Value From Waste – Struvite Recovery at the City of Edmonton’s Gold Bar WWTP


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Abstract: A pilot scale struvite recovery project was carried out at the city of Edmonton Gold Bar WWTP in preparation for a full scale technology demonstration. Pilot results showed that the process was capable of recovering over 75% of phosphate and 20% of ammonia from the sludge reject water. Based on pilot results and full scale design, an assessment of the process and environmental benefits resulting from struvite recovery was carried out using a life cycle assessment framework. This analysis showed that struvite recovery has the potential for offsetting meaningful amounts of greenhouse gas emissions through sustainable and energy efficient production of fertilizers. At full scale struvite recovery would result in the production of up to 1200 tonnes per year of struvite fertilizer along with a 20% reduction in the phosphorus load and a 5% reduction in ammonia load on the wastewater treatment plant. The life cycle assessment also showed that the full scale plant would result in the offset of approximately 12,000 tonnes of carbon dioxide equivalent emissions per year relative to conventional fertilizer manufacturing.

Keywords: Struvite recovery, life cycle assessment, greenhouse gas emissions, nutrient load reduction

INTRODUCTION

Nutrient recovery from sludge dewatering reject water has been a subject of considerable research and development efforts in Europe, Japan and North America over the past decade (Jeanmaire 2001; Ueno and Fujii, 2001, Adnan et al., 2002). Since 1999, the University of British Columbia has been developing a proprietary struvite recovery process, which has recently been launched commercially by Ostara Nutrient Recovery Technologies Inc. To date the technology has been tested at pilot scale in four wastewater treatment plants: the City of Penticton, BC, the Lulu Island WWTP in Richmond, BC, the Gold Bar WWTP in Edmonton, AB, and the Nansemond WWTP in Suffolk, VA. The technology has also been pilot tested for applications in greenhouse and animal waste treatment. The first full scale demonstration of this technology is currently underway at the City of Edmonton Gold Bar WWTP after successful completion of a 6 month pilot study.

There are two primary drivers for research and commercial development of nutrient recovery technologies which this paper will attempt to demonstrate in an integrated fashion by combining the pilot results with a life cycle assessment of the process. These concern plant specific process efficiencies and broader environmental benefits that arise from the application of struvite recovery technology at a wastewater treatment plant. The plant specific benefits concern reduction in nutrient loads returned to the treatment plant from sludge dewatering reject water (i.e. supernatant, centrate, filtrate, etc.) and control of unwanted struvite scale formation in the reject water conveying equipment. The global environmental benefits concern energy efficient production of fertilizers and sustainable use non renewable phosphate resources. Eutrophication and global warming are two major global environmental challenges we are currently facing, and nutrient recovery from wastewater provides an opportunity to combat these challenges in a sustainable way. (Millenium Ecosystem Assessment, 2005)
PROJECT OBJECTIVES AND METHODOLOGY:

Pilotscale testing

A pilotscale struvite recovery system was operated at the city of Edmonton’s Gold Bar WWTP for a period of approximately 6 months from March to November 2006. The objectives of this pilot demonstration were to demonstrate that the system could cost effectively recover 75% of soluble phosphate from the sludge lagoon supernatant. The pilot project made use of UBC’s proprietary reactor design described elsewhere (Britton et al., 2005, Adnan et al., 2002) and tested several combinations of magnesium and sodium hydroxide dosage rates to determine the range of possible conditions capable of meeting the treatment target, leading to an optimum economic operating regime. At full scale, the target recoveries would reduce the phosphorus and ammonia loads on the wastewater treatment plant by 20% and 5% respectively, while also eliminating the need for routine maintenance to remove struvite scale from the supernatant return line.

During the pilot testing period, lagoon supernatant samples were collected weekly and struvite recovery reactor effluent samples were collected 3 times per week. Each sample was tested for soluble magnesium by ICP (APHA, 1995), soluble ammonia by the Nessler method (Hach Inc.) and soluble phosphorus by the ascorbic acid method (Hach Inc.) at the City of Edmonton Gold Bar wastewater laboratory.

