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An Ghníomhaireacht um Chaomhnú Comhshaoil

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Enhanced Nitrogen Removal for Slaughterhouse Wastewater Using Novel Technologies

STRIVE

Environmental Protection Agency Programme

2007-2013

SSTI Strategy for Science, Technology and Innovation

Comhshaol, Oidhreacht agus Rialtas Áitiúil
Environment, Heritage and Local Government

Environmental Protection Agency

The Environmental Protection Agency (EPA) is a statutory body responsible for protecting the environment in Ireland. We regulate and police activities that might otherwise cause pollution. We ensure there is solid information on environmental trends so that necessary actions are taken. Our priorities are protecting the Irish environment and ensuring that development is sustainable.

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EPA STRIVE Programme 2007–2013

Enhanced Nitrogen Removal for Slaughterhouse Wastewater Using Novel Technologies

(2005-ET-MS-31-M3)

STRIVE Report

End of Project Report available for download on http://erc.epa.ie/safer/reports

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The EPA STRIVE Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

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Executive Summary

Efficient nitrogen (N) removal from slaughterhouse wastewater is a challenge for conventional activated sludge treatment processes. This project aimed to develop intermittently aerated sequencing batch reactor (IASBR) technology that could efficiently remove nitrogen from slaughterhouse wastewater. The IASBRs were operated at a laboratory-scale in the Environmental Engineering Laboratory at the National University of Ireland, Galway (NUI Galway) prior to the deployment of a pilot-scale unit at a local slaughterhouse in Co. Mayo. Modified IASBRs containing plastic media were operated at laboratory-scale only.

The laboratory-scale units had working volumes of 10 l and were intermittently fed with slaughterhouse wastewater. The operational sequence of the IASBRs and the movement of all mechanical devices, including peristaltic pumps, stirrers and air pumps, were controlled by programmable logic controllers (PLCs). Dissolved oxygen (DO), pH and oxidation-reduction potential in the reactors were monitored in real time using electrodes, and were catalogued by a LabVIEW computer programme. The configuration of the modified laboratory-scale IASBR was the same as that of the original IASBR, but a bulk volume of 4.0 l of plastic biofilm carriers was added to the reactor. The biofilm carrier elements had a nominal diameter and length of 9.1 mm and 7.2 mm, respectively, and a specific weight of approximately 0.95 kg/l. The effective specific surface area of the biofilm carriers available for biofilm growth was 500 m^2/m^3. The reactors were operated on an 8-h cycle, which comprised four phases:

1. Fill;
2. React;
3. Settle; and
4. Draw/Idle.

Over a 132-day study duration, at an average organic loading rate (OLR) of 1.2 g COD/l/day, the laboratory-scale IASBR achieved chemical oxygen demand (COD), total nitrogen (TN) and total phosphorus (TP) removals of 96%, 96% and 99%, respectively. Two operational strategies – intermittent aeration (IA) and continuous aeration (CA) – were used to treat the slaughterhouse wastewater at low DO levels. Under both regimes, respective TN removals of 94% and 91% were achieved. However, under IA, by maintaining low DO levels, electricity consumption associated with air supply can be reduced by up to 65%. Over a 120-day study duration, the modified laboratory-scale IASBR had an OLR of 1.18 ± 0.04 kg COD/m^3/day and a nitrogen loading rate (NLR) of 0.11 ± 0.01 kg N/m^3/day, and achieved COD, TN and TP removals in excess of 94%, 92% and 95%, respectively. As the performance of both systems was similar, and considering the cost of the biofilm media, the IASBR was deployed on-site.

The pilot-scale IASBR was constructed at the Environmental Engineering Laboratory, NUI Galway, and deployed on-site at the slaughterhouse wastewater treatment plant for Western Proteins in Ballyhaunis, Co. Mayo. It was monitored for 402 days. The pilot-scale IASBR influent was taken from the balance tank in the slaughterhouse wastewater treatment plant that collects and treats wastewater generated in the slaughterhouse and the rendering plant. Both the waste sludge and effluent were discharged into a 150-l holding tank, from which a submersible pump pumped the tank holdings into the Western Proteins aeration tank, allowing the pilot-scale system to act as a loop on the Western Proteins wastewater treatment plant.

The pilot-scale IASBR was operated under different aeration strategies (IA and CA), hydraulic retention times, sludge retention times, and OLRs. At a loading rate of around 0.5 kg COD/m^3/day, efficient removals of pollutants (COD – 97%, suspended solids (SS) – 98%, TN – 98%, and ortho-phosphorus (PO_4-P) – 99%) were achieved under the IA strategy, with production of an effluent (COD – 117 mg/l, SS – 26 mg/l, TN – 8 mg/l, and PO_4-P – 0.2 mg/l) that met the discharge standards.

The study on nitrous oxide (N_2O) emission from IASBRs treating ammonium-rich wastewater showed that the influent readily biodegradable COD (rbCOD) concentration was considered to be a key factor to stimulate N_2O emission to a high level in the oxygen-limited partial nitrification reactor via heterotrophic denitrification. Reduction of the influent rbCOD concentration, reduction of anoxic periods in operational cycles, and an increase in pH in the reactor would be the main options to avoid high N_2O emission.

This research project has developed a best available technology that has potentially huge implications for industries treating high-strength wastewater.

1 Introduction

1.1 Objectives

The main objective of the research project was to develop a best available environmental technology that could efficiently remove nitrogen (N) from slaughterhouse wastewater so as to achieve the objectives of the Water Framework Directive (WFD) (2000/60/EC), the European Council Nitrate Directive (91/676/EEC), the Integrated Pollution Prevention Control (IPPC) Directive (2008/1/EC), the EU guidance on Best Available Techniques in the Slaughterhouses and Animal By-Products Industries (EC, 2005a,b), and the Irish BAT Guidance Note on Best Available Techniques for the Slaughtering Sector (EPA, 2008a).

The project also aimed to achieve the following objectives:

- Efficient N removal from slaughterhouse wastewater by means of simultaneous nitrification and denitrification (SND) in laboratory- and pilot-scale intermittently aerated sequencing batch reactor systems (IASBRs)/intermittently aerated sequencing batch biofilm reactors (IASBBRs);
- Development of automatic control techniques that can be used to control the operation of IASBRs;
- Nitrogen removal kinetics;
- Development of a best available environmental technology; and
- Development of increased research capacity in environmental science and engineering at the National University of Ireland, Galway (NUI Galway).

1.2 Slaughterhouse Wastewater

In 2005, the meat industry in Ireland had a turnover of €3,713 million and employed 14,084 people (CSO, 2005). The value of exports of meat and meat preparations has increased from €299.5 million in 2000 to €607.6 million in 2006 (CSO, 2007). Slaughtering facilities that process more than 50 t/day are licensed by the EPA, while those that process less than 50 t/day are licensed by the Department of Agriculture, Fisheries and Food (DAFF). All rendering facilities in Ireland are licensed by the EPA. In 2008, the EPA had 46 active licences for slaughterhouses (EPA, 2008b), while, in 2005, DAFF had 217 active licences for slaughtering facilities (DAFF, 2005). In 2008, the EPA had 12 active licences for rendering plants, three of which include a slaughterhouse (EPA, 2008b).

Slaughterhouses produce high-strength wastewater (EC, 2005a,b; EPA, 2006). The amount of wastewater generated per cow is approximately 2 m^3/day and mainly originates in the rendering department and holding yards of slaughterhouses (Johns et al., 1995). In pig slaughterhouses, 1.6–8.3 m^3 of water per tonne of carcass are generated (EC, 2005a,b). Depending on whether preliminary treatment is carried out and its efficiency, the concentrations of contaminants in slaughterhouse wastewater can be variable, with:

- Suspended solids (SS) of 250–5,000 mg/l;
- Chemical oxygen demand (COD) of 1,000–20,000 mg/l;
- Total nitrogen (TN) of 150–10,000 mg/l; and
- Total phosphorus (TP) of 22–217 mg/l.

For large-scale slaughterhouses, on-site biological treatment is recommended by the European Commission to remove organic carbon (C) and nutrients before the wastewater is discharged to surface waters, or local wastewater treatment plants (EC, 2005a,b). If the treated effluent is discharged to a water environment, it must satisfy emission standards. The European Commission considers that the use of sequencing batch reactors (SBRs) is amongst the best available techniques (BATs) for slaughterhouse wastewater treatment, as SBRs are capable of removing organic C, nutrients and SS from wastewater, and have low capital and operational costs. Typical COD, TN and TP removals from slaughterhouse wastewater achieved in SBRs are 95%, 60–80%, and 40%, respectively (EC, 2005a,b). SBRs are not able to remove N from slaughterhouse wastewater as efficiently as COD because slaughterhouse wastewater contains very high TN, with a typical 5-day biochemical oxygen demand (BOD_5) to TN ratio of 7–9:1.

