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Optimal biological nutrient removal from abattoir wastewater
Summary of key findings

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Background

A technology was previously developed for biological removal of chemical oxygen demand (COD), nitrogen and phosphorus from abattoir wastewater. The research was undertaken by the Advanced Water Management Centre, The University of Queensland through a research project funded by the Environmental Biotechnology Cooperative Research Centre (EBCRC) (EBCRC Project 1.5), with direct support and participation by Meat & Livestock Australia (MLA). The technology was based on innovative design and operation of a sequencing batch reactor (SBR). The technology was successfully demonstrated in a 7L laboratory-scale SBR with >95% removal of COD, nitrogen and phosphorus from abattoir wastewater containing approximately 250 mgN/L and 40 mgP/L.

The key innovations of the technology included:

1. Multi-stage feeding – Each 6h SBR cycle contained three anoxic/anaerobic and aerobic sub-cycles with wastewater fed at the beginning of each anoxic/anaerobic period. The step-feed strategy was applied to avoid high-level build-up of nitrate or nitrite during nitrification, and therefore to facilitate the creation of anaerobic conditions required for biological phosphorus removal.
2. Prefermenter – a fermenter was included to ferment raw abattoir wastewater to deliver suitable carbon sources required for nitrogen and phosphorus removal. When added to the anaerobically pretreated abattoir wastewater (through the use of anaerobic ponds), the effluent of the prefermenter significantly altered the composition of the wastewater so that high-level biological nitrogen and phosphorus removal becomes possible.
3. Nitrogen removal through nitritation and denitritation (that is via the nitrite pathway) rather than via the conventional nitrate pathway. This saves aeration costs for nitrogen removal by 25% and also reduces the carbon demand for denitrification by 40%.

1 Project objectives

The objectives of the project were:

1. demonstrate the SBR technology with a pilot plant operated under field conditions to achieve over 90% COD, nitrogen and phosphorus removal from abattoir wastewater;
2. achieve the above performance under typical load variations experienced by abattoir wastewater treatment plants through the use of on-line process control;
3. During the trials, obtain data which allows rigorous and scientific evaluation of the effectiveness of the pilot scale process. At a minimum, the trials must determine and record COD, TN and TP removal efficiency, volumetric and biomass-specific rates of biological P removal and stoichiometric requirements for nutrient removal under the selected operating conditions.
4. Investigate the interactions of nitrogen removal and biological phosphorus removal to ensure good, stable nutrient removal performance;
5. Recommend strategies for upgrading existing SBRs for Bio-P removal; identify capital costs associated with biological phosphorus removal over and above those associated with the supply of a typical SBR for nitrogen removal; identify any technical issues that might hinder application of the technology to meat processing wastewater and provide recommendations for further work, if required.

2 Methodology

A pilot plant consisting of two SBRs, called SBR1 and SBR2, respectively, was set up at the Teys Bros. abattoir site near Beenleigh. The reactors were fed with wastewater under real operating conditions, notably actual variable wastewater composition and loads, as well as seasonal ambient temperature variation.

Both SBRs received the effluent from the on-site anaerobic pond as the primary source of wastewater, which contained >200 mgN/L, >35 mgP/L, and low levels of soluble COD with almost a negligible amount of volatile fatty acids (VFAs).

The low COD:N:P ratios of the pond effluent would not allow satisfactory N and P removal. A pilot-scale prefermenter was set up on site to ferment the "red" stream to produce VFAs that are required for nutrient removal, particularly for phosphorus removal. The prefermenter was operated at a hydraulic retention time of 1.5 days for most of the time. A mixture of the pond effluent and the effluent from the prefermenter was used as the feed for both SBRs. The ratio of the mixture varied between 20% to 30% in different periods of the plant operation.

Both SBRs were operated with a solids retention time (SRT) of 10-15 days, and a hydraulic retention time (HRT) of 42 hours. Each 6 hr SBR cycle consisted of three non-aerated/aerated sub-cycles, followed by a settling and a decanting period. Wastewater was added at the beginning of the three non-aerated periods with distribution ratios of 50%:30%:20%. Wastewater was fed to the bottom of both SBRs. The dissolved oxygen concentration during the aerobic periods was controlled at 1-2 mg/L.

The only difference in operation between SBR1 and SBR2 was that mixing was not provided to SBR1 during the first feeding period, resulting in the use of the patented UniFed technology. Mixing was provided during other feeding periods for SBR1, and all feeding periods for SBR2.

The long-term performance of both SBRs was monitored through regular measurement of the COD, N, P and suspended solids concentrations in the effluent form both SBRs. The mixed liquor suspended solids (MLSS) and mixed liquor volatile suspended solids (MLVSS) concentrations in both systems were also measured routinely. Cycle studies were carried out regularly on both systems to reveal full details of, and to gain scientific insight into the COD, N and P transformations in the reactor over a cycle.

3 Key findings

Both systems were demonstrated to successfully achieve >90% nitrogen removal, >90% phosphorus removal and >85% COD removal.

