TREATMENT OF CENTRATE FROM DEWATERING A THERMALLY HYDROLYSED SLUDGE AT DAVYHULME WwTW

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Abstract

Davyhulme WwTW is United Utilities largest sewage and sludge treatment facility. The current sludge treatment facility is being expanded to include thermal hydrolysis and dewatering of the digested sludge with the production of ammonia rich liquors. For AMP5, the works has been given a tighter ammonia standard of 1mg/l (from the current 3mg/l) with predicted growth in population. Consequently, the treatment options for this centrate and along with the population growth (specifically the ammonia load) has been assessed. This has included both treatment within the sewage works including extensive trial work and a review of the available liquor treatment plant technologies.

Keywords

Centrate, liquor treatment, thermal hydrolysis, digestion.

Introduction to Davyhulme WwTW

Davyhulme WwTW is United Utilities largest sewage and sludge treatment facility. The works serves the City of Manchester and parts of Greater Manchester, treating a population equivalent of about 1.2M. The works consists of two parallel streams based upon the activated sludge process which are both carbonaceous plants. The effluents from the two streams then combine to be treated on the BAFF (biological aerated flooded filter) for full nitrification. This is shown in Figure 1.

![Process Flow Diagram of Davyhulme WwTW](image_url)
The current consent (on a 95%ile basis) is 30mg/l SS, 20mg/l BOD and 3mg/l ammonia and the final effluent is discharged to the Manchester Ship Canal.

The current sludge treatment facility at Davyhulme treats indigenous sludge and liquid sludge imports in conventional mesophilic anaerobic digesters (MADs) following gravity belt thickeners. The digested sludge is then pumped to the Shell Green incineration plant. During late 2012/early 2013, a thermal hydrolysis plant provided by CAMBI and associated ancillary equipment will be commissioned. Details of this new sludge treatment facility, SBAP (sludge balanced asset programme) have been covered elsewhere (Jolly, 2010). Following digestion, some of the sludge will be dewatered at Davyhulme for recycling to agriculture, while the remainder will be pumped to the Shell Green incinerator. Two dewatering centrifuges are being provided, each capable of producing 16000 tdspa of digested sludge cake. The current operational strategy is that either one or both of these centrifuges will operate depending upon the availability of the land bank for sludge recycling. The ammonia rich centrate from these centrifuges will have the excess solids removed by use of a DAF (dissolved air flotation) plant, followed by balancing. It will be returned to ASP1 stream for ammonia removal in the BAFF plant. Alkalinity dosing (sodium hydroxide) is being provided. An assessment by the SBAP project team showed that there is adequate capacity within the existing BAFF plant to treat this additional ammonia load and still meet the current consent of 3mg/l ammonia but not the future ammonia consent.

**AMP5 Project**

The drivers for the AMP5 project at Davyhulme are:

- A change to the ammonia consent to 1mgl (on 95%ile basis). There is no change to the BOD and SS consent.
- An increase in population of circa 125,000 by 2026.
- An increase in passenger usage at Manchester Airport in the same timescale.

Obviously, the increase in population and airport passengers impacts on the flow, BOD, SS and ammonia loads that the works has to treat. As stated earlier, the existing plant is unable to treat the centrate load and meet the future ammonia consent. Consequently there was a major concern that the BAFF plant would not be able to treat the projected ammonia load to the future consent. (The increase in BOD and SS has been investigated too but was the subject of a parallel study and is not discussed further here.)

To further understand the impact of the increased ammonia load, two separate studies were undertaken which were:

- A review of liquor treatment plants and their performance to treat the centrate separately and return their discharge back to the works, thereby reducing the load to the BAFF plant.
- A trial on the BAFF, dosing of ammonium sulphate, as a surrogate, to assess the ammonia load the BAFF could treat to meet the new consent.
Review of Liquor Treatment Plants

Centrate Quality and Quantity

Although SBAP is still to be commissioned, centrate load has been a key requirement to assess the loads to the liquor treatment plant (LTP). Although the SBAP project team had assumed ammonia concentrations in their work, it was considered out-of-date and the centrate quality warranted further investigation. Table 1 gives some of the data found for digestates or centrates (following dewatering of a thermally hydrolysed digested sludge).

