Recuperative thickening (RT) is the process of decoupling the solids retention time (SRT) from the hydraulic retention time (HRT) by removing and thickening solids from anaerobic digesters, and returning the thickened solids back to the anaerobic digester.

RT was implemented at Bondi WWTP to reduce biosolids odours. Detailed assessment of performance and operation of RT technology was carried out to identify factors that determine performance, opportunities for improvement and knowledge gaps that need experimental research.

Implementation of RT at Bondi WWTP increased digester SRT from 15 days to 40 days, reducing biosolids production by 22%, increasing biogas production by 20% and reducing hydrogen sulphide generation from biosolids by 80%.

Five key knowledge gaps ("5-S" hypotheses) that need research to improve RT performance are as follows:

- Difference in performance achieved by RT compared to equal SRT that can be achieved in conventional digestion and how to optimise SRT
- Quantification of RT on minimising short circuiting
- Effect of shear imparted by the thickening technology
- Effect of polymer addition and sequestration of biomolecules and colloidal material on digestion performance
- Selection of methanogens due to thickening

Addressing the knowledge gaps through a laboratory and full scale research program was recommended.

INTRODUCTION

Sydney Water provides water and wastewater services for Sydney, Blue Mountains and the Illawarra, including operation of 28 WWTPs. Generation of biosolids is an integral part of the wastewater treatment cycle; however, it creates an additional responsibility of disposal on water utilities. Biosolids management can contribute to approximately 60% of wastewater treatment annual operating costs (Bharambe et al., 2014).

Beneficial reuse of biosolids by applying it to agricultural land is the most common and cost effective method of biosolids management practices in Australia. However, nuisance odour sometimes generated from some biosolids during transport and land application has resulted in continuous review of this practice by Sydney Water.

Reduction in biosolids production and minimising odour potential were two primary drivers identified during development of the Sydney Water Biosolids Management Strategy (Shea et al., 2012). Various treatment technologies have emerged over the past decade to help minimise biosolids production and odour potential.

This paper assesses RT that Sydney Water has implemented as part of the primary sludge anaerobic digestion process at Bondi WWTP to increase digester SRT and defer capital expenditure associated with constructing additional anaerobic digester capacity. Optimising existing facilities by implementing RT was considered as a cost effective way to defer major capital expenditure. The first RT process in Australia was implemented by Sydney Water at Bondi WWTP in 2008.

The process of RT results in a longer SRT without the need to excessively pre-thicken the digester feed. It is particularly suited to primary sludge, which has a relatively high degradability, but is also relatively slow to degrade (Batstone et al., 2012).

RT can be configured as a separate operation in which a side stream is taken from a primary or secondary digester and the concentrated solids are returned back to the digester, or as a co-thickening operation with a feed sludge stream thickened prior to digestion.

Bondi WWTP is one of the three largest WWTPs in Sydney, treating an average of 120 million litres per
day (MLD) and serving a population of approximately half a million people. Bondi WWTP is a high-rate primary treatment plant and the treated effluent is pumped deep in the ocean (~ 65 m), about two kilometres from the shoreline. A full process flow diagram for the plant is shown in Figure 1.

![Figure 1: Bondi WWTP process flow diagram](image1.png)

There are two primary digesters (Digesters 1 and 3 which operate in parallel) each with floating roofs and two secondary digesters (Digesters 4 and 2 which operate in series) each with fixed roofs. Both primary and secondary digesters use a gas mixing system and the primary digesters are operated at a nominal temperature of 37 °C. The secondary digesters are not heated and operate at a temperature of about 35 °C. Digester 2 also serves a Feed Averaging Tank prior to dewatering. HRT in Digester 4 is managed by supernating from the secondary digester to the head of the plant (Tang, 2010).

Average primary sludge solids concentration to the primary digesters is approximately 3.8% ±0.9%. The RT plant is between Digesters 2 and 4. Approximately 50% of the daily primary solids load from Digester 4 is thickened using two rotary drum thickeners to an average solids concentration of 8% w/w prior to feeding back to the inlet of the primary digesters. Sludge thickening is assisted by adding 9 kg polymer /dry tonne solids. The polymer used for RT is the same as that used for centrifuge dewatering a cationic - medium / high charge density polymer. A diagram outlining the recuperative thickening process is provided in Figure 2.

![Figure 2: Bondi recuperative thickening Simplified Process Flow Diagram](image2.png)

Since 2008, two more RT processes have been implemented (Warriewood and North Head WWTPs) while a third is being implemented at Malabar WWTP. However a more detailed performance and operational assessment of RT technology needs to be carried out to identify opportunities for improvement and also identify factors that determine its performance. This paper will reduce this information gap by assessing existing information and insights based on a critical evaluation of the RT process as applied at Sydney Water’s Bondi WWTP.

