Municipal Wastewater and Pig Slurry Treatment in a Batch Reactor

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Original scientific paper
Received: October 19, 2006
Accepted: September 15, 2007

The degradation of organic compounds, and TKN elimination were studied in a batch reactor under different aerobic and anoxic/anaerobic conditions. The objective of this experimental procedure was to reduce γ_{COD} to below 100 mg L^{-1} and γ_{TKN} to below 10 mg L^{-1}. The experiments were carried out in such a way that the aeration and non-aeration phases were repeated, in sequences. The following systems were tested: 2 + 2 (2 h of aeration and 2 h without aeration), 3 + 2, and 4 + 1. Satisfactory results were obtained in all cases. The expected results were obtained after 10 h of retention time for systems 3 + 2 and 4 + 1 and, after 12 h for system 2 + 2. The best results were obtained for system 4 + 1 after 10 h. The wastewater treated in the batch reactor had the following characteristics: γ_{COD} was 913 mg L^{-1}, γ_{TKN} was 56.0 mg L^{-1}, and $\gamma_{\mathrm{NH_4^+-\mathit{N}}}$ was 33.0 mg L^{-1}. The following results were obtained for treated wastewater (effluent): γ_{COD} = 54 mg L^{-1}, γ_{TKN} = 4.4 mg L^{-1}, and $\gamma_{\mathrm{NH_4^+-\mathit{N}}}$ < 1.2 mg L^{-1}, respectively. The maximal values for specific substrate utilization and nitrification rate were obtained for system 4 + 1; $U_{\mathrm{X,max}}$ was 0.406 h^{-1} and $q_{\mathrm{N,max}}$ was 0.0182 h^{-1}. Such batch tests are appropriate for fast determination of main treatment parameters in regard to existing wastewater treatment plants, where expansion is on programme.

Key words:
Batch reactor, municipal wastewater treatment, nitrogen removal, pig slurry

Introduction

Biological wastewater treatment is generally used for the degradation of organic compounds and for nitrogen reduction within wastewater.[1,2] In an aerobic system, heterotrophic bacteria degrades organic compounds into simpler compounds, then finally into water and CO_2. Autotrophic bacteria transforms organic nitrogen under aerobic conditions into ammonium nitrogen, and then nitrifying bacteria oxidizes ammonium into nitrate under aerobic conditions.[3,4] Nitrate is reduced to nitrogen gas (N_2) under anoxic conditions. Batch reactors enable both aerobic and anoxic/anaerobic processes because they can be exposed to alternating anaerobic and aerobic conditions.[5–10] This is also necessary for enhanced biological ortho-phosphate removal, EBPR.[11–14] In each cycle, ortho-phosphate is released during an initial anaerobic period.[15] Subsequently, the reactor is aerated and ortho-phosphate-accumulated organisms take up the ortho-phosphate.[16] Organisms in such a system are potentially subjected to competition from oxygen.[17,18] Nitrifying bacteria as a pure culture is known to have a lower efficiency for oxygen compared to heterotrophic bacteria, which may cause problems when integrating nitrifying activity in a batch reactor.[19,20]

Application of the SBR is especially suitable for pig slurry treatment. A full scale SBR plant was designed and realized based on laboratory results and process modelling. This plant, over ten months of operation, achieved even better results compared to those in the laboratory.[21] We also investigated the feasibility of using an internally-available carbon source for biological nitrogen and phosphorus removal. A new integrated animal wastewater treatment process consisting of two reactors was operated using various sequences, for the treatment of high strength pig manure. By achieving successful real-time control, very high removal efficiencies regarding organic matter, nitrogen and phosphorus were obtained during both operations. Real-time control made it possible to utilize an internally-available organic material for phosphorus removal and the denitrification of produced NO_x–N, without any external carbon source.[22] A full-scale swine waste treatment system was used to investigate the impact of integrating an intermittent aeration unit on the overall process performance of the swine waste treatment system. The intermittent aeration unit was used for treating a combination of raw liquid manure and anaerobically treated concentrated manure. The removal efficiencies, Total-*N*