Typically, biological N removal in SBRs is through pre-denitrification, which occurs during the fill phase (or an anoxic phase between the fill and the aerobic react phases). Anoxic heterotrophic denitrifiers reduce nitrate-N (NO_3-N)/nitrite-N (NO_2-N), which is produced in the preceding operational cycle and remains in the reactor after the draw phase, to nitrogen gas (N_2). Denitrifiers consume the readily biodegradable COD (rbCOD). If simultaneous phosphorus (P) and N removal is expected to be achieved in the reactor, P-accumulating organisms (PAOs) will compete with denitrifiers for rbCOD for anaerobic P release. This competition between PAOs and denitrifiers will result in unstable biological P removal if the influent wastewater does not contain sufficient rbCOD. Therefore, chemical precipitation is applied to guarantee a low level of P in the effluent.

Slaughterhouse wastewaters are characterised by high fats, grease and proteins. Fats are of particular concern because, if the pH is high, there may be saponification, by which the reaction of fats with metallic bases leads to soap-like substances that are harder to break down. Proteins are less readily biodegradable than simple organics, so wastewater treatment systems should incorporate longer hydraulic retention times (HRTs) to account for this. A long HRT is also needed to allow hydrolytic enzymes to break down the fats.

Although the presence of N and P in slaughterhouse wastewater is said to inhibit the growth of filamentous bacteria that cause activated sludge bulking (EC, 2005a,b), there is evidence of sludge bulking in activated sludge systems treating slaughterhouse wastewater. Travers and Lovett (1984) found that at DO levels below 0.5 mg/l in a completely mixed activated sludge system, there was a high sludge volume index (SVI) (>250 ml/g) and large numbers of filamentous bacteria, *Microthrix parvicella*. Other filamentous bacteria found in slaughterhouse wastewater treatment systems include *Thiothrix* spp. and Type 021N, which were detected in an aerobic–anoxic SBR treating wastewater from a pig slaughterhouse (Jonsson, 2005).

Foaming is a common occurrence in biological treatment of slaughterhouse wastewater (Sroka et al., 2004). Normally, foaming is caused by bacteria such as *Microthrix parvicella* or *Nocardia/Microthrix* spp. when fats and edible oils are present (Tchobanoglous et al., 2003). It may also be caused by aeration with diffusers, since slaughterhouse wastewater contains fats or detergents (Eikelboom, 2000).

1.3 Legislative Requirements

Slaughterhouse wastewater, which is sometimes combined with rendering wastewater, is recognised as a risk to the environment by the IPPC Directive (2008/1/EC). This Directive requires that slaughterhouses with a production capacity of greater than 50 t/day and rendering facilities with a treatment capacity exceeding 10 t/day be licensed and monitored.

The Urban Waste Water Treatment Directive (91/271/EEC) sets out discharge standards to which industries should comply (Table 1.1). In Ireland, these directives are transposed into Irish law by the Environmental Protection Agency (EPA) Act, 2003. In addition, the Act also covers the licensing of slaughtering facilities where the daily capacity exceeds 1,500 units (one sheep is equal to one unit, one pig is equal to two units, and one head of cattle is equal to five units). Facilities that render animal carcasses and by-products are also covered by this Act.

1.4 Treating Slaughterhouse Wastewater

The treatment of slaughterhouse wastewater comprises four stages:

1. Preliminary;
2. Primary;
3. Secondary; and
4. Tertiary treatments.

Table 1.1. Discharge standards in Ireland (EC, 1991)[1].

Parameters	Concentration (mg/l)	Minimum reduction (%)
5-Day biochemical oxygen demand (at 20°C) without nitrification	25	70–90
Chemical oxygen demand	125	75
Total suspended solids	35	90
Total phosphorus	1–2[2]	80
Total nitrogen	10–15[2]	70–80

[1]EC (European Commission), 1991. Council Directive 91/271/EEC of 21 May 1991 concerning urban waste-water treatment. *Official Journal of the European Communities* **L135:** 40–52.
[2]Lower limit applies to sensitive areas that are subject to eutrophication.

The raw wastewater is first screened to prevent any large objects within the wastewater stream from damaging or blocking any of the equipment in the wastewater treatment plant. Then fats, oils and greases (FOG) are removed using either a grease trap or dissolved air flotation (DAF). The preliminary and primary treatments of slaughterhouse wastewater are summarised in Table 1.2.

Secondary treatment for slaughterhouse wastewater uses biological methods to reduce the pollutant loads of organic matter, SS, N and P. Secondary biological methods can be broken down into two types – anaerobic treatment and aerobic treatment.

As a secondary treatment process, the SBR process is among the BATs for slaughterhouse wastewater treatment. The review on the performance of SBR in slaughterhouse wastewater treatment is detailed in the End of Project Report. However, SBRs are not able to remove N from slaughterhouse wastewater as efficiently as COD because slaughterhouse wastewater contains very high TN, with a typical BOD_5 to TN ratio of 7–9:1.

Table 1.2. Summary of preliminary and primary treatments of slaughterhouse wastewater.

Wastewater	Scale	Configuration (pressure)	Chemicals used	Performance (removals %)	Reference
Raw poultry slaughterhouse	Industrial	Industrial DAF (300 kPa)	PAC, anionic polymer	COD – 43% SS – 43% O&G – 49%	de Nardi and Fuzi (2008)[1]
Raw poultry slaughterhouse	Industrial	Laboratory-scale DAF with 40% recycle (450 kPa)	PAC, anionic polymer	SS – 74% O&G – 94%	de Nardi and Fuzi (2008)[1]
Settled wastewater	Laboratory	Coagulated	Alum	COD – 65% SS – 34% TP – 45%	Amuda and Alade (2006)[2]
Settled wastewater	Laboratory	Coagulated	Ferric chloride	COD – 63% SS – 28% TP – 20%	Amuda and Alade (2006)[2]
Settled wastewater	Laboratory	Coagulated	Ferric sulfate	COD – 65% SS – 20% TP – 39%	Amuda and Alade (2006)[2]

COD, chemical oxygen demand; DAF, dissolved air flotation; O&G, oil and grease; PAC, polyaluminium chloride; SS, suspended solids; TP, total phosphorus.
[1]de Nardi, I.R. and Fuzi, T.P., 2008. Performance evaluation and operating strategies of dissolved-air flotation system treating poultry slaughterhouse wastewater. *Resources Conservation and Recycling* **52:** 533–544.
[2]Amuda, O.S. and Alade, A., 2006. Coagulation/flocculation process in the treatment of abattoir wastewater. *Desalination* **196:** 22–31.

A conventionally operated SBR can be changed to an IASBR, where one complete operational cycle comprises four phases:

1. Fill;
2. React (alternating aeration and mixing);
3. Settle; and
4. Draw.

In the react phase, aeration and mixing are alternatively applied. In an IASBR, during the aeration periods, dissolved oxygen (DO) is high and aerobic nitrifiers oxidise ammonium to oxidised N (NO_2-N and NO_3-N) and, during the following mixing periods, DO decreases to such a low level that anoxic denitrifiers reduce oxidised N to N_2 gas. The intermittent aeration strategy can also reduce the demand for rbCOD contained in the influent wastewater in the fill phase by minimising the occurrence of N removal in the fill phase, so that PAOs will obtain sufficient rbCOD for anaerobic P release, which is beneficial to biological P removal. In addition, in an intermittently aerated reactor, the organic C stored by PAOs could be used by denitrifiers for denitrification in the latter anaerobic periods, resulting in less dependence of denitrification on the rbCOD content in the influent wastewater. Therefore, stable and efficient N and P removal can be achieved in IASBRs, which is an advantage over conventional SBRs.

Tertiary treatment is not often applied to slaughterhouse wastewater due to the high costs. However, filtration, constructed wetlands (CWs), membrane filtration, coagulation and precipitation, may be used, depending on intended use of final effluent and permit restrictions (EC, 2005a,b). The tertiary treatment of slaughterhouse wastewater is summarised in Table 1.3.

Table 1.3. Summary of tertiary treatment of slaughterhouse wastewater.

