 2011.

A major driver for PAD is the benefit of reduced nitrogen recycled back to the liquid stream without supplemental carbon or alkalinity needed. This benefit, in addition to the solids destruction performance, have been evaluated using the first two years of data from the SCRWRF.

SCRWRF PAD FACILITY
The SCRWRF digestion system was initially placed into service in late 2011. A number of operational issues and their remedies were developed after startup. Once these remedies were in place, the post aerobic digester was restarted in mid-March 2013. The SCRWRF process flow diagram is illustrated in Figure 1.

Figure 1. SCRWRF Process Flow Diagram with Post-Aerobic Digestion

The post aerobic digestion tank also serves as a variable-level sludge storage tank for feeding the centrifuges.

The SCRWRF PAD system was designed to operate in either continuous low level aeration or with intermittent aeration, which supports ammonia removal and total nitrogen removal. It was not clear at the time of design which approach would provide the most benefits. Full scale operation found that intermittent aeration provided the most benefits to the facility.

Because the PAD system at the SCRWRF was a greenfield project, it is not possible to compare pre- and post-PAD data. Thus, where possible, representative data is compared between periods of time when treatment was taking place to periods of time when no treatment was taking place in the aerobic digester.

RESULTS
In the following subsections, process data from the established PAD system is summarized and evaluated against the predicted advantages applicable to the SCRWRF.

Sidestream Nitrogen Removal
Ammonia removal performance data from the acceptance test period is displayed in Figure 2. As shown in this figure, the average percent removal of ammonia during this period of time was 98.6% (minimum 96.6%), and the average PAD effluent ammonia concentration was 14.0 mg/L (maximum...
Average influent ammonia levels during this period were in excess of 950 mg/L. Total inorganic nitrogen (TIN) removal (ammonia plus nitrate) performance data from the acceptance test period is displayed in Figure 4. As shown in this figure, the average percent removal of TIN during this period of time was 95.0% (minimum 77.5%), and the average PAD effluent TIN concentration was 27.6 mg/L (maximum 103.8 mg/L). Average influent TIN levels during this period were in excess of 950 mg/L (peaking at 1,150 mg/L on September 25, 2013 when the maximum PAD effluent TIN concentration and minimum TIN percent removal occurred). These removals do not take into account the additional nitrogen load added by the release of nitrogen in the aerobic digestion step.

Evaluating a larger time period of data (since the start up of PAD), as shown in Figure 3, a specific period of time (from May 4, 2013 to June 3, 2013) can be seen when nitrifying bacteria in the post aerobic digester were close to washing out, due to both temperature and oxygen conditions, to be further discussed later. During this “Nitrification Upset in Aerobic Digester” period, some ammonia removal continued to occur. The average percent removal of ammonia during this more extensive period of time was 95.0% (minimum 78.1%), and the average PAD effluent ammonia concentration was 34.3 mg/L (maximum 329 mg/L).

Figure 2. SCRWRF PAD Ammonia Performance during the Acceptance Test Period

Figure 3. SCRWRF PAD Ammonia Performance since Startup of PAD

Figure 4. SCRWRF PAD TIN Performance during the Acceptance Test Period
Evaluating a larger time period of data (since the start up of PAD), as shown in Figure 5, some TIN removal continued to occur during the “Nitrification Upset in Aerobic Digester” period. The average percent removal of TIN during this more extensive period of time was 88.7% (minimum 28.3%), and the average PAD effluent TIN concentration was 76.0 mg/L (maximum 391 mg/L). The higher average TIN values realized during this longer period resulted from the gradual optimization of nitrogen removal as the summer season progressed. In general, the operational staff erred on the side of optimizing nitrification, since poor nitrification can result in overall PAD failure.

Increased Volatile Solids Destruction

Data from the SCRWRF demonstrates VSR of an additional 30%-40% in the post aerobic digester after typical VSR of over 60% in the anaerobic digester, resulting in a total VSR of at least 80% in the SCRWRF digestion system. This data is demonstrated in the Table for the acceptance test period as well as the aforementioned “Nitrification Upset in Aerobic Digester” period of time.