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(T-N) and Total-P (T-P) were η = 92.4 %, and η = 59.4 %, respectively, for the intermittent aeration unit.[23] Combined anaerobic–aerobic SBR for the treatment of piggery wastewater was also investigated. They found that the higher the recycle-to-influent ratio, the lower the concentrations of nitrogen oxides in the final effluent.[24] Some authors have also reported: the use of Aerobic Thermophilic Sequencing Batch Reactors (AT-SBR) for studying the treatment of pig manure with a HRT of 6 d. Temperatures up to T = 75 °C were reached without external heating. Better performances were achieved for COD removal when the temperature was limited to T = 50 °C. However, higher temperatures increased the rate of phosphorus crystallization and the volatilization of ammonia.[25] They also tested the use of aerobic nitrifiers in the SBR. Nitrite was the main NO_x species in the effluent for most the reactor's operation time instead of the commonly expected nitrate. This led to the conclusion that the activities of the *Nitrobacter* species were probably inhibited in the SBRs studied.[9]

In our experiment, we decided to treat a municipal wastewater stream containing a percentage of pig slurry from a nearby farm as it passes through a municipal treatment facility. This was because our municipal treatment facility is receiving pig slurry that is greatly influencing the quality of wastewater treatment in the wastewater treatment plant. We chose the SBR because of its effective pig slurry treatment. Therefore, we chose to implement nitrification, denitrification and ortho-phosphate in a single batch reactor in order to save the reactors volume and operation costs. We prepared artificial wastewater that was aerated at different time intervals. We wanted to find out how much influence the aeration time of wastewater, in combination with no aeration had on nitrogen and phosphorus compounds treatment in the SBR, using selected artificial wastewater. Activated sludge containing such microorganisms was transported from the wastewater treatment plant.

Materials and methods

Specific growth rate and substrate utilization

The increase in microbial population can be assessed by the specific growth rate, μ.[26] There are several expressions for μ, the most commonly used is the Monod equation:[27,28]

$$\mu = \mu_{\max} \frac{\gamma_S}{K_S + \gamma_S} \tag{1}$$

Where

μ – specific growth rate, h^{-1}

$\mu_{\max}$ – maximum specific growth rate, h^{-1}

K_S – the saturation constant at half the maximum rate value, mg L^{-1}

γ_S – the limiting of substrate mass concentration, mg L^{-1}

Degradation of organic compounds can be described as a substrate utilization rate:

$$U = \frac{d\gamma_S}{dt} \tag{2}$$

Specific organic utilization rate is expressed as:

$$U_X = \frac{d\gamma_S}{dt\,\gamma_X} \tag{3}$$

Where:

U – organic compounds utilization rate, mg L^{-1} h^{-1}

$d\gamma_S$ – substrate utilized in time difference dt, mg L^{-1}

U_X – specific organic compounds utilization, mg L^{-1} h^{-1}

γ_X – mixed liquor suspended solids (concentration of the activated sludge), mg L^{-1}

Nitrification

Nitrification is a microbial process by which reduced nitrogen compounds are sequentially oxidized to nitrite and nitrate. The nitrification process is primarily accomplished by two groups of autotrophic bacteria that can build organic molecules using energy obtained from inorganic sources, in this case ammonia and nitrite.

In the first step of nitrification, ammonia-oxidized bacteria oxidize ammonia to nitrite according to the equation:

$$NH_4^+ + 1.5\,O_2 \rightarrow NO_2^- + H_2O + 2\,H^+ \tag{4}$$

In the second step of the process, nitrite-oxidized bacteria oxidize nitrite to nitrate according to the equation:

$$NO_2^- + 0.5\,O_2 \rightarrow NO_3^- \tag{5}$$

Nitrosomonas is the most frequently identified genus associated with the first step and *Nitrobacter* is the most frequently identified genus associated with the second.[29]

Various groups of heterotrophic bacteria can also carry out nitrification, although at a slower rate than autotrophic organisms. Heterotrophic bacteria also occur in wastewater applications.[1]