Wastewater	Scale	Pretreatment	Treatment method	Performance (removals %)	Reference
Slaughterhouse	Laboratory	Coagulation and aerobic–anoxic SBR	Reverse osmosis (2.0 MPa)	COD – 97% BOD_5 – 88% TP – 100% TN – 75%	Bohdziewicz et al. (2002)[1]
Slaughterhouse	Laboratory	Aerobic SBR	Reverse osmosis (2.0 MPa)	COD – 86% BOD_5 – 50% TP – 98% TN – 90%	Sroka et al. (2004)[2]
Slaughterhouse	Industrial	Aerobic activated sludge	Constructed wetland (HRT – 2.7–3.5 days)	SS – 83–89% TP – 14–56% TN – 37–61%	Finlayson and Chick (1983)[3]

BOD_5, 5-day biochemical oxygen demand; COD, chemical oxygen demand; HRT, hydraulic retention time; SBR, sequencing batch reactor; SS, suspended solids; TN, total nitrogen; TP, total phosphorus.
[1]Bohdziewicz, J., Sroka, E. and Lobos, E., 2002. Application of the system which combines coagulation, activated sludge and reverse osmosis to the treatment of the wastewater produced by the meat industry. *Desalination* **144:** 393–398.
[2]Sroka, E., Kaminski, W. and Bohdziewicz, J., 2004. Biological treatment of meat industry wastewater. *Desalination* **162:** 85–91.
[3]Finlayson, C.M. and Chick, A.J., 1983. Testing the potential of aquatic plants to treat abattoir effluent. *Water Research* **17:** 415–422.

2 Experiment Systems Set-Up

The laboratory- and pilot-scale experiment systems are described below. They are detailed in the End of Project Report.

2.1 Laboratory-Scale Systems

The configuration of laboratory-scale SBR systems is illustrated in Fig. 2.1. The reactor tank was made from transparent Plexiglas and had a working volume of 10 l, with an inner diameter of 194 mm and a height of 400 mm. Peristaltic pumps were used to fill the reactor tank with slaughterhouse wastewater from the influent tank during the fill phase and to decant the effluent from the reactor tank during the draw/idle phase. A mechanical mixer with an 80-mm × 100-mm rectangular paddle was installed over the reactor. An air pump supplied air through a porous stone diffuser, located at the bottom of the reactor tank. The airflow rate was regulated by an air flowmeter. The operational sequence of the SBR system and the movement of all mechanical devices were controlled by a programmable logic controller (PLC).

Dissolved oxygen, pH and oxidation–reduction potential (ORP) in the reactor tank were real-time monitored using DO, pH and ORP electrodes connected to corresponding transmitters that transformed the signals from the three electrodes into 4–20 mA analogue signals. Then, a data acquisition card transformed analogue signals into digital signals, which were processed by the LabVIEW computer programme.

The configuration of the laboratory-scale sequencing batch biofilm reactor (SBBR) systems was the same as that of SBR systems, but only a bulk volume of 4.0 l of Kaldnes® K1 plastic biofilm carriers (Anoxkaldnes AS, Norway) was added in the reactor. The biofilm carrier elements have a nominal diameter and length of 9.1 mm and 7.2 mm, respectively, with a specific weight of approximately 0.95 kg/l. The effective specific surface area of the biofilm carriers that is available for biofilm growth is 500 m^2/m^3.

The slaughterhouse wastewater treated in the laboratory-scale unit was collected with 10-l plastic containers from the conditioning tank in the wastewater treatment plant of West Proteins in Ballyhaunis. It was then stored in a refrigerator at approximately 4°C for up to 10–20 days before using.

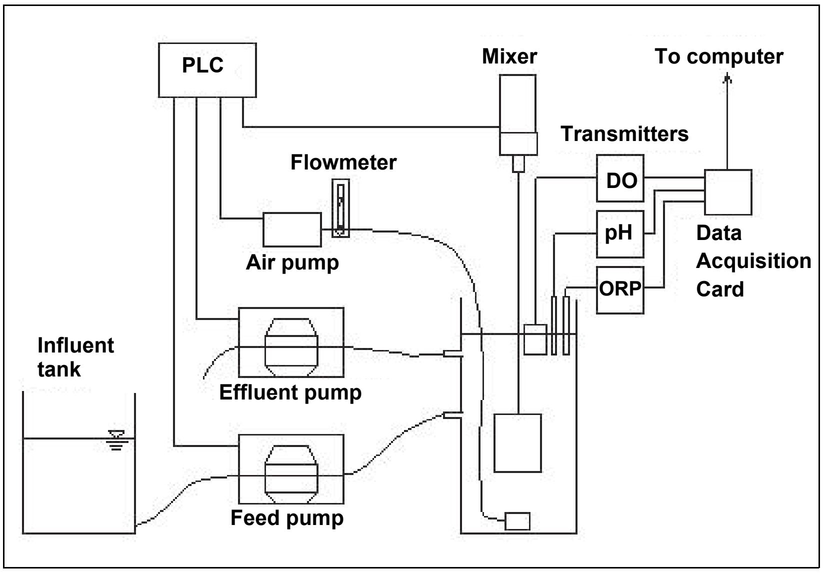

Figure 2.1. Schematic diagram of the laboratory sequencing batch reactor system. PLC, programmable logic controller; DO, dissolved oxygen; ORP, oxidation–reduction potential.

The influent wastewater in the influent tank was prepared daily by filtering the raw wastewater through a 0.6-mm mesh screen. A submerged aquarium pump was placed in the influent tank to stir the wastewater.

2.2 Pilot-Scale System

The pilot-scale SBR (Fig. 2.2) was constructed at the Environmental Engineering Laboratory, NUI Galway, and deployed on-site at the slaughterhouse wastewater treatment plant for Western Proteins. The pilot-scale SBR influent was taken from the balance tank in the wastewater treatment plant. The design and operation of the pilot-scale SBR was based on the experience in the design and operation of the laboratory-scale SBR work. The pilot-scale SBR's performance was monitored over 402 days. A site manual and safety statement for the pilot-scale SBR were prepared.

The pilot-scale reactor tank was a 200-l barrel with a working volume of 150 l, a mean inner diameter of 259 mm and a height of 715 mm, giving a height-to-diameter ratio of 2.76.

The volumes of influent pumped to the reactor, sludge withdrawn, and effluent withdrawn were controlled by float switches, which were connected to a PLC. The de-sludging pump was turned on and off by the PLC, in addition to the effluent pump. Both the waste sludge and effluent were discharged into a 150-l holding tank, from which a submersible pump pumped the tank holdings into the Western Proteins aeration tank. An automatic sampler was used to take effluent samples.

The conditions in the pilot-scale SBR could be controlled to be aerobic, anaerobic or anoxic by turning on/off an 85-l/min air pump connected to the PLC. The air pump pumped air into the tank via a fine bubble diffuser located at the bottom of the reactor tank. Stirring was carried out by a 100-mm × 80-mm steel paddle connected to a motor which had a variable resistor attached to vary the speed. A DO controller, connected to the PLC, allowed the DO levels in the tank to be controlled. Further information regarding the set-up of the laboratory-scale and pilot-scale SBRs is detailed in the End of Project Report.

Figure 2.2. Photo of the pilot-scale sequencing batch reactor showing the reactor tank (on left) and the holding tank (on right).

3 Laboratory-Scale Research Results

The results are now briefly discussed. They are described in the End of Project Report in detail. An overview of the operational conditions and performance of the IASBR with activated sludge and an identical modified IASBR with the addition of biofilm carrier (IASBBR) is detailed in Table 3.1.

3.1 Organic and Nutrient Removal from Slaughterhouse Wastewater

3.1.1 IASBR with biofilm carriers

The duration of a complete cycle was 8 h and comprised four phases:

1. Fill (7 min);
2. React (393 min);
3. Settle (30 min); and
4. Draw/Idle (50 min).

The IASBR was intermittently aerated, four times at 50-min intervals and for 50 min each time by means of an air pump and a stone diffuser with an air supply of 0.8 l/min. The operational sequence of the IASBR in a complete cycle is depicted in Fig. 3.1. An identical IASBR with activated sludge was operated under the same conditions applied in the IASBBR and was a control reactor. Both reactors were operated at ambient temperature of 18–24°C.

The HRT was 3.3 days. The mixed liquor suspended solids (MLSS) in the reactor were kept at approximately 5,000 mg/l by retaining the sludge retention time (SRT) at 11–12 days. The average organic loading rate (OLR) was 1.18 ± 0.04 kg COD/m^3/day and nitrogen loading rate (NLR) was 0.11 ± 0.01 kg N/m^3/day. The pH values in the reactor ranged from 7.0 to 8.0, so external alkali addition was not deemed necessary.

Table 3.1. Operational conditions and performance of the intermittently aerated sequencing batch reactor (IASBR) and the intermittently aerated sequencing batch biofilm reactor (IASBBR).

	IASBR	IASBBR
Study duration (days)	132	120
Hydraulic retention time (days)	3.3	3.3
Mixed liquor suspended solids (mg/l)	3,500	5,000
Sludge retention time (days)	10	11–12
Average organic loading rate[1]	1.2 g COD/l/day	1.18 ± 0.04 kg COD/m^3/day
Average nitrogen loading rate (kg N/m^3/day)	0.11 ± 0.01	0.11 ± 0.01
pH	7.0–8.0	7.0–8.0
Sludge volume index (ml/g)	87–107	200–225
Average floc size of the suspended sludge (µm)	23.7	13.8
% removals:		
COD	96	94
TN	96	92
TP	99	95

[1]Organic loading rates (OLRs) were higher than the average OLR in the current full-scale wastewater treatment plant in the slaughterhouse.
COD, chemical oxygen demand; TN, total nitrogen; TP, total phosphorus.