Prior to the acceptance test period, operational controls for the post aerobic digester were being refined, especially for air control. Specifically, dissolved oxygen levels and aeration periods were the air control parameters being honed. As shown in Figure 5, the ranges for these air control parameters were identified for optimizing TIN removal by the acceptance test period. After the acceptance test period, the operational strategy was modified to investigate the effects of changing tank levels, temperature, pH, and air controls on PAD and dewatering performance. Through these investigations, it was determined that the ideal pH range for minimizing optimum dewatering polymer dose is 6.9 to 7.6. The pH is controlled via the relative levels of nitrification/denitrification.

To further demonstrate the increased VSR with PAD, the kilograms of dry biosolids hauled per kilogram of raw influent biochemical oxygen demand (BOD) is plotted in Figure 6. PAD effluent ammonia concentrations are also plotted in Figure 6 to illustrate the periods of time when the post aerobic digester was and was not functional. As demonstrated in Figure 6, the final biosolids hauled per kilogram of influent BOD decreased during periods when PAD was functional.
Table 1. Volatile Solids Destruction through PAD System

<table>
<thead>
<tr>
<th>Parameter</th>
<th>During Acceptance Test Perioda</th>
<th>Nitrification Upset in Aerobic Digester Periodb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anaerobic Digester Influent Volatile Solids, kg/d (lb/d)</td>
<td>11,600 (25,500)</td>
<td>18,400 (40,800)</td>
</tr>
<tr>
<td>Anaerobic Digester Effluent Volatile Solids, kg/d (lb/d)</td>
<td>3,920 (8,650)</td>
<td>3,760 (8,280)</td>
</tr>
<tr>
<td>PAD Effluent Volatile Solids, kg/d (lb/d)</td>
<td>2,330 (5,140)</td>
<td>2,610 (5,750)</td>
</tr>
<tr>
<td>Anaerobic Digester VSR (%)</td>
<td>66.2%</td>
<td>79.6%</td>
</tr>
<tr>
<td>PAD VSR (%)</td>
<td>40.6%</td>
<td>30.6%</td>
</tr>
<tr>
<td>Anaerobic Digester + PAD VSR (%)</td>
<td>79.9%</td>
<td>85.8%</td>
</tr>
</tbody>
</table>

a From September 23, 2013 to October 23, 2013
b From May 4, 2013 to June 3, 2013
c The anaerobic digester effluent is the same as the PAD influent.
d The overall VSR for the “Nitrification Upset in Aerobic Digester” period is higher than the overall VSR for the acceptance test period because of higher VSR in the anaerobic digester only.

Cumulative final biosolids production is compared to raw influent BOD in Figure 7. As illustrated in Figure 7, the average rate of cumulative solids production decreased by 12-43% for periods when PAD was online when compared to the average rate of cumulative solids production for the preceding periods when PAD was offline. Moreover, it is anticipated that the generation rate of final biosolids produced would increase with increased BOD load. However, as shown in Figure 7, the generation rate of final biosolids produced did not increase even though the influent BOD load increased significantly in the time period shown.

Other Benefits of PAD
Improved dewatering performance was evaluated by comparing average cake solids concentrations from the acceptance period and the “Nitrification Upset in Aerobic Digester” period. Although the average cake solids concentration was higher for the period when PAD was functioning properly (23.4%), a significant difference could not be determined between the data from this period and the period when nitrification was not functioning (which had an average cake solids concentration of 22.8%).

Figure 6. Trends in Final Biosolids Hauled Per Kilogram of Influent BOD

Figure 7. Cumulative Solids Production
Other anticipated benefits for PAD could not be analyzed at the SCRWRF. For example, ferric chloride is applied to the primary clarifiers as part of the chemically enhanced primary treatment process. Since iron salts bind with hydrogen sulfide, odor reduction due to the PAD process alone cannot be evaluated at the SCRWRF. Similarly, struvite stabilization does not apply to the SCRWRF because the process does not involve biological phosphorus removal.