Table 1: Digestate and centrate ammonia concentrations

<table>
<thead>
<tr>
<th>Works</th>
<th>NH3 Concentration (mg/l)</th>
<th>Reference Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whitlingham - Pilot</td>
<td>1900-2900 (digestate)</td>
<td>Tattersall (2011)</td>
</tr>
<tr>
<td>Whitlingham – Operational</td>
<td>Avg 1210 and Avg 1382 (centrate)</td>
<td>Tattersall (2011)</td>
</tr>
<tr>
<td>Aberdeen</td>
<td>2500-3000 (digestate)</td>
<td>Jolly (2011)</td>
</tr>
<tr>
<td>Seven plants</td>
<td>Avg 2537 Range 1500 – 3000 (digestate)</td>
<td>Higgins (2011)</td>
</tr>
</tbody>
</table>

The ammonia concentration from the ‘seven plants’ is an average of the data reported, with the higher concentrations being from Cambi plants that treat a secondary sludge only, as is the Cardiff plant. The data for Aberdeen is from its commissioning in 2004. Based upon Table 1, it was assumed that the ammonia in the Davyhulme digestate was between 2500 to 3000mg/l which supported the values used in the earlier SBAP design work. Following mass balance calculations, the maximum load was 4465kg/d and with an assumed maximum centrate quantity of 2350m3/d gave concentration in the centrate of 1900mg/l; the lower concentration was 1400mg/l based on other assumptions. This maximum load is for two operational dewatering centrifuges.

History of LTPs – Early Plants

LTPs originated in the mid to late 1990s to treat centrate from dewatering conventionally digested sludges where there was inadequate capacity within the sewage works to treat the additional ammonia loads. Typically the ammonia loads can increase by about 30% or greater, dependent on the quantity of imports treated by the digestion plant. These early liquor treatment plants were based on the activated sludge process, either as a conventional ASP flowsheet (aeration basin and final clarifier) or a sequencing batch reactor (SBR). Table 2 shows early LTPs installed in the UK, along with the type and their performance.
Table 2: Early LTP Performance

<table>
<thead>
<tr>
<th>Works</th>
<th>Type of ASP</th>
<th>Design Load NH3 (kg/d)</th>
<th>Design Influent NH3 (mg/l)</th>
<th>Actual Performance (% NH3 removal)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minworth</td>
<td>ASP</td>
<td>2500</td>
<td>800</td>
<td>Circa 98%</td>
<td>Philp (1999)</td>
</tr>
<tr>
<td>Newthorpe</td>
<td>SBR</td>
<td>180</td>
<td>522</td>
<td>98%</td>
<td>Jolly (2000)</td>
</tr>
<tr>
<td>Goddards Green</td>
<td>SBR</td>
<td>368</td>
<td>307</td>
<td>Circa 95%</td>
<td>Jolly (2000)</td>
</tr>
<tr>
<td>Cliff Quay</td>
<td>ASP</td>
<td>Not available</td>
<td>1400</td>
<td>Circa 99%</td>
<td>Bungay (2011)</td>
</tr>
</tbody>
</table>

It should be noted that Goddards Green includes liquors from raw sludge thickening too, hence the low ammonia concentration compared to the other plants. In the majority of cases, these plants were for full nitrification only, with no denitrification phase. A later ASP LTP at Ashford, commissioned in 2008 (Bungay, 2011), has an anoxic zone to allow for denitrification to reduce oxygen requirements, hence energy costs. Although there is alkalinity in the centrate, additional alkalinity needs to be added for the nitrification process to reach completion. Provision of anoxic zones reduces the alkalinity requirements. Choice of chemicals for alkalinity provision was usually sodium hydroxide or sodium bicarbonate, with sodium hydroxide being the more recent preference. The nitrification rate is temperature dependent and an early pilot plant was heated to operate at 15 to 25°C (Jeavons, 1998); while the plant installed at Cliff Quay in 1998 is heated to maintain a temperature of 25°C (Bungay, 2011). This reduces aeration volume but with a penalty on blower sizing and operational costs as oxygen is less soluble at higher temperatures. The majority of these earlier plants tended to operate at ambient temperatures following dewatering of the digested sludge after a period of storage. More recently, to reduce the size of the LTP, the use of membrane technology instead of conventional settlement has allowed LTPs to operate at higher MLSS concentrations and to give better removal but necessitates a chemical cleaning system for the membranes.