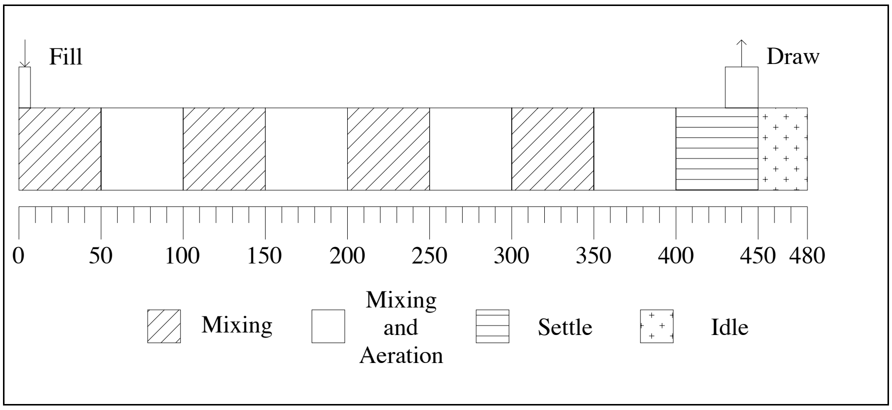

Figure 3.1. Operation strategies of the intermittently aerated sequencing batch reactor with biofilm carriers and with activated sludge flocs in one operational cycle (8 h/480 min).

The study lasted for 120 days. The settleability of the suspended sludge in the IASBBR was poorer than that in the IASBR. The suspended sludge in the IASBBR had an SVI ranging from 200 to 225 ml/g, while, in the activated sludge IASBR reactor, the SVI ranged from 87 to 107 ml/g. The average floc sizes of the suspended sludge in the IASBBR and the IASBR were 13.8 and 23.7 µm, respectively.

The IASBBR had good performance in organic matter and nutrient removal; COD, TN and TP removals from the slaughterhouse wastewater were over 94%, 92% and 95%, respectively. It had good P removal and, generally, the effluent ortho-phosphorus (PO_4-P) concentration was less than 0.4 mg/l; TN ranged from 5 to 22 mg/l; NO_2-N, 0.1–15 mg/l, was the main form of oxidised N in the effluent. Generally, the effluent NO_3-N concentration was less than 1.0 mg/l. The effluent ammonium-nitrogen (NH_4-N) concentration was always less than 1.0 mg/l. Stable partial nitrification/denitrification occurred in the reactor and removed approximately 66% of the influent TN. On the basis of a mass balance calculation, the other 32% of the TN was consumed by micro-organisms for biomass synthesis, which was equal to the nitrogen mass contained in the biomass de-sludged from the reactor.

Phosphorus release occurred in the first non-aeration period and the highest PO_4-P concentration, 16.8 mg/l, was achieved at the 50th min. The mass of P released from sludge was almost five times the mass of P in the influent. Phosphorus uptake occurred in the first two aeration periods. During the rest of the react phase, the PO_4-P concentration in the reactor was less than 0.2 mg/l. The estimated P uptake rate in the IASBBR of 13.5 mg/l/h was much lower than that measured in the activated sludge IASBR – 32.4 mg/l/h. This may be due to the lower MLSS in the IASBBR tank compared with that of the activated sludge IASBR.

The difference between the IASBBR and the activated sludge IASBR in nutrient removal from slaughterhouse wastewater was very small. However, in consideration of the cost of biofilm media, the advantages of the IASBBR were negligible; thus, an IASBR with activated sludge configuration was used in further studies.

3.1.2 IASBR with activated sludge

The concentrations of SS, COD, BOD_5, TN, TP and NH_4-N in the influent wastewater over the study period were 1,403 ± 596 mg/l, 4,672 ± 952 mg/l, 2,895 ± 585 mg/l, 356 ± 46 mg/l, 29 ± 10 mg/l and 342 ± 87 mg/l, respectively. The IASBR was seeded with the recycle sludge taken from the secondary clarifier of the local slaughterhouse's wastewater treatment plant. The volatile suspended solids (VSS)/SS ratio of the seed sludge was 0.86. After seeding, the IASBR tank had an MLSS concentration of about 3,500 mg/l.

The operation sequence is shown in Fig. 3.1. The reactor was continuously operated for 132 days, with a HRT of 3.3 days. pH values in the reactor ranged from 7.0 to 8.0. During the periods of Days 88–102 and Days 116–132, influent COD concentrations were as high as 6,620 and 5,710 mg/l, respectively. Excluding these two periods, the average influent COD and SS concentrations were 3,931 and 983 mg/l, respectively, giving an average OLR of 1.2 g COD/l/day. TN was relatively stable during the study period with an average value of 356 mg/l. The average VSS/SS ratio was 0.92. The SVI ranged from 87 to 107 ml/g, indicating that the sludge had a good settlement capability.

At an influent OLR of 1.2 g COD/l/day, average effluent concentrations of COD, TN and TP were 150 mg/l, 15 mg/l and 0.8 mg/l, respectively. This represented COD, TN and TP removals of 96%, 96% and 99%, respectively. The low effluent P concentrations showed that tertiary treatment was not necessary. The effluent SS concentrations were below 60 mg/l, with an average level of 33 mg/l.

In the aeration periods of the react phase, NO_2-N was 64–96% of the total oxidised N, indicating that partial nitrification occurred in the SBR. Ninety-five per cent of N removal by means of denitrification was via NO_2-N. Many researchers have found that the major selective pressures for partial nitrification are DO and NH_4-N concentrations in the bulk liquid phase (Cecen, 1996; Chuang et al., 2007). In the present SBR, the average DO levels during the four aeration periods were 0.7, 1.3, 2.6 and 6 mg/l and NH_4-N concentrations were 23.4, 17.5, 5.9 and 0.6 mg/l. Neither the DO nor the NH_4-N concentration was consistent with the findings of the other researchers mentioned above. The NO_2-N to total oxidised N ratios were 96% and 89% in the third and fourth aeration periods, respectively; these were higher than the ratios in the first and second aeration periods, 64% and 72%, respectively.

The batch experiment results showed that nitrite oxidising bacteria (NOB) existed in the IASBR, but it took almost 1 h for NOB to recover activity after the operational condition of the IASBR was shifted from the anaerobic condition to the aerobic condition. Since the aeration period was 50 min, shorter than the lag time of NOB, the NOB activity was inhibited, which caused the accumulation of nitrite. However, further research should be carried out to study the mechanisms triggering NO_2-N accumulation in the IASBR.

3.2 Effect of Aeration Rate on Nutrient Removal in IASBRs

Two identical laboratory-scale IASBRs were used in this study and the operation sequence is given in Fig. 3.1. The two IASBRs (SBR1 and SBR2) were seeded with the recycle sludge taken from the secondary clarifier of the local slaughterhouse's wastewater treatment plant. The VSS/SS ratio of the seed sludge was 0.86. After seeding, the two SBRs had an initial MLSS of about 3,500 mg/l. A summary of the operational regime and performance data of both reactors is tabulated in Table 3.2.

SBR1 was operated at 0.2 l air/min during Days 1–70, 0.4 l air/min during Days 71–120 and 1.2 l air/min during Days 121–230. SBR2 was operated at 0.8 l air/min during Days 1–120. During Days 1–120, COD and SS in the influent wastewater fluctuated greatly and had average influent COD and SS concentrations of 4,700 and 1,400 mg/l, respectively, giving an average OLR of 1.4 g COD/l/day. TN was relatively stable during this period and had an average value of 350 mg TN/l. During Days 121–230, raw slaughterhouse wastewater contained lower COD, SS and TN. Therefore, when SBR1 was operated at an aeration rate of 1.2 l air/min, the average OLR was 0.86 g COD/l/day and the average NLR was 0.075 g N/l/day.

At aeration rates of 0.2 and 0.4 l/min, the effluent contained high concentrations of COD and nutrients, and the effluent quality did not reach the emission standards required by the Irish EPA. The effluent quality at the 0.4 l/min aeration rate was much better than that at the 0.2 l/min aeration rate and produced lower effluent COD, TN and TP concentrations. Biological P removal did not occur at the 0.2 l/min aeration rate, but took place when the aeration rate was increased to 0.4 l/min. At 0.4 l air/min, effluent PO_4-P was less than 0.6 mg/l and effluent TP was approximately 1.8 mg/l.

