Monitoring and control of a partially packed biological aerated filter (BAF) reactor for improving nitrogen removal efficiency

Pramanik Biplob, Suja Fatihah, Zain Shahrom and Elshaifie Ahmed

ABSTRACT

This paper examines on-off systems and automatic monitoring and control of a biological aerated filter to identify the end point of nitrification and denitrification processes, and chemical oxygen demand (COD), ammonia-nitrogen removal (NH₃-N) and aeration savings. Oxidation-reduction potential (ORP), pH and dissolved oxygen (DO) were measured on-line and chemical parameters were measured in the wastewater. The ‘nitrate knee’ in the ORP profile was characterised by a breakpoint at average 160 min, representing the complete removal of NO₃-N, i.e. the end of the denitrification period, as well as the end of the nitrification period was clearly shown in the pH profile (ammonia valley) at average 210 min for all C/N ratios. The NH₃-N removal efficiencies were 92.30, 97.57 and 98.02% whilst the COD removals of 95.06, 96.38 and 97.56% were achieved for the C/N ratios of 10, 4 and 1 respectively. Therefore, the on-off control was operated at average 230 min for aeration time and 130 min for the anoxic period. Thus significant improvements can be achieved with respect to the continuous aeration strategy, and average operational costs reduced by 36.11%. The study showed that an on-off controller can easily be implemented in wastewater process-control, and monitoring systems improve effluent quality and reduce energy consumption.

Key words | biological aerated filter, dissolved oxygen, on-off controller, oxidation-reduction potential, pH

INTRODUCTION

With the continuing need to increase wastewater effluent quality by removal of nitrogen and carbon, process monitoring and control have become more important, both economically and technically. Aeration control is of great importance because of the generally large energy consumption of the aeration system. The aeration cost may be up to 70% of the total electricity cost of wastewater treatment plants for carbon and nitrogen removal (Zhan et al. 2009). However, the lack of suitable on-line sensors for monitoring key process variables such as nutrient concentrations limits the effective control of effluent quality, especially in biological wastewater treatment (Harremoes et al. 1995; Hong et al. 2007; Biplob 2010). The use of on-off control of the biological aerated filter (BAF) may help to solve these problems, although little information is available on the performance of the BAF under controlled and monitored conditions.

In this study, on-line control of a BAF reactor was evaluated with regard to removal efficiency. On-line monitoring of oxidation-reduction potential (ORP), pH and dissolved oxygen (DO) and control of DO and pH value was performed for this study on a BAF reactor, using a system which has been applied previously to maintain the nitrification-denitrification via nitrite process and to...
an automatically controlled sequencing batch reactor (SBR) reactor for nitrogen removal (Yu et al. 2000; Yuana & Gaoa 2010). The pH, DO and ORP values were continuously monitored and controlled on-line to determine the effects of variation of these parameters on the bioprocess system. The DO concentration is an important parameter that influences the operation of the aerobic phase in biological reactors. Excessive DO levels will cause unnecessary power consumption due to increased aeration and may affect the anoxic processes, while low DO levels will inhibit the growth of nitrifying bacteria (Yong et al. 2006). Previous studies also indicated that the management of DO levels at a low level will not only save aeration energy but also improve the denitrification rate (Ekman et al. 2006; Yang et al. 2010; Chen et al. 2010). So the optimal DO for the simultaneous nitrification and denitrification should be the lowest DO level for which effluent ammonia concentration can meet with the discharge standards (Liu et al. 2010). In most aerobic biological systems, such as nitrification processes, oxygen is the requisite oxidant and the presence of DO at specific levels is a necessary condition for these processes to proceed unimpeded. The DO concentration roughly corresponds to microbial activity in aerobic conditions, where DO is utilised to oxidise chemical oxygen demand (COD) and ammonia-nitrogen (NH₃-N).

The overall reactions of biological and physiochemical processes are represented by ORP; as such many researchers have explored the efficiency and reliability of automatic control approaches to biological nitrogen removal by monitoring ORP (Plisson et al. 1996; Caulet et al. 1998). It also provides much better information about the processes in the anoxic phases. Some researchers have reported linear relationships between ORP and log DO, which indicates the superior sensitivity of ORP over DO measurements at low oxygen levels (Peddie et al. 1990; Janssen et al. 1998; Ndegwa et al. 2007). The ORP data are used for the real-time and time distribution controls because they provide important information about the treatment process during the operation time. The operation cycle for the aerobic and anoxic phases is optimised because the operation time is very important in saving energy during treatment. In bio-treatment, the pH also indicates the characteristics of biological reactions occurring in aerobic and anoxic processes. The on-line controller is able to detect the process state, by identifying each phase of the treatment system, and to control the evolution of the BAF reactor plant.