Life cycle assessment

The life cycle assessment undertaken in this study was used to compare two scenarios, one of which involves the separate treatment of wastewater and fertilizer production and the other in which these two functions are integrated through the implementation of struvite recovery at the wastewater treatment plant. The functional unit selected for this process was the treatment of wastewater from a population of approximately 200,000 concurrently with the production of 500 kg/day of slow release nitrogenous and phosphatic fertilizer for a period of one year. This equates to the design capacity of the full scale facility currently being tested in Edmonton to treat 20% of the lagoon supernatant flow. Figures 1 describes the boundaries of the two systems compared in this analysis as well as the various inputs and outputs considered. For simplicity the impact of the reduced ammonia and phosphate loads on the main wastewater treatment plant have been ignored, and only the direct impact of the struvite recovery process have been considered. Further benefits are likely to arise as a result of the reduced ammonia and phosphate load on the wastewater treatment plant in terms of reduced construction and operating activities.

The economic input-output life cycle assessment (EIO-LCA) model developed by Carnegie Mellon’s Green Design Institute was used to quantify the economy wide environmental impact associated with all items that could not be directly quantified (Hendrickson, et al., 1998, 2006). The model uses 1992 economy wide average values for the United States to calculate the environmental impact of activities in 500 economic sectors based on their dollar value. Correction factors were used to convert these values to 2005 Canadian dollars in which capital and operating cost estimates were calculated. 1992 dollars were converted to 2005 dollars by applying the ratio of the US Labour Department’s consumer price index for 1992 (140.3) and July 2005 (195.4). US dollars were converted to Canadian dollars at the exchange rate of 0.8425 USD/CAD, current on August 31, 2005.
Figure 1: Schematic representation of the two scenarios evaluated using life cycle assessment including system boundaries, inputs and outputs.

PILOT RESULTS

As with previous pilot scale trials using this struvite recovery technology, it was possible to operate the reactor in a flexible range of conditions in order to achieve the desired degree of phosphate recovery. The operational conditions that could be modified included pH, magnesium dose, reactor hydraulic loading and reactor struvite production rate. Overall 8 conditions were tested to determine the optimal process and economic conditions under which to operate the reactor. Average results for each of these test periods are shown in Table 1. By the end of the study it was apparent that the initial conditions tested led to the most stable and economic operation and the best product quality. This involved a Mg:P dosing rate of 1.1:1 on a molar basis, and a pH setpoint of 7.9 for the reactor. Further increases in magnesium dosing rate proved to be uneconomic relative to pH control, and also let to the risk of aggravating struvite formation in downstream processes.
Table 1. Summary of pilot scale struvite recovery test run results. Results are average results for each test run.

<table>
<thead>
<tr>
<th>Test</th>
<th>Feed flow (L/min)</th>
<th>Feed [NH4-N] (mg/L)</th>
<th>Feed [PO4-P] (mg/L)</th>
<th>Effluent [NH4-N] (mg/L)</th>
<th>Effluent [PO4-P] (mg/L)</th>
<th>P removal (%)</th>
<th>N removal (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>2.4</td>
<td>810</td>
<td>180</td>
<td>7.90</td>
<td>610</td>
<td>28</td>
<td>80%</td>
</tr>
<tr>
<td>#2</td>
<td>1.7</td>
<td>690</td>
<td>160</td>
<td>7.98</td>
<td>616</td>
<td>64</td>
<td>64%</td>
</tr>
<tr>
<td>#3</td>
<td>1.9</td>
<td>780</td>
<td>150</td>
<td>7.85</td>
<td>717</td>
<td>50</td>
<td>81%</td>
</tr>
<tr>
<td>#4</td>
<td>3.3</td>
<td>680</td>
<td>170</td>
<td>7.79</td>
<td>663</td>
<td>73</td>
<td>54%</td>
</tr>
<tr>
<td>#5</td>
<td>2.9</td>
<td>720</td>
<td>200</td>
<td>7.87</td>
<td>710</td>
<td>61</td>
<td>67%</td>
</tr>
<tr>
<td>#6</td>
<td>1.9</td>
<td>740</td>
<td>225</td>
<td>7.67</td>
<td>650</td>
<td>60</td>
<td>71%</td>
</tr>
<tr>
<td>#7</td>
<td>2.3</td>
<td>790</td>
<td>230</td>
<td>7.83</td>
<td>600</td>
<td>61</td>
<td>65%</td>
</tr>
<tr>
<td>#8</td>
<td>1.2</td>
<td>1226</td>
<td>340</td>
<td>7.80</td>
<td>676</td>
<td>70</td>
<td>82%</td>
</tr>
<tr>
<td>Average</td>
<td>2.2</td>
<td>805</td>
<td>207</td>
<td>7.84</td>
<td>655</td>
<td>58</td>
<td>71%</td>
</tr>
</tbody>
</table>