OPERATIONAL CHALLENGES
Parameters critical to the operation of PAD are displayed in Figure 8 and include PAD ammonia, dissolved oxygen, temperature, and pH. The PAD ammonia and pH must be monitored to avoid nitrification failure because the lack of nitrification can lead to high pH, which results in ammonia toxicity, leading to system failure. Proper automation and controls are critical to successfully operating a PAD system.
The main operational challenge experienced with this first of its kind installation at SCRWRF is regarding temperature. Significant biological heat can be generated by nitrifying bacteria in the post aerobic digester, to the extent that it is possible for the nitrifying bacteria to be killed off (between 40 degrees C and 44 degrees C). Without control, internal temperatures were capable of exceeding 40 degrees C even during ambient temperatures as low as 0 degrees C. In order to maintain optimal temperatures for nitrifier viability, an air cooling system and sprinklers on the aluminum lid were installed in the PAD system.

The high temperatures are also believed to be one of the causes of the foam that had been observed by the operations staff. A foam overflow system was installed to combat foam by piping it to the blended sludge storage tank which feeds the anaerobic digesters. Refining control over the aeration cycles was also determined to be critical for foam control.

**COSTS**

Capital cost for the construction and design of the PAD system at SCRWRF was approximately USD$2,040,000, a portion of which would have been spent for the needed sludge storage tank prior to dewatering. Capital cost savings for a PAD system include avoidance of carbon and alkalinity chemical storage and feed systems.

The average annual cost to operate PAD blowers at SCRWRF is USD $146/day or USD $53,200/year and averages USD $0.36/pound of ammonia removed.

However, the annual cost saved at the SCRWRF in biosolids disposal costs due to the additional total solids destruction in the post aerobic digester ranges from USD $65,000/year to USD $200,000/year, depending on the percent volatile solids of the anaerobic digester effluent.

**CONCLUSIONS**

The first North American full scale post aerobic digester is successfully operating at the SCRWRF.

The post aerobic digester at the SCRWRF has demonstrated a minimum of 78.1% of ammonia removal from the anaerobic digesters, even during a period when nitrifying bacteria in the post aerobic digester were close to washing out. The SCRWRF PAD has demonstrated the capability of reliably achieving at least 90% ammonia removal and ammonia effluent concentrations less than 50 mg/L.

When operational controls were optimized for TIN removal, the SCRWRF PAD demonstrated efficient TIN concentrations of less than 40 mg/L and TIN removals of greater than 95% based on the influent ammonia loads.

Data from the SCRWRF PAD demonstrates an additional 30%-40% VS destruction beyond typical VS destruction of over 60% in the anaerobic digester, resulting in a total VS destruction of at least 80% in the SCRWRF digestion system.

Additional evidence of additional VSR destruction in the PAD is that final biosolids hauled per pound of influent BOD decreased during periods when PAD was functional and that the average rate of cumulative solids production decreased by 12-43% when PAD was online.

The main operational challenge experienced with this first of its kind installation at SCRWRF is regarding temperature due to significant biological heat generated from the PAD process. Proper automation and controls are critical to maintain for the key parameters of ammonia, dissolved oxygen, temperature, and pH. Foam is another challenge experienced during startup for which both operational and engineering solutions are possible.

Reduced optimum dewatering polymer dose nor improved dewaterability could be proven at the SCRWRF. However, the ideal pH range for minimizing optimum dewatering polymer dose at the SCRWRF was empirically determined to be 6.9 to 7.6. Odor reduction and struvite stabilization could not be evaluated at the SCRWRF but are two additional advantages to the PAD process.

The cost to provide air to the post aerobic digester is not insignificant; however, the annual aeration cost is more than made up for by the savings in final biosolids disposal costs due to the additional total solids destruction.

**REFERENCES**