The ORP and pH profiles are capable of pinpointing the ends of nitrification and denitrification through the identification of breakpoints in aerobic and anoxic processes. Detailed data (NH₃-N, COD and NO₃-N) were taken for monitoring and controlling the BAF reactor. The terms ‘nitrogen breakpoint’/‘DO elbow’ and ‘ammonia valley’ indicate the end of nitrification, in ORP and pH profiles, respectively (Al-Ghusain et al. 1994; Ra et al. 1999). Several investigators have also identified the ‘nitrate knee’ in ORP profiles and the ‘nitrate apex’ in pH profiles, which indicate the end of denitrification (Koch & Oldham 1985; Al-Ghusain & Hao 1995). The nitrogen breakpoint was effectively used to adjust the duration of the aerobic phase in accordance with the variation of influent NH₃-N concentration. The ORP values increased with aeration and reach a maximum at the end of the aerobic phase.

In the last decade, on-off control systems have gained acceptance in several fields, perhaps because of their advantage of being a possible control strategy for automation and monitoring in wastewater treatment plants to identify the endpoint of biological reactions (Spagni & Marsili-Libellis 2010). The on-off controller is simple and cheap. The concept of the on-off controller was based on the architecture of minimum two inputs and one output. Therefore, it can be easily applied to a process where there is not a need for exact control. The on-off controller often produced high oscillations at the setpoint due to its robustness (Rhee et al. 2004). The control of a BAF reactor is quite simple from the point of view of the control policy, but its implementation presents some difficulties related to actual technological limitations because of the high number of variables involved and the multivariable nature of the problem (Guerrero et al. 2011). Therefore, despite the popularity of on-off controllers, research was needed to investigate the effectiveness of ORP, pH and DO profiles for indicating biological nitrogen removal and to establish control strategies for these processes to reduce aeration and achieve good nitrogen removal performance.
MATERIALS AND METHODS

Operation of BAF and experimental design

A BAF with a working volume of 26 L has been used in this study. The height and diameter of the cylinder reactor are 1.5 m (0.65 m in the attached growth zone and 0.85 m in the suspended growth zone) and 0.15 m respectively. The upper part of the reactor was filled with plastic media (Kaldnes K1, Sweden) and a polypropylene mesh was positioned between the suspended growth and attached growth zones to keep the media in place. The system was operated at 30 ± 2 °C temperature. A schematic of the experimental set-up is shown in Figure 1.

The experimental equipment consisted of the partial-bed reactor, one feed tank, one effluent tank, interconnecting pipe network, pumping facilities, personal computer (PC), one alkaline tank, diffuser and the sensors for ORP (RD1R5, Serial no 0911430462, Band Hach, USA), pH (PD1R1, Serial no 0804670014, Band Hach) and DO (5540DOA, Band Hach). A Masterflex peristaltic pump (USA, Model No 77200-60) was used to supply the feed. The data were recorded using ORP (P33, Serial No 0804670018, Band Hach), pH (P33, Serial No 0804670014, Band Hach) and DO (D33, Serial No 0802670003, Band Hach) meters. An air compressor was used for aeration. The air pump was connected to the air diffuser, which was placed at the bottom of the column to provide air to the reactor. During the study period, the COD load was set at 0.405 kg COD m⁻³ d⁻¹ and the loads of NH₃-N were calculated based on C/N ratios.

On-line process control set-up

On-line monitoring of ORP, pH and DO and control of DO and pH value was used in this study. The monitoring and control system was developed in the Visual Basic (version 6.0) software platform, which provided all process signals.
(DO, pH and ORP) through a digital acquisition board and was monitored by a local PC. The system was developed by ControlEZ Technology Sdn Bhd, Selangor, Malaysia. Three signal transmitters (for three probe meters) were connected to a data acquisition card which was set up in a PC. The PC showed the pH, DO and ORP values. The current value passed from the reactor to the meter board, and finally the voltage value was obtained from the PC. The set-up of the control system is shown in Figure 2.

During the experimental period, the DO was set at 2.5 mg/L. The air valve was automatically on when the DO fell to below 2.5 mg/L. Likewise, the valve was automatically off when the DO was above the setpoint.