At high aeration rates of 0.8 and 1.2 l air/min, the effluent quality met the emission standards. The optimum aeration rate of 0.8 l air/min produced the best system performance. Removals of COD, TN and TP were up to 97%, 94% and 97%, respectively. The

Table 3.2. Operational conditions and performance of Sequencing Batch Reactor 1 (SBR1) and Sequencing Batch Reactor 2 (SBR2).

	Air flow (l air/min)			
	0.2	**0.4**	**0.8**	**1.2**
SBR1				
Days of operation	1–70	71–120		121–230
Average OLR (g COD/l/day)	1.4	1.3		0.86
Average NLR (g N/l/day)	0.11	0.09		0.075
% Removals:				
COD	68	93		97
TN	<5	34		92
TP	43	94		97
SBR2				
Days of operation			1–120	
Average OLR (g COD/l/day)			1.4	
Average NLR (g N/l/day)			0.10	
% Removals:				
COD			97	
TN			95	
TP			97	

COD, chemical oxygen demand; NLR, nitrogen loading rate; OLR, organic loading rate; TN, total nitrogen; TP, total phosphorus.

average effluent was 115 ± 13 mg/l COD, 19 ± 8 mg/l TN and 0.7 ± 0.3 mg/l TP.

Partial nitrification followed by denitrification occurred in the IASBRs at aeration rates of 0.8 and 1.2 l air/min. At the aeration rate of 0.8 l/min, NO_2-N/total oxidised nitrogen (TON) during most of the operational cycle was over 80%. When the aeration rate was 1.2 l/min, NO_2-N/TON ranged from 15% to 65%. The cyclic operation could be the cause of partial nitrification.

In the present study, the application of DO, pH and ORP real-time data to control the operation of IASBRs was studied. The results show that the end of nitrification can be identified from DO and pH real-time data using

$$\frac{d^2DO}{dt^2} = 0 \qquad \text{and} \qquad \frac{dpH}{dt} = 0$$

It was observed that there were three stages of ORP variation:

1. ORP was approximately –26 mV in anoxic conditions;
2. ORP was approximately –12 mV in anaerobic conditions; and
3. ORP was positive in aerobic conditions.

The end point of denitrification in non-aeration periods can be set at an ORP value of –12 mV.

3.3 N Removal in SBRs under Controlled Low DO Levels

A laboratory-scale SBR was operated at low DO levels under two aeration strategies: intermittent aeration (IA) and continuous aeration (CA). The characteristics of N removal from real slaughterhouse wastewater in this SBR at low DO levels were investigated.

The sequencing operation of the SBR under the two aeration strategies – IA and CA – is shown in Fig. 3.2. The total cycle duration was 8 h, giving three cycles per day. The duration of the react phase was 6 h and 7 h under the IA and CA aeration strategies, respectively. During the react phase, the stirrer rotated continuously at 110 rev./min. Under both operational strategies, the first hour was set as a non-aeration period for pre-denitrification, and then the reactor tank was either intermittently or continuously aerated at low DO levels. Under the IA aeration strategy, the seventh hour was the settle phase and in the last 10 min of the settle phase, the supernatant was decanted.

In IA, during the second, fourth and sixth hour of the operational cycle, the air pump was working and the maximum DO was controlled at 10% saturation. When the DO was lower than 10% saturation, the aeration rate was regulated at 1.0 l air/min via the solenoid valve; when the DO was equal to or higher than 10% saturation, the aeration rate was regulated at 0.2 l air/min.

In CA, from 60 to 120 min in a cycle, aeration rates of 0.4–1.2 l air/min were applied to keep the DO concentration at approximately 10%. From 120 to 420 min, the reactor was aerated at aeration rates ranging from 0.1 to 0.4 l air/min. In this study, the DO of 10% saturation and the deviation of pH in the reactor (d*pH*/d*t*) of >0.005 unit/min were the criteria for determining the end point of nitrification. When this point was reached, aeration ceased until the end of the operational cycle.

In several operational cycles after the SBR was at steady state, the oxygen uptake rate (OUR) – a measure of the deviation of DO (i.e. d*DO*/d*t*) as it decreases during non-aeration periods – was monitored in situ every 10 min. A Clark-type mini-DO sensor, which can detect as low as 0.2% DO saturation and has a response time of 5–6 s from 1% to 90% of DO saturation, was used to measure DO in the reactor.

During the 74-day operation with the IA aeration strategy, the average influent COD and TN concentrations were 2,800 and 220 mg/l, respectively (Table 3.3). The average OLR and NLR were 0.77 kg COD/m^3/day and 0.06 kg N/m^3/day, respectively. Following the IA operation, the SBR was operated with the CA aeration strategy for 21 days. During this period, the average influent COD and TN concentrations were 3,500 and 350 mg/l, respectively. The average OLR and NLR were 0.81 kg COD/m^3/day and 0.08 kg N/m^3/day, respectively.

Good effluent quality and stable performance were achieved within 4 days after the commencement of the respective operational strategies. SS and COD removals of 99% and 98%, respectively, were

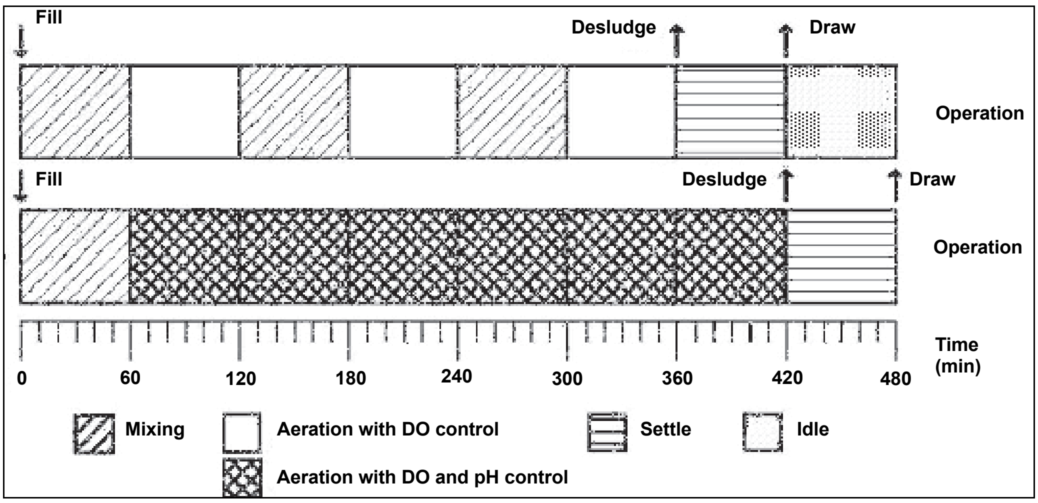

Figure 3.2. Operation strategies of the sequencing batch reactor: intermittent aeration (top) and continuous aeration (bottom). DO, dissolved oxygen.

Table 3.3. Operational conditions and performance of the laboratory-scale sequencing batch reactor at 10% saturation.

	Intermittent aeration	Continuous aeration
Operation period (days)	74	21
Average influent COD concentration (mg/l)	2,800	3,500
Average influent TN concentration (mg/l)	220	350
Organic loading rate (kg COD/m^3/day)	0.77	0.81
Nitrogen loading rate (kg N/m^3/day)	0.06	0.08
% Removals:		
COD	>98	>98
SS	>99	>99
TN	95	91

COD, chemical oxygen demand; SS, suspended solid; TN, total nitrogen.

achieved. The effluent COD concentrations were 52 mg/l (IA) and 50 mg/l (CA). The average TN removals were 95% (IA) and 91% (CA), and the average effluent NH_4-N concentrations were 1.1 mg/l (IA) and <0.5 mg/l (CA). This shows that complete nitrification was achieved under a maximum DO of 10% saturation. NO_3 was the main N component in the effluent. Because NLR was higher when the reactor was operated with CA and aeration was terminated just after the depletion of NH_4-N, NO_2-N in the effluent was higher than during IA, but was mainly below 5 mg/l. TN concentrations in the effluent were 12 mg/l (IA) and 30 mg/l (CA). Under the intermittent aeration strategy, lower effluent TN concentrations were achieved. In addition, by maintaining low DO levels, electricity consumption associated with air supply can be reduced by up to 65%. Under the IA operational strategy, the final SS, COD, TN and NH_4-N concentrations met the standards for discharging slaughterhouse wastewater to surface waters.

This study also showed that it is feasible to use in situ OUR as a parameter to determine the end point of nitrification and aeration. After the SBR reaches steady state conditions, the change of OUR indicates that nitrification is complete and, as a result, that aeration should be ceased. In situ OUR measurement is a better parameter than in situ DO measurement in the control of the SBR operation, because the variation of DO depends not only on the OUR, but also on the oxygen transfer rate.