All these changes are the consequence (result) of biodegradation kinetics in the water system. Although the kinetics of nitrification have normally been modelled by zero-order and first-order reactions, a Monod type equation expressing the effect of substrate concentration on the growth of nitrifying bacteria has satisfactorily fitted the data in most nitrification studies.[30] The effects of individual independent-limiting substrates on the specific growth rate can also be expressed, thus, the effects of $NH_4^+ - N$ and dissolved oxygen on the growth rate of *Nitrosomonas* can be described as follows:

$$\mu_{\mathrm{N}} = \mu_{\mathrm{N,max}} \left(\frac{\gamma_{NH_4^+ - N}}{K_{\mathrm{N}} + \gamma_{NH_4^+ - N}} \right) \left(\frac{\gamma_{\mathrm{DO}}}{K_{O_2} + \gamma_{\mathrm{DO}}} \right) \tag{6}$$

Where:

μ_{N} – specific growth rate of *Nitrosomonas*, h^{-1}

$\mu_{\mathrm{N,max}}$ – maximum specific growth rate of *Nitrosomonas* (nitrifiers), h^{-1}

K_{N} – half-saturation constant for $\gamma_{NH_4^+ - N}$, mg L^{-1}

γ_{DO} – dissolved oxygen mass concentration, mg L^{-1}

K_{O_2} – half-saturation constant for oxygen, mg L^{-1}

Similar relationships can be written for the oxidation of nitrite in terms of *Nitrobacter* and with $\gamma_{NO_2^- - N}$ as substrate. Because the first step of nitrification is generally the rate-limiting reaction, the nitrifier growth rate can be modelled based on the conversion of ammonium to nitrite by *Nitrosomonas*. The ammonium oxidation rate can be measured in order to quantify how fast the ammonium is oxidized to nitrate. It should be noted that over ζ = 99 % of the total ammonia nitrogen $(NH_3 + NH_4^+) - N$ in normal domestic wastewater of pH 7 is in the form of ammonium ions $(NH_4^+ - N)$. The ammonium oxidation rate (q_{N}) for activated sludge is often expressed in units of mg $NH_4^+ - N$ removed per hour for each g MLVSS in the aeration tank, as follows:[30]

$$\frac{\mathrm{d}\gamma_{NH_4^+ - N}}{\mathrm{d}t} = q_{\mathrm{N}} \gamma_{\mathrm{X}} \tag{7}$$

And

$$q_{\mathrm{N}} = \frac{\mathrm{d}\gamma_{NH_4^+ - N}}{\mathrm{d}t\, \gamma_{\mathrm{X}}} \tag{8}$$

The ammonium oxidation rates (q_{N}) are commonly 1 – 3 mg g^{-1} h^{-1}.[30]

Denitrification

The biological denitrification process is based on the following reaction, in which NO_3^- is reduced to N_2:

$$\begin{array}{lr} 2NO_3^- + 4e^- \rightarrow 2NO_2^- & (9) \\ 2NO_2^- + 6e^- \rightarrow N_2 \uparrow & (10) \\ \hline 2NO_3^- + 10e^- \rightarrow N_2 \uparrow & (11) \end{array}$$

In order to ensure good bacterial growth, it is necessary to have the correct mixture of nutrients containing carbon, nitrogen and phosphorus in the mass ratio of $\zeta_{C/N/P} = 100:5:1$.[31]

The efficiency of the denitrification reaction not only depends on the organics vs. nitrates ratio, but also on the pH, the water temperature and the retention time in the activated sludge treatment plant. The overall denitrification reaction is defined as:

carbon source + bacteria + nitrate →
→ N_2 + water + carbon dioxide

The kinetic reaction for denitrification by activated sludge can be expressed as:

$$\frac{\mathrm{d}\gamma_{\mathrm{N}}}{\mathrm{d}t} = q_{\mathrm{D}} \gamma_{\mathrm{X}} \tag{12}$$

Where

$\mathrm{d}\gamma_{\mathrm{N}}/\mathrm{d}t$ – denitrification rate $\gamma_{NO_2^- + NO_3^- - N} / t$, mg L^{-1} h^{-1}

γ_{N} – nitrite plus nitrate mass concentration, mg L^{-1}

t – time, h

q_{D} – specific denitrification rate $m_N/(m_{\mathrm{VSS}}t)$, mg mg^{-1} h^{-1}

And

$$q_{\mathrm{D}} = \frac{1}{\gamma_{\mathrm{X}}} \cdot \frac{\mathrm{d}\gamma_{\mathrm{N}}}{\mathrm{d}t} \tag{13}$$

This indicates that the denitrification rate is independent of the nitrate mass concentration and the only function of the volatile suspended solids concentration.