The pH was also set at 7.5 (unit). One peristaltic pump (Model 77200-62, USA) set at a flow rate of 10 mL/min was used for alkaline addition (0.1 N NaOH), and was automatically on when the pH value was below 7.5.

In on/off regulation, the regulator instantaneously commands the system. As long as the regulated variable value is lower than the setpoint, the command variable is set to 100% (on). As soon as the values reach or exceed the setpoint, the command variable is set to 0% (off).

Dissolved oxygen control in the BAF reactor carried out using the simple on/off algorithm was based on the application of fixed voltages: 5 V, when the DO concentration was lower than the setpoint (2.5 mg/L), and 0 V, when it exceeded this setpoint. Note that the value of 5 V was empirically chosen for the application. For a lower voltage, the DO tended to be higher than the setpoint. Regarding the on/off control quality with these values, the DO presented fluctuations and significant setpoint overtakings.

Synthetic wastewater

Synthetic wastewater prepared in the laboratory was used to provide a consistent organic substrate for the loadings. The synthetic feed was formulated by considering major nutritional requirements for microbial growth including sources of carbon; sources of energy; electron acceptors; nitrogen sources; sources of other major mineral nutrients such as sulphur, phosphate, potassium, magnesium and calcium; vitamin and trace metal requirements. The composition of the synthetic wastewater, prepared with tap water, is shown in Table 1.
Activated sludge

Activated sludge from the Indah Water Putrajaya Sewage Treatment Plant was used as a seeding culture because of its high suspended biomass concentration, which leads to rapid biofilm formation (Mann et al. 1999). The mixed-liquor suspended-solids (MLSS) value was approximately 2,500 mg/L. In this seeding process, the activated sludge was fed daily batchwise with 0.405 kg COD m⁻³ d⁻¹ of synthetic wastewater until a high concentration of biomass was obtained and a biofilm was formed on the plastic particles.

Analysis

Chemical analyses of COD, NH₃-N and NO₃-N were conducted according to the standard methods (APHA 1998). During the operation period, the BAF reactor was operated for 12 days for each C/N ratio, but the samples for NH₃-N, NO₃-N and COD were analysed on day 1 for each C/N ratio. Samples were collected at 15 min intervals from the effluent pipe, over 6 h hydraulic residence time (HRT). The on-line pH, DO and ORP data were stored in the data file by each minute. All samples were analysed after being filtered through 47-mm filter paper with the pore size of 0.45 μm.

RESULTS AND DISCUSSION

Studies on on-off control of BAF systems using DO, pH and ORP probes (DO, pH and ORP probe for monitoring and DO, pH probe for controlling) have been carried out to enhance nitrogen removal and to reduce operational costs under an off-on aeration system. Bending points on the pH, DO and ORP curves are identified by the on-off controller and used to define the end of nitrification and denitrification.

Operating stability in a biological reactor is very important for wastewater treatment. The quality of the effluent would be influenced by the variation in the influent loading because of lack of more flexible operation of the reactor. The biological reactor operation with real-time control could usually provide stable performance at the time when a disturbance in the wastewater influent loading occurred in the treatment system (Janssen et al. 1998). The NH₃-N removal efficiencies were 92.30, 97.57 and 98.02% whilst the COD removals of 95.06, 96.38 and 97.56% were achieved for the C/N ratios of 10, 4 and 1 respectively, at 6 h cyclic time during the controlled operation of BAF. Zhan et al. (2009) also investigated the intermittent SBR and the COD and ammonia removal was 98 and 99%, respectively.

Controlling parameter profiles

The typical pH profile

A decrease in pH was caused by the reduction of alkalinity, and acid production during nitrification (Peng et al. 2006; Biplob et al. 2011). After completion of nitrification, the pH started to increase because no more acid was produced during the conversion of nitrite to nitrate and the excessive aeration stripped CO₂ gas from the system (Yuana & Gaoa 2010). Theoretically, pH should not vary in the course of converting nitrite to nitrate because no hydrogen ions are produced, which is contrary to the process of ammonia conversion to nitrite. In bio-treatment, the pH value of a biological system responds to microbial reactions, and hence the pH variation often provides a good indication of the ongoing biological reactions.

With the start of aeration, the pH values began to decrease at 210 min, when the C/N ratio was 1 (Figure 3(a)). Similar pattern of pH values were observed when C/N was 4 at 225 min (Figure 3(b)). When C/N was 10, the pH value was observed to decrease at 195 min (Figure 3(c)).