**METHODOLOGY**

A review on the state of the industry in terms of application of RT for biosolids reduction and quality improvement was performed. A critical assessment of RT process was conducted by comparing the results of this review with the operating procedures and process performance results at the Bondi WWTP.

Three years of operational data from Bondi WWTP was collected and statistically evaluated in conjunction with the chronology of key plant events that could have had a potential impact on RT operation and performance. This data analysis was further used to identify knowledge gaps on key process parameters influencing optimal RT performance.

From the assessment, five possible effects of RT were postulated (“5-S” hypotheses): increasing SRT; reducing Short circuiting; Shear; Sequestration of both colloidal and partially soluble biomolecules on the sludge; and Selection of methanogens were developed to identify and quantify knowledge gaps that affect the performance of RT.

Recommendations for a laboratory and full scale research program, to generate additional
knowledge for incorporating into Sydney Water’s Biosolids Knowledge Management System (BKMS) tool, were also developed, along with short and long-term recommendations for further enhancing digestion performance at Sydney Water’s RT digestion facilities.

RESULTS AND DISCUSSION

Assessment of historical data showed inconsistent RT operation probably due to the high raw sludge flow variability. The raw sludge volatile solids (VS) load also varied significantly throughout the year. This suggested a seasonal variation to the volume of thickened primary sludge.

The thickened primary sludge flow and corresponding volatile solids loading rate (VSLR) variation resulted in process instability in the digester. An average HRT in the primary digester is approximately 11.5 days with standard deviation of 4.7. This suggests that during high flow periods the nominal HRT in the primary digesters was about 40% of the HRT of primary digesters during low flow periods (refer Figure 3 and Figure 4). Such high variability in the primary sludge flow may be a result of limited primary sludge storage volume within the primary settling tanks.

Due to the relatively low nominal HRT, the digester solids concentration, and thus the SRT of the primary digesters is very responsive to the RT operation. The solids concentration in the digestion system has been ranging from 1.9% to 3.8% during the three years of analysed operational data. This is considered to be the result of several factors including intermittent and inconsistent RT operation with variable thickened sludge concentrations (ranging from 3.5 to 12% w/w) and the inherent inconsistency in secondary digester supernatant due to its lower controllability compared to a mechanical thickening process.

Average SRT of the system without RT was approximately 15 days with corresponding average volatile solids reduction (VSR) of 60%. During the three years of analysed operational data of the plant with RT, failure of ancillary equipment resulted in intermittent operation of RT causing digester SRT to vary between 20 to 70 days. Hence, during the three years VSR was variable, ranging from 55% to 90% with an average VSR in the order of 70%. The maximum total VSR occurred when the total SRT was between 40-50 days (Figure 5). Figure 5 also shows the dependency of the VSR on parameters in addition to the SRT, such as digester temperature and mixing. This is shown by the incidence of both high and low VSR values occurring at these SRT ranges. It is therefore desirable to optimise all of these factors if the optimal VSR is to be realised consistently.

![Figure 3 Primary digesters daily HRT based on feed raw sludge volume](image)

![Figure 4 Primary sludge Nominal VSLR for Primary Digesters](image)

![Figure 5 Total VSR vs. Total Nominal SRT (including recuperative thickening)](image)

It was also observed that the maximum VSR occurred when the primary digester operating total solids (TS) concentrations were below 2.5% w/w. As stated earlier, a gas mixing system has been used to mix content in the digester. Typically gas mixing systems have difficulty maintaining a completely mixed digester for solids concentrations above 2.5 to 3% w/w due to an increase in viscosity of digester content. This trend was also observed in Figure 6 and Figure 7, where the VSR drops as the digester contents exceeds a TS concentration of 3% solids on a weight basis. Recently conducted tracer test at the primary digesters also confirm the
homogeneity of the digester contents at the digester operating total solids concentration of 2.5-3% w/w with an average RT thickened sludge solids concentration of 8% w/w.

The key parameter for dewatered cake disposal cost savings is the number of wet tonnes of biosolids produced. The assessment indicated approximately 22% reduction in wet biosolids production due to RT operation, subsequently resulted in overall reduction in biosolids management cost.

Volatile organic sulphur compounds occur as a result of protein degradation. More bioavailable

Recuperative thickening began

The digested sludge at Bondi WWTP is dewatered with centrifuges and transported with shaftless screw conveyors to dewatered cake storage bins before being transported to land application sites for beneficial reuse. Prior to RT implementation, the cake in the storage bins generated odours that could result in customer complaints during transport and/or application.