Wastewater composition

Mixed municipal and industrial wastewater was used for our experiments. The wastewater was composed of approximately φ = 60 % household wastewater, φ = 38 % industrial wastewater (municipal wastewater from the sewerage system) and φ = 2 %

pig slurry (from the nearest pig farm), respectively. The pig slurry contained a high concentration of total Kjeldahl nitrogen (TKN), in which ζ = 55–70 % of TKN was in an ammonium form (Table 1).

Table 1 – *Average composition of different types of wastewater*

Wastewater	Municipal	Pig slurry	Composed
γ_{COD}, mg L^{-1}	640	7000	731
γ_{TKN}, mg L^{-1}	45	1450	65
$\gamma_{\mathrm{NH_4^+}-N}$, mg L^{-1}	18	1180	34.5
$\gamma_{\mathrm{NO_3^-}-N}$, mg L^{-1}	0.5	2.5	0.5
$\gamma_{\mathrm{o}-P}$, mg L^{-1}	2.5	9.1	2.6
V, m^3	16485	238	-
φ, %	98.6	1.4	-

The pig slurry was obtained from the outflow of a pig farm located near the wastewater treatment plant. Municipal wastewater (a mixture of household and industrial wastewater) was obtained from the sewerage system that flows into the city's wastewater treatment plant. The wastewater used for the experiments was a mixture of municipal wastewater and pig slurry, with no preliminary treatment.

Experimental system

A range of batch tests was carried out. An V = 8 L batch reactor was used for the experiments (Fig. 1). V = 0.5 L of concentrated mixed liquor suspended solids taken from the return sludge pumping station of the municipal wastewater treatment plant was placed (γ_{MLSS} = 6.25 g L^{-1}, γ_{MLVSS} = 5.22 g L^{-1}) into the reactor. V = 6.0 L of wastewater was added to this sludge (a mixture of φ = 98 % municipal wastewater and φ = 2 % pig slurry). The temperature in the reactor was kept constant (T = 20 °C). The activated sludge and wastewater was mixed using a Hydro 40 II stirrer. The system was aerated periodically using a Hi-top 1500 aquarium pump.

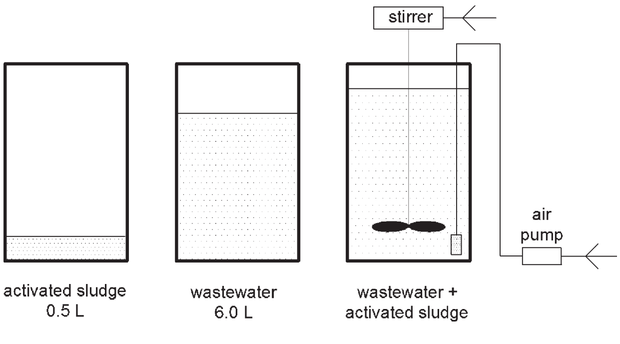

Fig. 1 – *Experimental set-up*

Start-up. The activated sludge was first adapted to the tested wastewater (a mixture of municipal wastewater and pig slurry) due to a semi-continuous procedure when aerobic and anoxic/anaerobic conditions were also considered.