3.4 N_2O Emission from the IASBRs Treating Synthetic Ammonium-Rich Wastewaters

During wastewater treatment, nitrous oxide (N_2O) emission is caused by heterotrophic denitrification and the denitrification pathway of autotrophic nitrification. The aim of this study was to examine N_2O emission from the IASBRs treating ammonium-rich wastewater under oxygen-limited conditions.

The IASBR used in this study was fed with synthetic wastewater. The synthetic wastewater consisted of 300 mg/l and 100 mg/l glucose, $(NH_4)_2SO_4$ (300 mg/l as NH_4-N), NaH_2PO_4 (31 mg/l as PO_4-P), 50 mg/l yeast extract, $NaHCO_3$ (1,075 mg/l as $CaCO_3$ alkalinity). The mole ratio of NH_4-N/HCO_3 was 1:1. The synthetic wastewater was prepared once every week and stored at 4°C in a refrigerator. When used, it was added to the influent tank daily. At the later stage, enhanced municipal wastewater was used to feed the reactor. The primarily settled municipal wastewater, taken from the Tuam Municipal Wastewater Treatment Plant, had an average COD of 350 mg/l and TN of 70 mg/l; 252 mg/l NH_4-N were added into the municipal wastewater to achieve a comparable COD and TN to those of the synthetic wastewater – the average COD and TN of the enhanced municipal wastewater were 370 mg/l and 400 mg/l, respectively.

The seed sludge was the return sludge taken from the Tuam Municipal Wastewater Treatment Plant.

Nitrification was efficient in this plant so the seed sludge biomass contained nitrifiers, both ammonia oxidising bacteria (AOB) and NOB. The MLSS of the seed sludge was 6,000 mg/l and the mixed liquor volatile suspended solids (MLVSS) value was 4,940 mg/l.

The emission of N_2O from the liquid phase in the IASBR to the atmosphere was mainly through diffusion and stripping of dissolved N_2O from the wastewater. Because a low airflow rate was applied in this study, online off-gas detection of N_2O was not feasible. Hence, N_2O emission from the liquid phase was indirectly calculated from the online measurement of dissolved N_2O concentrations in the liquid phase. An N_2O sensor, manufactured in the Environmental Engineering Laboratory, NUI Galway, was used to measure the N_2O-N concentrations. The sensor had a quick response time and reliable signals. It was calibrated with bottled N_2O gas. The sensor tip was immersed 2–3 cm below the water surface in the reactor tank.

The rate of N_2O emission from the liquid phase via diffusion and air stripping under the same aeration condition as that in the IASBR was measured, so that the gross N_2O emission from the wastewater could be estimated. The emission of N_2O through diffusion and air stripping can be estimated with batch clear water tests.

The N_2O emission via diffusion and air stripping into air during the mixing period was tested in a clear water batch experiment with similar conditions as in the IASBR. The batch test was carried out in a 2-l vessel. The saturation concentration of N_2O in water is relatively high, up to 30 mM at 20°C. Five millilitres of distilled water saturated with N_2O solution were added into the 2-l bulk water. The same type of stirrer and blade as in the IASBR was used to stir the liquid at 100 rev./min. The N_2O sensor was positioned for online monitoring and data were recorded every 3 s.

Because the sludge biomass concentration in the IASBR was relatively high, approximately 2,500 mg VSS/l, the dynamics of OUR and the N_2O production rate were too fast for the sensor response time. Hence, the test of OUR and the N_2O production rate was carried out in a batch experiment in a 450-ml glass vessel. A mini-DO sensor and an N_2O sensor were positioned in the glass vessel. The MLVSS in the batch test was one-fifth of the MLVSS in the reactor. The settled supernatant and the mixture liquor taken from the reactor were added into the glass vessel. An aquarium air pump was used to aerate the mixture in the vessel to DO >60% saturation and then aeration was terminated and the liquid phase was mixed at 100 rev./min. The concentrations of DO and N_2O in the liquid phase were recorded with the mini-DO sensor and the N_2O sensor, respectively. Then, the OUR and N_2O production rate were calculated from the online DO and N_2O profiles, respectively.

N_2O emissions in different influent conditions can be estimated (Table 3.4). Under oxygen-limited conditions, the N_2O production via the denitrification pathway of autotrophic nitrification was estimated to be less than 1.7% (the influent BOD was 0 mg/l). When the influent BOD concentration was increased from 0 to 550 mg/l, the N_2O emission increased by 6.98-fold.

From this study, it has been found that:

1. The influent rbCOD level was suspected to be a key factor in stimulating N_2O emission in the oxygen-limited IASBR via heterotrophic denitrification.

2. The rbCOD was converted into an internal carbon source for denitrification to produce N_2O. The N_2O production rate was related to the

Table 3.4. Estimated nitrous oxide emission from the intermittently aerated sequencing batch reactor tank treating ammonium-rich wastewater.

BOD-0	BOD-100	BOD-550
1.7%	6.2%	12.1%

BOD, biochemical oxygen demand.

polyhydroxyalkanoate (PHA) concentration in the biomass in zeroth or first orders. The N_2O production was in a zeroth order to sufficient poly-β-hydroxyalkanoate (PHB) in the biomass, and a first to second order to limited PHB in the biomass. The highest N_2O emission was estimated at 12%.

3. Nitrifier denitrification contributed significantly to N_2O emission from the oxygen-limited IASBR treating non-organic feed. The N_2O emission was 1.7%, and was comparable with the N_2O emission from pure cultures of AOB in oxygen-limited conditions.

4. Reduction of the influent rbCOD concentration, reduction of anoxic periods in operational cycles, and an increase in pH in the reactor could be the main options for avoiding high N_2O emissions.

4 Pilot-Scale Research Results

The pilot-scale unit was operated on-site for a total of 402 days (2 October 2007 – 7 November 2008) under eight different aeration strategies (continuous or intermittent aeration), SRT, HRT and organic loading conditions (Table 4.1). All operation regimes had three cycles per day (8 h/cycle). The COD concentrations of the influent varied widely which, in turn, caused wide-ranging OLRs. The unit was initially seeded with return activated sludge (RAS) from the Western Proteins' wastewater treatment plant.

Only the results obtained in the pilot-scale unit operated with continuous and intermittent aeration at an OLR of approximately 0.50 kg COD/m^3/day are described in this report. This loading rate produced the best results for a time period of 42 days in the intermittent aeration mode. Full details of the other operational strategies are detailed in the End of Project Report.

In the two stages, an 8-h cycle time was deployed. The time sequence, comprising 4 min of fill included in 380 min of react, 90 min of settle and 10 min of idle/draw in the two operational strategies, is detailed in Fig. 4.1. The mean OLR in continuous aeration operation was 0.51 kg COD/m^3/day and in intermittent aeration was 0.49 kg COD/m^3/day. A HRT of 8.9 days was kept constant in the entire study period. The MLSS was between 4,500 and 5,500 mg/l and the SRT was maintained at 21.5 days.

The influent to the pilot-scale SBR was taken from the conditioning tank of the wastewater treatment plant in Western Proteins. The characteristics of the influent to the pilot-scale unit in both stages were:

- COD: 4,674 ± 1,989 mg/l (CA) and 4,380 ± 1,172 mg/l (IA);
- SS: 1,887 ± 987 mg/l (CA) and 1,407 ± 436 mg/l (IA);
- TN: 414 ± 78 mg/l (CA) and 381 ± 102 mg/l (IA); and
- NH_4-N: 408 ± 87 mg/l (CA) and 465 ± 127 mg/l (IA).

At a loading rate of approximately 0.5 kg COD/m^3/day, efficient removals of pollutants (COD: 97%, SS: 98%, TN: 98%, and PO_4-P: 99%) were achieved under the IA aeration strategy, with production of an effluent (COD: 117 mg/l, SS: 26 mg/l, TN: 8 mg/l, and PO_4-P: 0.2 mg/l) that met the discharge standards. Table 4.2

Table 4.1. Details of the pilot-scale sequencing batch reactor operation during the study period.

Phase	Date (days)	Aeration operation	HRT (days)	SRT (days)	Average OLR (kg/m^3/day)
1	2 October 2007 – 6 November 2007 (35)	Intermittent	2.9	20	1.15
2	6 November 2007 – 26 February 2008 (112)	Continuous	5.9	20.5	0.83
3	26 February 2008 – 3 April 2008 (37)	Intermittent	5.9	13.2	1.11
4	3 April 2008 – 15 May 2008 (42)	Intermittent	8.9	21.3	0.45
5	15 May 2008 – 6 June 2008 (22)	Continuous	8.9	21.6	0.51
6	6 June 2008 – 1 July 2008 (25)	Intermittent	8.9	21.5	0.49
7	1 July 2008 – 18 July 2008 (17)	Intermittent	6.2	22.4	0.72
8	18 July 2008 – 7 November 2008 (112)	Intermittent	7.5	22.3	0.73

HRT, hydraulic retention time; OLR, organic loading rate; SRT, sludge retention time.