History of LTPs – Later Plants

Over time with the intention to reduce energy costs and chemical usage along with reducing the size of the LTP, two other LTPs technologies have emerged. They are based upon:

- Ammonia removal over nitrite.
- Deammonification.

Ammonia removal over nitrite is the conversion of ammonia to nitrite by nitrification then denitrification to nitrogen gas. A carbon source such as methanol is required for denitrification. For optimum process conditions, it requires a temperature of 30-35°C. Advantages of this process are that it gives Total N removal; it also saves 25% of the oxygen requirements (hence energy savings) and 40% of the carbon source requirements compared to the ASP LTPs if they were full nitrifying and denitrifying. However, carbon source requirements tend to be greater.
than stochiometric requirements and oxygen solubility decreases at these higher operational temperatures, hence there are impacts on air needs and blower sizing.

The earliest form of this process is the SHARON (Stable High Ammonia Removal Over Nitrite) which is designed on retention time along with an allowance for the ammonia conversion rate and has no settlement stage. SHARON gives greater than 85% ammonia removal (Thomas, 2007). Another marketed version is the ANITATM Shunt which is an SBR; the pilot plant at Epernay gave 85-90% ammonia removal with operational temperatures of 20-25°C with no temperature control (Lemaire, 2011).

The deammonification process is based upon half the ammonia being oxidised to nitrite and then the remainder of the ammonia reacts with the nitrite to give nitrogen gas. Energy consumption for this process is 60% less than the ASP LTPs with full nitrification and denitrification and has no chemical requirements. The deammonification bacteria are autotrophic, anaerobic and slow growing. Hence the plants are operated at long sludge ages, low dissolved oxygen levels (circa 0.2mg/l) and at a raised temperature of 30-35°C. This process is marketed in several forms. DEMON is an SBR version developed and patented by Innsbruck University; the plant at Pletteberg gave up to 85% ammonia removal (Jardin, 2011). Annamox, with internal settlement tanks was developed by Technical University Delft and is based upon the formation of bacterial granules; the plant at Olburgen typically removes greater than 85% of the ammonia (Reitsma, 2010). The final version is ANITATM Mox, which is a moving bed bioreactor; the Sjolunda plant giving 90% removal (Lemaire, 2011) using various types of support media.

As discussed, both these processes require the same operational temperature range of 30-35°C. The nitrification process is exothermic, typically a 1°C rise is obtained for each 100mg/l ammonia in the centrate. Hence centrates at ambient temperatures, especially those from conventional digestion, may not have adequate heat in them for the process requirements. For these processes, dewatering the digestate at warmer temperatures (minimal storage for cooling) with the exothermic reaction would give the process temperatures.

**LTPs for Treating Thermally Hydrolysed Digested Centrate**

The LTPs discussed above have all treated centrate derived from dewatering conventionally digested sludges with ammonia concentrations in the range of 600 to 1400mg/l but the centrate following thermal hydrolysis is higher and in the range of 1200 to 1900mg/l. This is a function of the higher %DS that the digesters are operated at following thermal hydrolysis. With a limited number of thermal hydrolysis plants in UK and Europe there is less experience of treating this strength of liquor in an LTP. In some cases, the centrate is treated within the existing works, for example Cardiff (Wilson, 2011).

With these higher ammonia concentrations, the temperature rise from the exothermic reaction may exceed the temperature required for the more recent LTPs technologies. Although storage of the digestate and the use of polymer make-up water in dewatering will cool the centrate, additional cooling of the process reactors is likely to be required.
A SHARON plant has been installed at Whitlingham to treat centrate (ammonia load of 1190-1542kg/d) from dewatering (using belt presses) a thermally hydrolysed digested sludge (Tattersall, 2011). A single SHARON plant is operated with glycerol, alkalinity and nutrient dosing. Pilot plant studies showed inhibition uncertainties for the nitritation stage so dilution of the centrate was accommodated into the design. Although this dilution provided some cooling for the process, a heat-exchanger for cooling was installed. Performance data, during its commissioning phase, was 95% ammonia removal.