Operating. After adaptation (about one week), batch tests were carried out by exchanging aerobic and anoxic/anaerobic phases, as follows:

– Experiment 1: t = 2 h aerobic phase + t = 2 h anoxic/anaerobic phase (2+2)

– Experiment 2: t = 3 h aerobic phase + t = 2 h anoxic/anaerobic phase (3+2)

– Experiment 3: t = 4 h aerobic phase + t = 1 h anoxic/anaerobic phase (4+1)

Every experiment was continued until the γ_{COD} was reduced to below 100 mg L^{-1} and γ_{TKN} to below 10 mg L^{-1}. We carried out analyses for at least for 4 periods. The dissolved oxygen concentration was between $\gamma_{\mathrm{O_2}}$ = 0.1 mg L^{-1} and $\gamma_{\mathrm{O_2}}$ = 8.5 mg L^{-1}, depending on redox conditions, and the pH values were between 7.7 and 8.2 with no chemical additions. The composed wastewater was stirred constantly in the reactor during all experiments. At the beginning of the test and after every period (aerobic + anoxic/anaerobic phases), the following analyses were carried out: γ_{COD}, γ_{TKN}, $\gamma_{\mathrm{NH_4^+}-N}$, $\gamma_{\mathrm{NO_2^-}-N}$, $\gamma_{\mathrm{NO_3^-}-N}$, and $\gamma_{\mathrm{o}-P}$. All analyses were conducted according to Standard Methods.[32]

Results

The results for individual experiments are shown in the following tables, where influent means the mixture of municipal wastewater and pig slurry, and the effluent treated wastewater after the defined periods (t = 4 h or t = 5 h, respectively). Specific organic utilization and nitrification rates were also calculated, and are shown in the same tables.

Experiments and discussion

During experimentation, activated sludge and wastewater were aerated periodically (t = 2 h with aeration and t = 2 h without aeration for the first experiment; t = 3 h aeration and t = 2 h without aeration for the second; t = 4 h aeration and t = 1 h without aeration for the third). Analyses were performed at the beginning and every four or five hours. The total experiment after adaptation of the activated sludge lasted t = 16 h, t = 20 h, and t = 20 h, respectively for experiments 1, 2, and 3. Tables 2, 3, and 4 show the parameters of individual analyses, treatment efficiencies, specific substrate utilization rates and nitrification utilization rates.

Table 2 – *Parameters for individual analyses, treatment efficiencies, specific substrate utilization rates and nitrification utilization rates – Experiment 1*

Parameter	Influent	Effluent			
t, h	0	4	8	12	16
γ_{COD}, mg L^{-1}	402	80	52	44	40
– treat. efficiency η, %		80.1	87.1	89.1	90.0
γ_{TKN}, mg L^{-1}	50.0	26.0	16.3	7.9	4.2
– treat. efficiency η, %		48.0	67.4	84.2	91.6
$\gamma_{\mathrm{NH_4^+}-N}$, mg L^{-1}	35.0	21.0	14.4	6.9	3.9
$\gamma_{\mathrm{NO_2^-}-N}$, mg L^{-1}	0.1	0.2	1.0	1.8	1.9
$\gamma_{\mathrm{NO_3^-}-N}$, mg L^{-1}	0.5	0.7	0.8	2.1	2.2
$\gamma_{\mathrm{o}-P}$, mg L^{-1}	4.6	3.7	3.6	3.6	3.5
– treat. efficiency η, %		19.6	21.7	21.7	23.9
U_{X}, h^{-1}		0.200	0.109	0.074	0.056
q_{N}, h^{-1}		0.0149	0.0105	0.0087	0.0071

Table 3 – *Parameters for individual analyses, treatment efficiencies, specific substrate utilization rates and nitrification utilization rates – Experiment 2*

Parameter	Influent	Effluent			
t, h	0	5	10	15	20
γ_{COD}, mg L^{-1}	518	69	56	48	47
– treat. efficiency η, %		86.7	89.2	90.7	90.9
γ_{TKN}, mg L^{-1}	51.0	18.7	8.8	2.5	2.3
– treat. efficiency η, %		63.3	82.7	95.1	95.5
$\gamma_{\mathrm{NH_4^+}-N}$, mg L^{-1}	34.0	18.0	7.7	0.9	0.8
$\gamma_{\mathrm{NO_2^-}-N}$, mg L^{-1}	0.2	1.3	1.0	1.2	0.2
$\gamma_{\mathrm{NO_3^-}-N}$, mg L^{-1}	0.5	1.3	0.5	2.0	1.6
$\gamma_{\mathrm{o}-P}$, mg L^{-1}	8.5	6.6	6.2	3.5	3.8
– treat. efficiency η, %		22.4	27.1	58.8	55.3
U_{X}, h^{-1}		0.223	0.115	0.078	0.059
q_{N}, h^{-1}		0.0161	0.0105	0.0080	0.0061