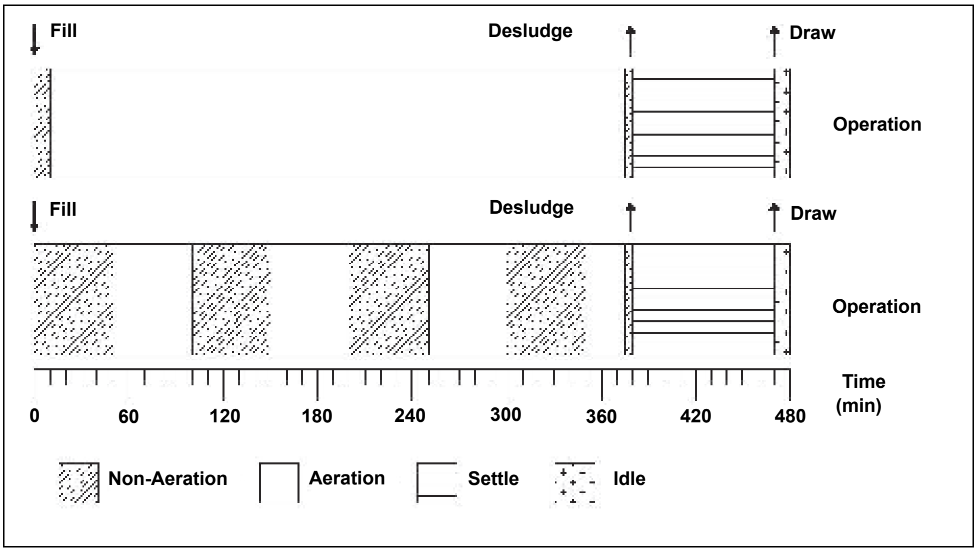

Figure 4.1. Time sequence in the continuous (top) and intermittent (bottom) aeration strategies.

shows the concentrations of pollutants in the effluent, along with corresponding percentage reductions.

Although the OLR varied significantly throughout the study period, for both CA and IA aeration strategies, COD and SS concentrations in the effluent were within the required emission standards. However, for TN, the effluent concentrations were up to 10 times the allowable concentration for discharge during the continuous aeration strategy.

Figure 4.2 shows that the changeover to IA from CA resulted in a drop in TN in the effluent from 96 mg/l to 8 mg/l over a 5-day period, with a simultaneous drop in the concentration of NO_3-N. A quick changeover period is ideal for wastewater treatment plants that are looking to switch over to an IA strategy. The pilot-scale unit efficiently removed nitrogen (TN removal of 98%), and the TN concentration in the effluent reached the discharge standard. At the same time, the effluent TP concentration was low enough to reach the discharge standard. This would avoid the operation cost spent on the purchase and addition of coagulants that are used to further reduce P in treated wastewater after secondary treatment.

Table 4.2. Effluent concentrations and percentage removals under the two operation strategies.

Characteristics	Continuous aeration		Intermittent aeration	
	Effluent (mg/l)	% Removal	Effluent (mg/l)	% Removal
COD	109 ± 27	97.7	117 ± 29	97.3
SS	22 ± 14	98.8	26 ± 11	98.2
TN	96 ± 25	76.8	8 ± 2.6	97.9
NH_4-N	1.4 ± 2.7	99.6	0.5 ± 0.09	99.9
NO_2-N	1.2 ± 1.3		0.02 ± 0.03	
NO_3-N	75 ± 42		3.3 ± 2.3	
PO_4-P	0.2 ± 0.4	99.4	0.2 ± 0.14	99.3

COD, chemical oxygen demand; NH_4-N, ammonium-nitrogen; NO_2-N, nitrite-nitrogen; NO_3-N, nitrate-nitrogen; PO_4-P, ortho-phosphorus; SS, suspended solids; TN, total nitrogen.

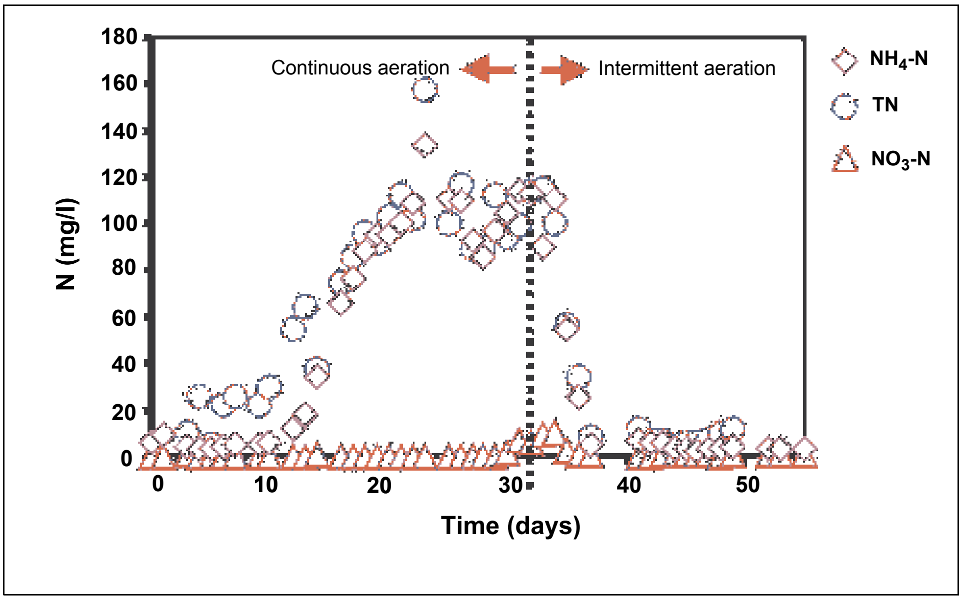

Figure 4.2. Concentrations of total nitrogen (TN), ammonium-nitrogen (NH_4-N) and nitrate-nitrogen (NO_3-N) in the effluent during the study period.

5 Mathematical Modelling

To gain a more complete picture of nitrogen dynamics taking place in the pilot-scale SBR and of partial nitrification, mathematical models were developed to simulate the operation of the pilot-scale unit and the partial nitrification system. The mathematical model was developed based on the Activated Sludge Model 1 (ASM1).

The simulation results can be viewed in Chapter 10 of the End of Project Report. These results show that the ASM1 was able to predict the DO, NH_4-N and TON trends in the pilot-scale SBR and can predict the performance of partial nitrification in the laboratory-scale SBR. However, further work is needed to improve the model.

6 Further Research

Recommendations for further research are:

- The development of an intelligent IASBR for treating slaughterhouse wastewater and other high-strength wastewaters. This technology can be applied by industries and local authorities to treat wastewaters, or to improve performance of their existing wastewater treatment facilities so as to reach stringent nutrient discharge standards.
- The expansion of the mathematical model in AQUASIM to better model the intermittently SBR systems and also to incorporate phosphorus removal.

7 Conclusions

This project aimed to develop a best available environmental technology for the removal of nitrogen from slaughterhouse wastewater. An IASBR was designed and operated at laboratory-scale before deployment on-site. The main conclusions from this study are:

- The pilot-scale study shows COD and TN removals of 97% and 98%, respectively, both beyond those required in IPPC licences. At similar OLRs, the performance of the pilot-scale unit was much better than that of the existing slaughterhouse wastewater treatment plant.

- The unit performed best under an intermittent aeration strategy at an average OLR of 0.5 kg COD/m^3/day, an average temperature of 16°C and an SRT of 22 days.

- The IASBR was found to be robust and flexible in treating slaughterhouse wastewater. It can also be used to treat domestic wastewater and other agricultural wastewater.

- Simultaneous nitrification and denitrification, and partial denitrification were observed during cycle studies of the IASBR.