Review of the feed phosphate concentrations in Table 1 shows a significant increase in concentration over the course of the study. Further review of historical data showed that phosphate concentrations in the sludge lagoon supernatant have been increasing over the years since biological phosphorus removal was implemented at the Gold Bar WWTP. These concentrations now equate to 25-30% of the phosphorus load and 20-25% on the ammonia load on the treatment plant. Struvite recovery from the sludge dewatering reject water therefore offers the possibility of reducing the ammonia and phosphate loads on the main treatment plant by approximately 5% and 20% respectively, resulting in proportional capacity increases and/or reduced nutrient discharge levels.

LIFE CYCLE ASSESSMENT RESULTS

Using results from the pilot trial, estimates of capital operating and maintenance costs for a full scale struvite reactor capable of treating 20% of the lagoon supernatant at the city of Edmonton were developed. These cost estimates were used to compare the impacts on air quality and global warming that result from production of equivalent values of struvite fertilizer and industry average nitrogenous and phosphatic fertilizers using the EIO-LCA model. Emissions resulting from the conventional production of fertilizer were directly drawn from that industrial segment in the model, while the emissions resulting from struvite production were estimated by summing the emissions resulting from building, operating (chemical use and power consumption) and maintaining the facility.

Table 2 shows the calculated indirect emissions resulting from the two scenarios, excluding the direct impact on the waste stream treated. The results show that struvite production results in reductions of over 50% in sulfur dioxide, carbon monoxide and nitrous oxide emissions and 80% lower green house gas (GHG) emissions on a carbon dioxide equivalent (CO2E) basis than traditional fertilizer manufacture. This results from the fact that conventional fertilizer manufacturing processes are energy intensive, involving mining, long transport distances, thermal processes, and in some cases direct combustion of fossil fuels for product manufacture (e.g. urea production). In contrast the struvite recovery facility operates on a total installed electrical capacity of approximately 25 HP, and uses waste heat from biogas combustion for product drying.
Another interesting result of this analysis is that struvite recovered from wastewater appears to have significantly lower levels of heavy metals when compared with common phosphorus and ammonia containing fertilizers. This is particularly true of cadmium, chromium and arsenic. Table 3 shows the relative concentrations of many metals in common fertilizer products and in recovered struvite. This data is summarized in terms its impact on clean soils in Table 2 using phosphate rock as the basis for comparison. This shows that each functional unit (180 tonnes of struvite fertilizer) results in a reduction of 7.1 kg of cadmium, 64 kg of chromium and 0.7 kg of arsenic applied to land.

### Table 3. Metal contents of common fertilizers and recovered struvite

<table>
<thead>
<tr>
<th>Contents (ppm)</th>
<th>Morocco P-rocks&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Triple Superphosphate&lt;sup&gt;2&lt;/sup&gt;</th>
<th>Ammonium polyphosphate&lt;sup&gt;2&lt;/sup&gt;</th>
<th>Diammonium phosphate&lt;sup&gt;2&lt;/sup&gt;</th>
<th>Recovered Struvite&lt;sup&gt;3&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
<td>200</td>
<td>7760</td>
<td>4250</td>
<td>9900</td>
<td>203</td>
</tr>
<tr>
<td>Cd</td>
<td>40</td>
<td>119</td>
<td>25</td>
<td>6.92</td>
<td>0.5</td>
</tr>
<tr>
<td>Cr</td>
<td>357</td>
<td>516</td>
<td>400</td>
<td>91.8</td>
<td>2.1</td>
</tr>
<tr>
<td>Ni</td>
<td>67</td>
<td>151</td>
<td>1</td>
<td>19</td>
<td>8.7</td>
</tr>
<tr>
<td>Ti</td>
<td>108</td>
<td>42</td>
<td>4</td>
<td>4</td>
<td>5.3</td>
</tr>
<tr>
<td>Zn</td>
<td>880</td>
<td>1260</td>
<td>315</td>
<td>81.6</td>
<td>29</td>
</tr>
<tr>
<td>Mn</td>
<td>10</td>
<td>133</td>
<td>35.9</td>
<td>377</td>
<td>145</td>
</tr>
<tr>
<td>Cu</td>
<td>23</td>
<td>40.2</td>
<td>3.3</td>
<td>5.4</td>
<td>67</td>
</tr>
<tr>
<td>As</td>
<td>5</td>
<td>31</td>
<td>4.8</td>
<td>18</td>
<td>1</td>
</tr>
</tbody>
</table>