Table 4 – *Parameters for individual analyses, treatment efficiencies, specific substrate utilization rates and nitrification utilization rates – Experiment 3*

Parameter	Influent	Effluent			
t, h	0	5	10	15	20
γ_{COD}, mg L^{-1}	913	97	54	47	37
– treat. efficiency η, %		89.4	94.1	94.9	95.9
γ_{TKN}, mg L^{-1}	56.0	19.5	4.4	4.0	3.0
– treat. efficiency η, %		65.2	92.1	92.9	94.6
$\gamma_{\mathrm{NH_4^+}-N}$, mg L^{-1}	33.0	16.0	1.2	0.65	0.59
$\gamma_{\mathrm{NO_2^-}-N}$, mg L^{-1}	0.8	3.1	3.0	0.2	0.3
$\gamma_{\mathrm{NO_3^-}-N}$, mg L^{-1}	4.7	2.9	4.8	6.3	4.8
$\gamma_{\mathrm{o}-P}$, mg L^{-1}	8.7	5.6	2.5	1.5	1.8
– treat. efficiency η, %		35.6	71.3	82.8	79.3
U_{X}, h^{-1}		0.406	0.214	0.144	0.109
q_{N}, h^{-1}		0.0182	0.0128	0.0086	0.0066

The goal of all experiments was a reduction of γ_{TKN} to below 10 mg L^{-1} and γ_{COD} to below 100 mg L^{-1}, which was reached in all tests. It was discovered that the specific substrate utilization and nitrification rates for individual experiments were different. The denitrification rate was impossible to determine because of the repetition of aerobic and anoxic/anaerobic phases.

Maximal specific substrate rates were calculated by means of eq. (3) and are shown in Fig. 2. The most effective system was in experiment 3 (U_{X} = 0.406 h^{-1}).

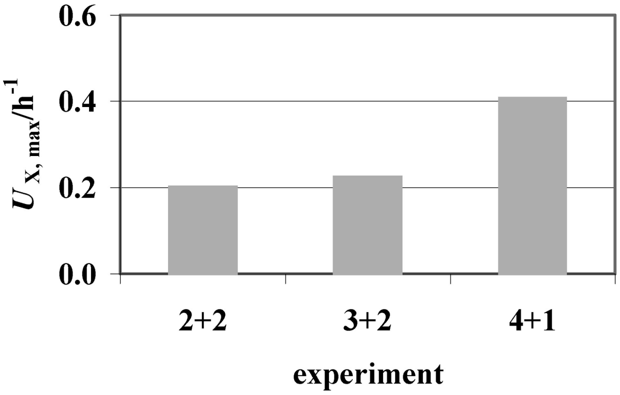

Fig. 2 – *$U_{X,max}$ for different experiments*

Comparison of specific substrate utilization rates (Tables 2-4) reveals that the quickest utilization was in experiment 3 and was comparable to experiments 1 and 2.

In regard to the nitrification rates calculated by means of eq. (8), the best results were obtained in experiment 3 (q_{N} = 0.0182 h^{-1}) and are shown in the Fig. 3.