No deammonification plants are operational on thermally hydrolysed centrate. However a DEMON pilot plant for the Blue Plains Advanced Wastewater Treatment Plant has been reported (Figdore, 2011). This showed inhibition to both the ammonia oxidising and deammonification bacteria. The compounds causing the inhibition were unknown but thought to be associated with the soluble inert COD and this is a function of feed solids characteristics and temperature of the thermal hydrolysis process. This inhibition reduced the ammonia loading for the DEMON plant. Use of dilution water, allowed for the higher ammonia loading rates. Typically in stable operational periods, ammonia in the effluent was below 150mg/l.

No references were found for treating centrate from thermally hydrolysed digested sludges in the older ASP LTPs. This may be a function of innovation. However, a reference plant was found for the treatment of landfill leachate (at ammonia concentrations akin to TH centrate) in an ASP with membranes replacing the final tanks. This plant gave over 98% ammonia removal (Personal Communication, 2011).

**Application to Davyhulme WwTW**

From undertaking this LTP review, there are several noticeable differences between the various processes which affect both the capital and operational costs They are:

- The need for Total N removal or just ammonia removal. There is only an ammonia consent at Davyhulme.
- The size of the reactors due to the different biological processes and settlement requirements.
- The need for chemicals.
- The energy requirements for the blowers due to the level of ammonia oxidation and operational temperature.
- The operational temperature and the need for cooling. This is important for Davyhulme as it is likely that the centrate will be between 25-35°C (from heat balance) as the digestate will be dewatered following very limited storage after digestion.
- Although seemingly solved, inhibition issues for the ammonia removal over nitrite and deammonification processes continue to add a degree of risk to these processes.

Hence this makes the selection of any one LTP process difficult. To further inform United Utilities of the different technologies, site visits were undertaken, to assess such areas as:
- Actual performance.
- Operational and maintenance requirements.
- Number of process tanks.
- Levels of stand-by for equipment.
- Instrumentation and control.
- Operational temperature and cooling.
- Access.
- Layouts.

Many of these are important for Davyhulme as the ammonia design load is considerably greater than those referenced and impacts on the design, layout, operation and maintenance.

The review and the visits of LTPs have been used in outline design work and at a later date, may be used for procuring an LTP for Davyhulme.

**BAFF Performance Trial**

*Introduction*

The BAFF plant at Davyhulme was installed in the mid 1990s and was originally designed to meet a 5mg/l ammonia consent (BOD and SS are as current). It is a Biostyr plant consisting of 36 individual cells with 3.6mm media. Effluent from the BAFF consistently meets the current consent standard.

Over the last eighteen months, extensive trial work has been undertaken to assess:

- If there is any spare capacity in the plant to treat the future ammonia loads and still meet the future ammonia consent of 1mg/l. This future load being the current base load, plus the increase for population growth along with the assumption that the LTP would remove 90% of the ammonia load from the centrate, following the LTP review.
- If the existing 3.6mm media was suitable for this consent. Earlier discussions, with the supplier, indicated that a smaller 3.3mm media may be required which at Davyhulme would have a major Capex implication.

Currently the BAFF plant is undergoing a major refurbishment project to ensure that the plant is in the best operational condition to meet the existing 3mg/l consent when the SBAP centrate liquors are returned. This refurbishment includes checking the air grids, replacing them or some of their components, improving actuator valve performance, topping up the media (lost over time) along with some other minor improvements.

**BAFF Trial**

Ammonium sulphate was dosed to act as a surrogate for the increased ammonia load, in addition to the actual base ammonia load seen on the works. Following an assessment of each individual cell’s performance at the start of the work, good performing cells were chosen to be
dosed. Once the current refurbishment project is completed, it is assumed that all the cells should perform at least as well as those chosen for the trial. Two cells have been dosed at any one time to give comparison.

Throughout the trial, on-line monitoring probes (reading at ten minute intervals) were used for influent and effluent ammonia measurements, along with the dissolved oxygen (DO) for the dosed cells. Existing flowmeters were used to measure the flows and hence calculate the loads. Also monitored during the trial were blower operation, backwash occurrences and known failure of mechanical equipment and instruments. During backwashing the inlet to the cell is closed but the dosing continues which leads to a high inlet ammonia reading, the outlet probe also shows a spike; if included these periods would artificially show performance failures on the dosed cells however there were no ammonia failures for BAFF plant. These were discounted from the results along with the periods of mechanical and instrument problems.