- Virtually complete removal of soluble inorganic nitrogen (ammonia plus oxidised nitrogen) was achieved in all three main experimental periods on a 50%ile basis. In two of the experimental periods the soluble inorganic N was approximately 1 mgN/L or less on an 80^{th} percentile basis. A remarkable feature of the SBR effluent was the very low effluent oxidised nitrogen (NOx, or nitrate + nitrite). In comparison, the SBR effluent contained approximately 9 to 17 mgN/L as organic nitrogen (50^{th} percentile basis). This organic N was partly associated with the relatively high suspended solids in effluent caused by the crude decanting system used for the pilot plant. Effluent suspended solids were in the range ~30 to 80 mg/L. This fraction of nitrogen is expected to decrease for full-scale systems where a more proper decanting system can be used.
- The residual phosphorus in effluent consisted of both orthophosphate and organic phosphorus. The organic fraction is expected to decrease during full-scale application as discussed above. Phosphorus removal was less stable than nitrogen removal. P removal was found to be sensitive to the VFA concentrations in the feed and therefore a sufficiently high fraction of prefermenter effluent is crucial for P removal. P removal was also found to be sensitive to nitrate/nitrite accumulation during aerobic periods. The carry-over of nitrate/nitrite to the non-aerated periods inhibits anaerobic P release, while free nitrous acid (FNA) inhibits P uptake. Therefore, good N removal is a pre-requisite for good P removal. P release during the settle and decant phases of the SBR cycle caused "leakage" of phosphorus into the effluent, which should be minimised. This could be achieved by shortening the settling time, which was enabled by the excellent settleability of the sludge (see below).
- Effluent CODs were a little high (100 to 150 mg/L soluble, and 200 to 250 mg/L total). The COD removal efficiency was consistently above 85%, but was below the targeted level of 90% for certain various periods. This aspect may need attention for future designs and may reflect a degree of under-aeration (i.e. marginally short hydraulic retention time of 42 h and high organic reactor loading rates of ca. 0.6 to 1.6 kg COD/m^3.d). With improved capture of effluent suspended solids (e.g. by improved decanting or effluent filtration), >90% total COD removal should be consistently achievable with SBRs treating abattoir wastewaters as described in this study. The effluent data suggests further that the abattoir effluent contains approximately 120 to 150 mg/L non-biodegradable soluble COD (on a 50%ile basis). However, considering the high COD strength of the raw abattoir wastewaters, the HRT of the pilot plant reactors (42 hours) was relatively short. It is likely that even better soluble COD biodegradation would have been achieved at longer HRTs (or lower volumetric loading rates).

Simultaneous nitrification and denitrification (SND) played an important role in nitrogen removal. This process was achieved through the application of a relatively low DO concentration (1-2mg/L). SND significantly reduced the demand for carbon sources for N removal, which was believed to have facilitated the achievement of good N and P removal with a relatively low COD:N:P ratios. Avoiding an excessively high-level of DO concentration (e.g. >2mg/L) is essential for the operation of the system.

The UniFed system (SBR1) did not appear to confer a discernible advantage in terms of enhanced bio-P removal performance over the non-UniFed system, suggesting the use of UniFed concept is not essential for biological nutrient removal from abattoir wastewater.

The performance of the prefermenter was relatively stable. At a hydraulic retention time around 1.5 days, volatile fatty acids of approximately 1000 mg/L (on a COD basis) from the “red” abattoir wastewater stream were produced. Most of the VFA produced is in the form of acetic and propionic acids, which are ideal substrates for biological nutrient removal, which is the objective of this study using abattoir wastewater. The feed composition was made up of approximately 20 to 30% (average 24%) pre-fermented “red stream” flow (fed from a pilot-scale prefermenter), with the balance made up of primary anaerobic pond overflow from the full-scale plant. Despite intermittent mixing, the prefermenter did accumulate significant amounts of fat and grease in a scum layer. This might have been partly due to the lack of operation of the DAF plant pre-treating the raw “red” stream at this particular site. Nevertheless, any full scale prefermenter design and operation would need to make provision for a robust scum removal system. Odour and internal corrosion control for the prefermenter would also require special design and operation attention.

Aside from nutrient removal, operation of the SBRs processes was largely stable, apart from occasional issues arising mainly from mechanical or electrical equipment or external factors (e.g. reliability of feed supply). Sludges in both SBRs possessed excellent settleability. Dilute sludge volume index (DSVI) were below 100 mL/g and often <60 mL/g during steady state operation of the reactors. The mixed liquor suspended solids averaged around 5000- 6000 mg/L, which was near the limit of acceptable high range for SBRs. The reactor performance was robust against temperature variations. The mixed liquor temperature dropped from ~32 to 36°C in summer to a minimum of around 18 to 20°C in winter. Consistent reactor performance was achieved despite of the temperature variation.

Effluent suspended solids were in the range ~30 to 80 mg/L, which is good given the crude nature of the decanting system in the pilot plant reactors.

Capital and operating costs associated with achieving enhanced biological P removal when treating abattoir wastewaters with SBRs were considered. The approach was to estimate the incremental capital cost for a system capable of EBPR (nominally capable of achieving >90% P removal) compared to a non-EBPR-type plant that would typically be capable of good COD and N removal but only limited P removal through normal heterotrophic growth processes. Cost considerations suggested that the incremental capital cost would be around $2.74 million (including engineering and contingencies) for EBPR when treating indicatively 3 ML/d abattoir wastewater via SBRs with a prefermenter, compared to a similar non-EBPR case. Potential net savings in operating costs may be in the order of $210,000 per annum for an EBPR plant of this type compared to the non-EBPR plant with chemical P removal. Savings in operating costs of this order would potentially allow a buy-back of around three-quarters of the amortised total incremental capital cost for the EBPR option over a 20 year period, at an interest rate of 8% per annum.