Volatile organic sulphur compounds occur as a result of protein degradation. More bioavailable
protein leads to more volatile organic sulphur compound generation. Longer digester SRTs result in extended degradation of protein resulting in lower Total Volatile Organic Sulphur Compounds (TVOSC) emission from dewatered biosolids cake (WERF, 2008). As discussed earlier, operation of RT resulted in an increase in VSR. An impact of increased VSR, due to longer SRT, was compared against the odour generation potential of dewatered cake. Foul air collected from the dewatered cake storage hopper is treated by scrubber 1. Hence, scrubber 1 outlet H2S concentration was used as a surrogate of odour generation potential of dewatered cake. As shown in Figure 10, well stabilised cake (VSR above 85%) emits very low H2S concentrations during cake storage compared to less stabilised biosolids.

Comparison of the concentration of odorous compounds in both pre RT and post RT biosolids (after 48 h storage) shows almost complete removal of H2S (>99%). The concentration of other odorous compounds decreased (Table 1). This is attributed to lower biological activity in the storage bins due to lower bioavailable proteins. Increase in VSR also resulted in significant reduction in other odorous compounds. It is worth mentioning that the odour stayed low even after 72 hours of storage. It must be stressed that odour causing compounds are still present in the biosolids.

The critical review of the RT facility at Bondi WWTP resulted in identifying five key knowledge gaps with respect to the effect of the crucial parameters on RT performance. These knowledge gaps are referred as the “5-S” hypotheses identified as follows:

1. **Solids Retention Time increase**: RT enhances the overall anaerobic digestion performance by increasing the SRT. Thus, RT can reduce the odour associated with digested biosolids by increasing their biological stabilization.

2. **Short circuit reduction**: RT enhances the overall anaerobic digestion performance by reducing short circuiting. Similarly, the prevention of short circuiting can also reduce the odour associated with digested biosolids.

3. **Shear**: shearing of the sludge during thickening could have both positive and negative effects on digestion. Release of biodegradable materials during shearing could enhance the anaerobic digestion progress. On the other hand, shearing may adversely affect the biomass methanogenic activity during storage, transport, and off-site land uses.

4. **Sequestration of biomolecules**: Polymeric flocculants are usually added during RT to maximise solids capture in the thickening process. These polymers capture soluble biomolecules (e.g. proteins and carbohydrate) and colloidal biodegradable particles from solution and “attach” them to the solids. This could increase their digestibility and contribute to reducing odour generation potential.

5. **Selection of methanogens**: Because of the shear conditions imparted during the thickening process, there can be a gradual shift in the microbial population in the digester from rod shape methanogens to rounded (coccoid) methanogens that would be more resistant to shear. This may contribute to increased process performance.

Closing these knowledge gaps will lead to more reliable prediction of process performance.

The knowledge gaps are being addressed within a university research undertaken by University of Wollongong and full scale monitoring program by Sydney Water. The university research will focus on the “5-S” knowledge gaps by using side by side laboratory scale controlled digestion experiments using the same feed raw sludge to compare with a
baseline. Side by side controlled digestion is not possible at full scale. However, the full scale validation of the research outcomes would provide added value to the university. The BKMS has been developed to capture RT process performance from different RT process configurations at various Sydney Water locations. The process performance results captured within the database can be compared with the Bondi WWTP full scale performance experience, and university research results. Full scale monitoring and test plans have been developed for Warriewood WWTP where RT on mixed waste activated sludge and raw (primary) sludge has also been implemented.

**CONCLUSION**

The study indicated that, RT at Bondi WWTP has provided significant benefits, including increased SRT from 15 days to 40 days, decreased biosolids wet mass by approximately 22% leading to lower outloading costs, and increased gas production by approximately 20%. Hydrogen sulphide generation is also reduced by approximately 80% after implementation of the RT process. Near elimination of odour issues has improved beneficial reuse options. However, based on detailed analysis of process performance and comparing it to earlier studies, there are some opportunities to further improve the performance of the RT digestion process at Bondi WWTP. These include: operating RT to target the optimal nominal SRT (40-50 days); reducing raw sludge daily variability, and improving digester mixing to allow better performance at higher solids concentrations.

Five key knowledge gaps with respect to RT performance were identified. The recommended path forward for closing the key knowledge gaps is via a developed laboratory research protocol and a full scale monitoring plan. The outcomes of this research and monitoring will lead to better prediction of RT process performance at other Sydney Water facilities.

**REFERENCES**