### FULL SCALE IMPLICATIONS

Expanding on the results of the pilot trial and the life cycle assessment outlined above it is possible to estimate the impacts of implementing a full scale struvite recovery plant at the Gold Bar WWTP. Such a facility would require the installation of 5 or 6 full scale reactors such as the one currently being evaluated on site, and used as the basis of the functional unit in the EIO-LCA. Figure 2 shows a photograph of the first full scale installation of Ostara’s struvite recovery technology, currently underway in Edmonton. This reactor is designed to treat 20% of the supernatant stream at the City of Edmonton Gold Bar WWTP, and would be one of 6 similar reactors in a complete installation, should the technology meet City performance expectations, recovering 75% of phosphate from 2.5 to 3 million litres per day of lagoon supernatant with a phosphate content of 160 mg/L and producing 1000 to 1200 metric tonnes of struvite annually.
Local WWTP benefits
This installation would result in the following changes at the wastewater treatment plant:

- 20% reduction in phosphate load (355 kg PO₄-P/day)
- 5% reduction in plant ammonia load (161 kg NH₄-N/day)
- decreased biosolids phosphate content leading to a 2-5% reduction in sludge solids mass (Jardin and Popel, 2001)
- increased wastewater alkalinity due to caustic addition (150 tonnes/year of 50% solution)
- decreasedalkalinity demand during nitrification due to reduced ammonia load
- reduction or potential elimination of struvite scale in the lagoon supernatant pipeline to the headworks which currently costs an estimated $100,000/year to keep clear through acid flushing (Neethling and Benisch, 2004)

Although not quantified in this study, these changes to wastewater influent characteristics at the treatment plant should result in ongoing operational savings due to the reduced “dead load” of nutrients being recycled through sludge treatment process.

GHG and sustainability benefits
In addition to the direct benefits to the wastewater treatment plant operation, struvite recovery offers the possibility of significant reductions in greenhouse gas emissions, due to energy efficient fertilizer production. Based on the EIO-LCA analysis carried out in this study, a 6 reactor installation in Edmonton would result in a reduction of 12,400 metric tonnes per year of carbon dioxide equivalent emissions compared to conventional fertilizer production.

The recycling of phosphate through struvite recovery would also be a positive step towards improving the sustainability of the phosphate fertilizer industry. Global reserves of high quality phosphate ore are forecast to be exhausted by the end of the century, resulting in increasing prices and environmental impacts from processing lesser quality or less accessible ore reserves (Steen, 1998). This is a non renewable resource which is essential to sustaining global agricultural output, and should be carefully managed to ensure the continued prosperity of future generations.

CONCLUSIONS
Struvite recovery has been proven to be technically feasible at the Edmonton Gold Bar WWTP during a 6 month pilot scale test. At full scale, the process results in a number of direct benefits to the wastewater treatment plant as well as providing interesting opportunities to reduce greenhouse gas emissions through energy efficient fertilizer manufacturing. In particular a full scale installation would result in a 20% reduction in plant phosphorus load, reducing or even eliminating supernatant line scaling and generate up to 12,400 metric tonnes per year of carbon offset credits. Further analysis would be required to quantify the economic value of these carbon credits and how they may impact the return on investment of a utility investing in struvite recovery.

ACKNOWLEDGEMENTS
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REFERENCES