**Results**

During the early trial work it was observed that the ammonia performance appeared to significantly decrease when DO dropped below 8mg/l, particularly for a 1mg/l ammonia discharge. Following this discovery the blowers were operated at a higher air output to ensure that DO was maintained greater than this value. Data which had a DO lower than 8 mg/l was also then discounted from the data analysis. This finding also impacts on the future power costs for the BAFF with a greater running cost needed to maintain this higher than normal DO (typically the plant was run at 5 to 6mg/l DO).

![Performance of the BAFF Cell 29 with Unlimited DO](image)

**Figure 2: Performance of the BAFF Cell 29 with Unlimited DO**
Figure 2 gives DO, ammonia load and effluent from one of the dosed cells during August and September 2011. The notes on the graph show periods when data was discounted due to known problems such as: inlet ammonia probe failure, plant operational problems and inadequate blower operation during storm events; these were not unusual events during the trial. It shows that the DO was maintained at above 8mg/l for the majority of the time with the ammonia loads generally above 5000kg/d and peaking above 15000kg/d during the storm events in September 2011. It can be seen, once the operational issues are discounted that the final effluent reliably met the future 1mg/l ammonia standard. It also shows the importance of mechanical and electrical reliability for maintaining the discharge consent.

The impact on the performance of the dosed cell was seen during storm events. During a ‘first foul flush’ the pollutants have built up in the sewerage system over a dry weather period which are then ‘flushed’ through the works with the storm giving a high load and loading onto the dosed cell. This increased pollutant load causes a drop in DO, as the blowers were unable to respond rapidly to the load increase, consequently there was corresponding rise in effluent ammonia concentration. On occasions there was another storm on the following day indicating a ‘second flush’. Whilst there is a similar rise in flow, the associated pollutant load is not present and so the DO remains high and the effluent below consent. During the first flush, the effluent was then above the 1mg/l ammonia level for the dosed cell with the total BAFF effluent maintaining final effluent compliance.

Over the 300 days of the different phases of the trial, the temperature in the BAFF cells was in the range of 10 to 17.6°C, with a period falling to 7.6°C for a few days. Over this same period, the average ammonia performance was 0.48mg/l with a 95%ile of 0.74mg/l. It also showed that the BAFF plant had spare capacity for a further 1000kg/d ammonia load (as average) and still meets the future ammonia consent. It has also shown that the current 3.6mm media is suitable for this application.

**Future Impacts**

The additional 1000kg/d ammonia capacity within the BAFF plant is of key importance to treat the SBAP liquors and the increase in population. The LTP review indicated that most LTPs are capable of removing of about 90% of the ammonia load in the SBAP liquors, leaving about 447kg/d to return to the works for treatment, giving an excess load of 553kg/d ammonia load for population growth. Dependent on the assumptions in the population and airport passenger growth, there is capacity within the Davyhulme BAFF until after 2016 to meet the future consent.

Further trial work is continuing to validate the earlier trials and to assess if the plant could take an even higher ammonia load. However to ensure that the Davyhulme BAFF plant is reliably capable of meeting this new ammonia consent standard, then:

- The DO must be greater than 8mg/l with associated impact on power costs.
- Instrumentation for controlling the BAFF must be calibrated on a regular basis.
- Operator error needs to be eliminated and further training required.
• Upstream processes, especially the final tanks should be operated to ensure low SS and associated low BOD is pumped to the BAFF so as not to compromise the nitrification process.

Closing Remarks

1. The LTPs in the market place are capable of removing over 90% of the centrate ammonia load but with very different requirements for: chemical usage, power needs, associated instrumentation, operational temperatures and footprint plus operational and maintenance requirements.
2. There are fewer LTP reference sites for treating centrate from thermally hydrolysed digested sludge and there are concerns of inhibition which appear to be solved with the use of dilution water.
3. The Davyhulme BAFF plant is capable of treating an additional 1000kg/d average ammonia load which accommodates a LTP effluent and some of the predicted ammonia load for population and airport passenger growth but with implications on power, operational and maintenance costs.

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References