Table 1 | Synthetic wastewater prepared with tap water and its composition

<table>
<thead>
<tr>
<th>Source</th>
<th>Composition</th>
<th>Concentration (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD</td>
<td>Glucose</td>
<td>1,000</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>NH₄Cl</td>
<td>600</td>
</tr>
<tr>
<td></td>
<td>KNO₃</td>
<td>50</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>KH₂PO₄</td>
<td>7.5</td>
</tr>
<tr>
<td></td>
<td>Na₂HPO₄</td>
<td>944</td>
</tr>
<tr>
<td>Nutrients</td>
<td>MgCl₂ 6H₂O</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>MnCl₂ 4H₂O</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>FeCl₂ 6H₂O</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>CaCl₂ 2H₂O</td>
<td>7.5</td>
</tr>
</tbody>
</table>
In the aerobic phase, the pH decreased mainly due to hydrogen ion release during the nitrification process. The aerobic phase can be terminated when the ammonium concentration falls to a minimum. This point was detected by pH data. After this point, pH continuously increased and reached a maximum value in the range 8.3–8.6 (Figures 3(a), (b) and (c)).

The decrease in pH is caused by the removal of ammonia from the system, as ammonia is strongly related to alkalinity of the wastewater. The end of nitrification was identified based on the bending points of pH and DO when the oxidation of NH$_3$-N was finished and the aeration stopped; however, it was not possible to detect the end of denitrification (nitrate phase) based on the pH data.

**The typical ORP profile**

On-line monitoring of ORP has been shown to be a practical and useful technique for process control of wastewater treatment systems to remove biological nitrogen. The ORP was only monitored during operation. The ORP-time profile showed distinctive turning points, which directly correlated with the changes in the system chemistry and biological activity. Typically, at C/N 1, ORP range during the aerobic phases was +128 mV to −21 mV and the anoxic phase ranged from −44 mV to +156 mV (Figure 4(a)). For C/N 4, a similar pattern of ORP ranges was observed at +134 mV to −26 mV during the aerobic phase while the anoxic phase was −56 mV to +158 mV (Figure 4(b)), and for C/N 10, the ORP range during the aerobic phases was 127 mV to −12 mV and that of the anoxic phases was −38 mV to 137 mV (Figure 4(c)).

It was found that the ORP value in the anoxic zone was about −44 mV (Figure 4(a)), −56 mV (Figure 4(b)) and −38 mV (Figure 4(c)), which could realize the maximum NO$_3$-N removal due to DO drops with the corresponding NO$_3$-N concentration of about 2.5 mg/L, 2.8 mg/L and 2.5 mg/L respectively. Peng et al. (2006) also found that the ORP value in the anoxic zone was about −90 mV with the nitrate concentration of 2 mg/L during their operation.

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**Figure 3** | pH profiles with time at (a) C/N 1; (b) C/N 4; (c) C/N 10.
and it was designated as the nitrate knee. This point indicates the end of denitrification and conversion of NO₃-N. Therefore, NO₃-N dominates the ORP value. Ndegwa et al. (2007) observed that the decline in ORP represents the more active microbial degradation of wastewater or the consumption of the more easily degradable organic matter in the wastewater.

The ORP was found to be a useful indicator of the DO concentration at this low level and the denitrification rate was found to decrease linearly with increasing ORP. Under aerobic conditions, ORP value decreased, but the increase in ORP after the termination of nitrification is probably due to increase in DO. The trends of ORP values are linearly correlated to the logarithm of DO concentrations. The ORP value is mainly dependent on the DO concentration. The increase in DO corresponds to a decrease in bacterial respiratory activity due to the depletion of substrate (Pavgelj et al. 2001). Here, the ORP profiles showed the capability of pinpointing the end of denitrification through the identification of breakpoints in the anoxic process.

The typical DO profile

The DO profile can only be used in the aerobic phase when the value is above zero. The DO concentration is an important parameter that influences the operation of the aerobic phase in biological reactors because of its impact on the biological processes and the energy costs related to aeration. The proper control of DO could achieve improved process

Figure 4 | The ORP profile with time at: (a) C/N 1; (b) C/N 4; (c) C/N 10.
performances, and there is an economic incentive to mini-
mize excess oxygenation while the nitrifying bacteria
convert NH$_3$-N to NO$_3$-N by supplying only necessary air
to the mixed liquors in the BAF reactor.