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Acronyms

AOB	Ammonia oxidising bacteria
ASM1	Activated Sludge Model 1
BAT	Best available techniques
BOD_5	5-Day biochemical oxygen demand
C	Carbon
CA	Continuous aeration
COD	Chemical oxygen demand
CW	Constructed wetland
DAF	Dissolved air flotation
DAFF	Department of Agriculture, Fisheries and Food
DO	Dissolved oxygen
FOG	Fats, oils and greases
HRT	Hydraulic retention time
IA	Intermittent aeration
IASBBR	Intermittently aerated sequencing batch biofilm reactor
IASBR	Intermittently aerated sequencing batch reactor
IPPC	Integrated Pollution Prevention Control
MLSS	Mixed liquor suspended solids
MLVSS	Mixed liquor volatile suspended solids
N	Nitrogen
N_2	Nitrogen gas
N_2O	Nitrous oxide
NLR	Nitrogen loading rate
NH_4-N	Ammonium-nitrogen
NO_2-N	Nitrite-nitrogen
NO_3-N	Nitrate-nitrogen
NOB	Nitrite oxidising bacteria
OLR	Organic loading rate
ORP	Oxidation-reduction potential
OUR	Oxygen uptake rate
P	Phosphorus
PAC	Polyaluminium chloride

PAO	Phosphorus-accumulating organism
PHA	Polyhydroxyalkanoate
PHB	Poly-β-hydroxyalkanoate
PLC	Programmable logic controller
PO_4-P	Ortho-phosphorus
RAS	Return activated sludge
rbCOD	Readily biodegradable COD
SBBR	Sequencing batch biofilm reactor
SBR	Sequencing batch reactor
SND	Simultaneous nitrification and denitrification
SRT	Sludge retention time
SS	Suspended solids
SVI	Sludge volume index
TN	Total nitrogen
TON	Total oxidised nitrogen
TP	Total phosphorus
TSS	Total suspended solids
VSS	Volatile suspended solids
WFD	Water Framework Directive

An Ghníomhaireacht um Chaomhnú Comhshaoil

Is í an Gníomhaireacht um Chaomhnú Comhshaoil (EPA) comhlachta reachtúil a chosnaíonn an comhshaol do mhuintir na tíre go léir. Rialaímid agus déanaimid maoirsiú ar ghníomhaíochtaí a d'fhéadfadh truailliú a chruthú murach sin. Cinntímid go bhfuil eolas cruinn ann ar threochtaí comhshaoil ionas go nglactar aon chéim is gá. Is iad na príomh-nithe a bhfuilimid gníomhach leo ná comhshaol na hÉireann a chosaint agus cinntiú go bhfuil forbairt inbhuanaithe.

Is comhlacht poiblí neamhspleách í an Ghníomhaireacht um Chaomhnú Comhshaoil (EPA) a bunaíodh i mí Iúil 1993 faoin Acht fán nGníomhaireacht um Chaomhnú Comhshaoil 1992. Ó thaobh an Rialtais, is í an Roinn Comhshaoil agus Rialtais Áitiúil a dhéanann urraíocht uirthi.

ÁR bhFREAGRACHTAÍ

CEADÚNÚ

Bíonn ceadúnais á n-eisiúint againn i gcomhair na nithe seo a leanas chun a chinntiú nach mbíonn astuithe uathu ag cur sláinte an phobail ná an comhshaol i mbaol:

- áiseanna dramhaíola (m.sh., líonadh talún, loisceoirí, stáisiúin aistrithe dramhaíola);
- gníomhaíochtaí tionsclaíocha ar scála mór (m.sh., déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta);
- diantalmhaíocht;
- úsáid faoi shrian agus scaoileadh smachtaithe Orgánach Géinathraithe (GMO);
- mór-áiseanna stórais peitreail.
- Scardadh dramhuisce

FEIDHMIÚ COMHSHAOIL NÁISIÚNTA

- Stiúradh os cionn 2,000 iniúchadh agus cigireacht de áiseanna a fuair ceadúnas ón nGníomhaireacht gach bliain.
- Maoirsiú freagrachtaí cosanta comhshaoil údarás áitiúla thar sé earnáil - aer, fuaim, dramhaíl, dramhuisce agus caighdeán uisce.
- Obair le húdaráis áitiúla agus leis na Gardaí chun stop a chur le gníomhaíocht mhídhleathach dramhaíola trí comhordú a dhéanamh ar líonra forfheidhmithe náisiúnta, díriú isteach ar chiontóirí, stiúradh fiosrúcháin agus maoirsiú leigheas na bhfadhbanna.
- An dlí a chur orthu siúd a bhriseann dlí comhshaoil agus a dhéanann dochar don chomhshaol mar thoradh ar a ngníomhaíochtaí.

MONATÓIREACHT, ANAILÍS AGUS TUAIRISCIÚ AR AN GCOMHSHAOL

- Monatóireacht ar chaighdeán aeir agus caighdeáin aibhneacha, locha, uiscí taoide agus uiscí talaimh; leibhéil agus sruth aibhneacha a thomhas.
- Tuairisciú neamhspleách chun cabhrú le rialtais náisiúnta agus áitiúla cinntí a dhéanamh.

RIALÚ ASTUITHE GÁIS CEAPTHA TEASA NA HÉIREANN

- Cainníochtú astuithe gáis ceaptha teasa na hÉireann i gcomhthéacs ár dtiomantas Kyoto.
- Cur i bhfeidhm na Treorach um Thrádáil Astuithe, a bhfuil baint aige le hos cionn 100 cuideachta atá ina mór-ghineadóirí dé-ocsaíd charbóin in Éirinn.

TAIGHDE AGUS FORBAIRT COMHSHAOIL

- Taighde ar shaincheisteanna comhshaoil a chomhordú (cosúil le caighdéan aeir agus uisce, athrú aeráide, bithéagsúlacht, teicneolaíochtaí comhshaoil).

MEASÚNÚ STRAITÉISEACH COMHSHAOIL

- Ag déanamh measúnú ar thionchar phleananna agus chláracha ar chomhshaol na hÉireann (cosúil le pleananna bainistíochta dramhaíola agus forbartha).

PLEANÁIL, OIDEACHAS AGUS TREOIR CHOMHSHAOIL

- Treoir a thabhairt don phobal agus do thionscal ar cheisteanna comhshaoil éagsúla (m.sh., iarratais ar cheadúnais, seachaint dramhaíola agus rialacháin chomhshaoil).
- Eolas níos fearr ar an gcomhshaol a scaipeadh (trí cláracha teilifíse comhshaoil agus pacáistí acmhainne do bhunscoileanna agus do mheánscoileanna).

BAINISTÍOCHT DRAMHAÍOLA FHORGHNÍOMHACH

- Cur chun cinn seachaint agus laghdú dramhaíola trí chomhordú An Chláir Náisiúnta um Chosc Dramhaíola, lena n-áirítear cur i bhfeidhm na dTionscnamh Freagrachta Táirgeoirí.
- Cur i bhfeidhm Rialachán ar nós na treoracha maidir le Trealamh Leictreach agus Leictreonach Caite agus le Srianadh Substaintí Guaiseacha agus substaintí a dhéanann ídiú ar an gcrios ózóin.
- Plean Náisiúnta Bainistíochta um Dramhaíl Ghuaiseach a fhorbairt chun dramhaíl ghuaiseach a sheachaint agus a bhainistiú.

STRUCHTÚR NA GNÍOMHAIREACHTA

Bunaíodh an Ghníomhaireacht i 1993 chun comhshaol na hÉireann a chosaint. Tá an eagraíocht á bhainistiú ag Bord lánaimseartha, ar a bhfuil Príomhstiúrthóir agus ceithre Stiúrthóir.

Tá obair na Gníomhaireachta ar siúl trí ceithre Oifig:

- An Oifig Aeráide, Ceadúnaithe agus Úsáide Acmhainní
- An Oifig um Fhorfheidhmiúchán Comhshaoil
- An Oifig um Measúnacht Comhshaoil
- An Oifig Cumarsáide agus Seirbhísí Corparáide

Tá Coiste Comhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag ball air agus tagann siad le chéile cúpla uair in aghaidh na bliana le plé a dhéanamh ar cheisteanna ar ábhar imní iad agus le comhairle a thabhairt don Bhord.

National Development Plan 2007 - 2013

Science, Technology, Research and Innovation for the Environment (STRIVE) 2007-2013

The Science, Technology, Research and Innovation for the Environment (STRIVE) programme covers the period 2007 to 2013.

The programme comprises three key measures: Sustainable Development, Cleaner Production and Environmental Technologies, and A Healthy Environment; together with two supporting measures: EPA Environmental Research Centre (ERC) and Capacity & Capability Building. The seven principal thematic areas for the programme are Climate Change; Waste, Resource Management and Chemicals; Water Quality and the Aquatic Environment; Air Quality, Atmospheric Deposition and Noise; Impacts on Biodiversity; Soils and Land-use; and Socio-economic Considerations. In addition, other emerging issues will be addressed as the need arises.

The funding for the programme (approximately €100 million) comes from the Environmental Research Sub-Programme of the National Development Plan (NDP), the Inter-Departmental Committee for the Strategy for Science, Technology and Innovation (IDC-SSTI); and EPA core funding and co-funding by economic sectors.

The EPA has a statutory role to co-ordinate environmental research in Ireland and is organising and administering the STRIVE programme on behalf of the Department of the Environment, Heritage and Local Government.

Environmental Protection Agency
An Ghníomhaireacht um Chaomhnú Comhshaoil

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SSTI Strategy for Science, Technology and Innovation

Comhshaol, Oidhreacht agus Rialtas Áitiúil
Environment, Heritage and Local Government