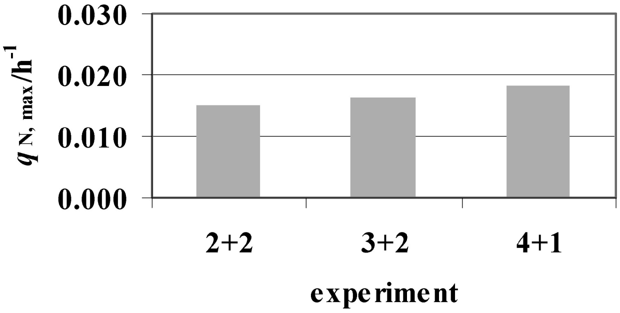

Fig. 3 – $q_{N,max}$ *for different experiments*

When comparing the results in Table 4, we discovered that they had reached the prescribed values for γ_{TKN} (< 10 mg L^{-1}) and γ_{COD} (< 100 mg L^{-1}). Thus, we had reached the prescribed values in experiment 1 for γ_{COD} after t = 4 h (80 mg L^{-1}), and for γ_{TKN} after t = 12 h (7.9 mg L^{-1}); in experiment 2 for γ_{COD} after t = 5 h (69 mg L^{-1}), and for γ_{TKN} after t = 10 h (8.8 mg L^{-1}), and in experiment 3 for γ_{COD} after t = 5 h (97 mg L^{-1}), and for γ_{TKN} after t = 10 h (4.4 mg L^{-1}), respectively. Taking into account both the prescribed values, the following values were obtained (Table 5) for both critical parameters (COD and TKN).

The efficiency of ortho-*P* reduction is presented in Table 5.

Table 5 – *Minimal time required for reaching both limit values (for COD and for TKN) and values of ortho-P*

Parameter	Experiment 1 after t = 12 h	Experiment 2 after t = 10 h	Experiment 3 after t = 10 h
γ_{COD}, mg L^{-1}	44	56	54
γ_{TKN}, mg L^{-1}	7.9	8.8	4.4
$\gamma_{\mathrm{NH}_4^+-N}$, mg L^{-1}	6.9	7.7	1.2
$\gamma_{\mathrm{o}-P}$, mg L^{-1}	3.6	6.2	2.5

Different experimental conditions lead to different results. Among all the experiments, the best final result was obtained in experiment 3, namely after 10 hours the lowest values for COD (γ_{COD} = 54 mg L^{-1}), TKN (γ_{TKN} = 4.4 mg L^{-1}), and ammonia nitrogen ($\gamma_{\mathrm{NH}_4^+-N}$ < 1.2 mg L^{-1}), respectively. The maximal specific substrate and nitrification rates (Fig. 2 and Fig. 3) show the same values.

Conclusions

We carried out batch experiments for treatment of mixed municipal wastewater (domestic and industrial) and pig slurry, using a batch reactor with aerobic and anoxic/anaerobic phases in sequences. We chose the following sequences: t = 2 h of aerobic phase and t = 2 h of anoxic/anaerobic phase (2+2), t = 3 h of aerobic phase and t = 2 h of anoxic/anaerobic phase (3+2), and t = 4 h of aerobic phase and t = 1 h of anoxic/anaerobic phase (4+1), respectively. From all the results, we calculated the specific substrate utilization rate and found the highest value in the experiment 4+1 (U_{X} = 0.41 mg L^{-1} h^{-1}). The nitrification rate was also the highest in experiment 4+1 (q_{N} = 0.018 mg L^{-1} of $\mathrm{NH}_4^+ - N$ per mg L^{-1} of MVSS per hour). The best results for final effluent were obtained in experiment 4+1, being the most suitable results for the effluent. After t = 10 h the γ_{COD} was 54 mg L^{-1}, γ_{TKN} was 4.4 mg L^{-1}, and $\gamma_{\mathrm{NH}_4^+-N}$ was < 1.2 mg L^{-1}, respectively.

The best results for ortho-*P* removal (η = 71 %) were obtained in experiment 3.

Batch tests are suitable for determining proper substrate utilization and ammonia reduction for those wastewater treatment plants that would like to improve their treatment. Such tests are relatively simple and do not require sophisticated equipment. Skilled staff at the treatment plant can carry out such experiments themselves together with corresponding analytical support and some professional advice.

List of symbols

K – half saturation constant, mg L^{-1}
q_{D} – specific denitrification rate, mg mg^{-1} h^{-1}
q_{N} – ammonium oxidation rate, mg mg^{-1} h^{-1}
U – organic compounds utilization rate, mg L^{-1} h^{-1}
T – temperature, °C
t – time, h
V – volume, L
γ – mass concentration, mg L^{-1}
ζ – mass ratio
η – efficiency, %
μ – specific growth rate, h^{-1}
φ – volume ration, %

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