Dissolved oxygen data are always used to identify the
end point of nitrification. For C/N 1, a DO breakpoint indi-
cates the end of the nitrification period at 165 min with the
corresponding DO value of about 0.3 mg/L (Figure 5(a)).
The decline of DO concentration could lead to a decreased
oxygen penetration depth, further affecting the nitrification
efficiency (Yuana & Gaoa 2010). For C/N 4, the end of nitri-
fication was at 165 min with the corresponding DO value of
about 0.4 mg/L (Figure 5(b)). For C/N 10, the end of nitri-
fication was at 150 min with DO 0.2 mg/L (Figure 5(c)). pH
and DO curves tend to show a breakpoint occurring at the
same moment in time. Marsili-Libelli (2006) proposed that
when the curve of DO concentrations with respect to time
levels off, i.e. $\frac{d\text{DO}}{dt} = 0$; nitrification ends and it is also
assigned the termination point of aerobic phase during the
operation.

The ultimate DO breakthrough occurs when ammonia
concentration becomes essentially depleted and/or
reaches a limiting value, which means that there is
no oxygen demand for nitrification oxidation. The DO
value began to increase at the beginning of aeration in the
reactor.

**On-off control system performance at different C/N ratios**

In this study, the real-time control of BAF reactor was per-
formed by the air on-off operation. The pH, DO and ORP
have been found to be very useful parameters for monitoring
biological systems to detect the end points. In order to eval-
uate the meaning of the relevant points, the dynamics of
nitrogen forms can be analysed. The NH$_3$-N, COD and
NO$_3$-N data were obtained at 15 min intervals to detect
the completion times of the nitrification and denitrification
processes in the aerobic and anoxic phases during one
cycle (6 h).

![Figure 5](http://iwaponline.com/jwrd/article-pdf/1/3/160/375898/160.pdf)

**Figure 5** The DO profile with time at: (a) C/N 1; (b) C/N 4; (c) C/N 10.
Figures 6–8 shows the chemical profiles and on-line signals of DO, pH, and ORP, from which the end point of nitrification and denitrification could be obtained. The control system detects all the breakpoints by using the real-time information control unit.

Under oxic conditions, ammonia decreases with time and nitrate concentration increases with time as ammonia is converted to nitrate through nitrification. However, for the three C/N ratios, the end of nitrification was clearly visible in the pH profile (ammonia valley) by 210, 225 and 195 min (average 210 min) (Figures 6(b), 7(b) and 8(b)). When the ammonia valley point appeared in the pH profile, chemical analyses showed the complete removal of ammonia and therefore indicated the end of nitrification. Once the ammonia valley is reached, rapid increase in pH was observed during operation. This is primarily due to stripping of CO₂ from the system. There are characteristic points in the curves of DO and pH, respectively, which could indicate the end point of nitrification. For the three C/N ratios, the oxic phase stopped automatically at 165, 165 and 150 min (Figures 5(a), (b) and (c)) which indicated the DO...
breakpoint in the system. Moreover, the possibility of stopping the aeration just after the appearance of the ammonia valley allows an energy saving (Andreottola et al. 2001).

However, the anoxic phase termination time was more apparent from the ORP signal because the presence of the nitrate breakpoint signified the termination of anoxic conditions. When the nitrate breakpoint was found, aeration was started to avoid the reactor system entering into a non-respiratory state (Rhee et al. 2004). The nitrates were consumed very rapidly at the beginning of the anoxic phase. When the aerobic process had just finished, the ORP and DO values rose rapidly. At 120, 120 and 105 min, the NO₃-N concentration was still at maximum value, indicated that denitrification had not yet started for the C/N ratio of 1, 4 and 10 respectively. These results showed that the nitrate knee in the ORP profile was characterised by a breakpoint at 165, 165 and 150 min (average 160 min) which represents the removal of NO₃-N (Figures 6(a), 7(a) and 8(a)).

During the aerobic phase, the minima of the pH curve characterised the end of nitrification. When NH₃-N concentration reached the minimum level, pH began to increase (Figures 6(b), 7(b) and 8(b)). The breakpoint of the ORP profile also appeared at around the same time as the ‘ammonia valley’. The reduction of alkalinity and the acid production during nitrification decrease pH. The complete removal of NH₃-N indicates that alkalinity consumption in the wastewater has stopped, hence the end of further pH decrease. The nitrate breakpoint measured by ORP indicate the end of the denitrification period whilst the DO breakpoint and ammonia valley indicate the end of the nitrification period, as pointed out in earlier. The presence of the nitrate breakpoint signified the termination of anoxic condition, which corresponded to transformation from the respiration of oxygen or nitrates to the nonrespiration process (Chen et al. 2002).

For the control of DO, nitrogen removal can enhanced. Sufficient DO, a long HRT and a long solid retention time (SRT) allow for complete nitrification. The increase in DO corresponds to a decrease in bacterial respiration activity due to depletion of substrate, and could be directly related to COD and ammonia concentrations. It has also been reported that SRT should be longer than 10 days in order to achieve efficient nitrogen removal (Furumai et al. 1999). In this study, SRT was 25 days which was sufficient for nitrogen removal. This SRT was estimated based on the MLSS concentration only, ignoring the small depth of biofilm.

Both ORP and pH profiles are able to show the end of denitrification and nitrification during the operation. According to the variation of influent characteristics and biological activities, these data can be used to determine the duration of aerobic and anoxic phase of the BAF system.

**Aeration consumption performance**

High oxygen concentration requires a high airflow rate, leading to high energy consumption and may also deteriorate the sludge quality (Holenda et al. 2008). So, controlling the aerator operation to a minimum run time, depending on the required oxygen concentration, helps in saving energy and maintenance costs because the aerator equipment is the most energy-consuming part of a biological wastewater treatment plant.

In an on-off aeration system, the air valve is turned on and off automatically. Significant amounts of energy could be saved in biological treatment processes that take advantage of on-off aeration. For all ratios during experimental operation, the average on-off control aeration was operated as follows: 250 min aeration and 130 min anoxic.

To determine the amount of energy that could be saved when the real-time control was applied to a continuous-flow activated sludge reactor system, Doan & Lohi (2009) proposed the following equation:

\[
\% P = \frac{t_{op} \times 100}{24} \tag{1}
\]

where \( \% P = \) the percentage consumption (100% energy consumption represents continuous aeration), \( t_{op} = \) total aeration time per 24 h of treatment.

The study shows that for the average periods of aeration and anoxia, the saving was 36.11% during the operation period according to Equation (1). Yu et al. (1997) also reported that 42% of aeration energy could be saved when the real-time control was applied to a continuous-flow activated sludge reactor system. With real-time control using
step-feed SBR technology, 30% savings on aeration time were shown by Guo et al. (2007).

The aeration control is of great importance due to the generally large energy consumption of the aeration system. Finally, it is true that wastewater aeration represents one of the most energy intensive operations in a wastewater treatment system. Off-on aeration has been recommended as the most efficient way to reduce the cost of aeration.

**CONCLUSION**

The automatic monitoring and control of a partially packed bed BAF system, based on on-off controller concepts, has been applied to provide good removal efficiency of nitrogen and save aeration operational cost. The continuous monitoring of pH, DO and ORP allows the analysis of the dynamics of the nitrogen forms to achieve optimisation of the treatment. As the anoxic and oxic periods were appropriately controlled using ORP and pH profiles, complete nitrification and denitrification were achieved in this system. Based on the results obtained in this study, the practical importance of the on-off control for nitrogen removal of synthetic wastewater treatment can be summarised as follows:

1. Good effluent quality was obtained in the BAF system operated at on-off DO strategies; the maximum NH3-N and COD removals of 98.02 and 97.56% respectively were achieved at C/N of 1.
2. Under the on-off aeration strategy, average electricity savings of 36.11% for control of the aeration in BAF system can be obtained.
3. It is suggested that pH and ORP should be chosen as nitrification and denitrification parameters respectively. The ammonia valley by pH reflects the end of the nitrification period and the nitrate breakpoint (nitrate knee) measured by ORP indicates the end of the denitrification period.

The use of the on-off operation is good for ammonia-nitrogen removal as well as nitrate-nitrogen, as overall oxygen requirements were reduced and alkalinity was recovered; the disadvantage of using on-off operation are that greater operator attention is required, capital costs are incurred because of mixer requirements and poor effluent quality may occur if on-off control is not managed carefully. So, the easy operation and the low cost make the BAF system an interesting option for the biological treatment of synthetic wastewater by using an on-off controller. Future experiments on the on-off diagnosis system should analyse how the plant is operated to arrive at decisions about how it is controlled under good conditions.

**ACKNOWLEDGEMENTS**

This research was funded by University Kebangsaan Malaysia (UKM-ASPL-07-05-020).

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First received 30 April 2011; accepted in revised form 29 June 2011