Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 196 (2017) 800 – 807

Procedia Engineering

www.elsevier.com/locate/procedia

Creative Construction Conference 2017, CCC 2017, 19-22 June 2017, Primosten, Croatia

Online Monitoring of a Sequencing Batch Reactor Treating Domestic Wastewater

Ali Waheid Alattabi[a,b]*, Clare Harris[a], Rafid Alkhaddar[a], Ali Alzeyadi[a] and Muhammad Abdulredha [a]

[a]*Department of Civil Engineering, Faculty of Engineering and Technology, Liverpool John Moores University, Liverpool, L33AF, UK.*
[b]*Department of Civil Engineering, College of Engineering, University of Wasit, Iraq.*

Abstract

Domestic wastewater consists of considerable concentrations of pollutants that can boost water eutrophication if not treated before final discharge, which could damage the ecosystem and negatively affect human health. Sequencing batch reactor (SBR) technology is considered a promising biological wastewater treatment technology to address these issues. In recent years, SBR selection has increased as an effective technology for the treatment of domestic and industrial wastewaters due to its setup simplicity and ease of operation. However, many researchers have reported differences in cycle time. The importance and originality of this study is that it explores the parameters of pH, temperature, oxidation-reduction potential (ORP) and dissolved oxygen (DO) throughout the SBR cycle to predict the end of the treatment cycle. A laboratory-scale SBR was used in this study with a five-litre working volume. It was equipped with four electronic sensors (probes) to monitor the pH, ORP, temperature and DO. The SBR was operated under constant aeration, 1.0 l/min, ±12 C° temperature and 6 h cycle time. Each cycle of the SBR operation included Fill (30 minutes), React (240 minutes), Settle (30 minutes), Draw (30 minutes) and Idle (30 minutes). Influent and effluent samples were analysed for COD, ammonia-N and nitrate-N. The pH, ORP and DO values at the end of the 6 h HRT treatment cycle were between 6.6-7.9, 147-169 mV and 4.6-6.6 mg/l respectively. The results show complete degradation of COD and nitrogen compounds was seen when the DO profile increased due to bacterial respiration. The results prove that online monitoring of SBR operating parameters could significantly predict the end of the treatment cycle, and the pH, DO and ORP profiles could be used as onsite process control parameters.

© 2017 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer-review under responsibility of the scientific committee of the Creative Construction Conference 2017

---

* Corresponding author. Tel.: +44(0)7466448764
E-mail address: a.w.alattabi@2014.ljmu.ac.uk

1877-7058 © 2017 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer-review under responsibility of the scientific committee of the Creative Construction Conference 2017
doi:10.1016/j.proeng.2017.08.010

Keywords: Organic loading rate; residential complexes' wastewater; sequencing batch reactor; sludge settling performance; sludge volume index

---

1. Introduction

Domestic wastewater could be considered a major source of water pollution due to its organic content and trace elements. It can be recognised by high concentrations of biochemical oxygen demand (BOD), COD and colour. Biological wastewater treatment is an attractive technology to treat this type of wastewater due to the economic advantages it offers in terms of operation costs. However, the treatment sites require a great deal of land and are costly to maintain, and the treatment process itself requires a lot of attention. Thus, alternatives have been introduced such as the sequencing batch reactor. The SBR is an activated sludge process that utilises a fill and draw sequence, and can be operated in just one tank. It works as an equalisation, neutralisation and biological treatment and secondary clarifier in a single tank through a timed control sequence, which makes it environmentally friendly technology [1]. During one cycle, SBR technology has five operating steps – Fill, React, Settle, Draw and Idle [2]. During the first stage (Fill), the waste and substrate are added to the microbial activity. It can be static fill, mixed fill, or react fill. In the static fill, there is no mixing or aeration through the introduction of the waste influent. Mixed fill involves turning on a mixing device during the fill phase, while aeration is turned on during the fill phase in the react fill mode of operation. The second stage is React and the objective of this stage is to complete reactions proposed during the fill phase. This could consist of mixing or aeration, or a combination of both. The third stage is the Settle stage, which is performed to separate the treated water from the solids, and the treated water is decanted from the reactor during the fourth stage (Draw). Idle is the final stage in an SBR system and is only used in multi-basin applications to remove some of the sludge and recycle the rest, to keep the sludge active inside the system to biodegrade the organic matter effectively.

Due to its one tank design and setup simplicity the SBR system has recently been identified as attractive technology for the treatment of domestic, industrial and municipal wastewater, and has been successfully used for such treatment purposes. However, to ensure an effective biological wastewater treatment, a good process control is required [3]. The SBR technology is a modified activated sludge process used for pollutant removal [4]. In biological treatment, the pH parameter reflects the biological reaction characteristics occurring in an aerobic/anoxic process, while the ORP profile demonstrates the anaerobic/anoxic and aerobic processes in the reactor system [5,6]. The ORP parameter could also indicate the DO concentration, activity of the organism, organic substrate and some toxic elements in the SBR system. It also reflects some operational conditions such as overloading, over-aeration and under-aeration [7]. In the biological system, the pH value responds to microbial reactions, and therefore the pH variation in some cases provides a better indication of the biological reactions in the operated cycle – for instance, if the pH value increases this indicates a denitrification process, and a decline in pH could indicate a nitrification process [8,9]. Recent studies have identified the importance of ORP as a control parameter for the anaerobic environment and low DO systems [10,11].

The SBR system is known as a flexible technology to effectively treat a wide range of wastewater characteristics. Although, the SBR system has received considerable critical attention recently, there is no adequate information regarding the SBR's operational stability for nutrient removal and control parameters to adjust the treatment cycle, as well as researchers have even reported differences in cycle time due to differences in the wastewater characteristics. Thus, the main aim of this study is to monitor online the parameters of pH, temperature, ORP and DO in real time throughout the SBR system to find the time needed for nutrient removal and hence to predict the end of the treatment cycle. Consequently, the offline measurements of wastewater pollutants such as COD, ammonia-nitrogen and nitrate-nitrogen which are costly and time-consuming could be replaced by an online monitoring system which is cost effective and easy to monitor.

Nomenclature

Ammonia-N	Ammonia-nitrogen
BOD	Biochemical oxygen demand
COD	Chemical oxygen demand
DO	Dissolved oxygen
HRT	Hydraulic retention time

Nitrate-N	Nitrate-nitrogen
ORP	Oxidation-reduction potential
pH	potential of hydrogen
SBR	Sequencing batch reactor

2. Materials and methods

2.1. Bacteria source and synthetic wastewater

The seed bacteria used as a biodegradable agent in this study were provided by Liverpool Wastewater Treatment Works, Sandon Docks, Liverpool, UK. The domestic wastewater was prepared in the lab by mixing the following chemicals with deionised water [12]: 500 mg glucose/L; 200 mg $NaHCO_3$/L; 25 mg NH_4Cl/L; 25 mg KNO_3/L; 5 mg KH_2PO_4/L; 5 mg $MgSO_4.7H_2O$/L; 1.5 mg $FeCl_3.6H_2O$/L; 0.15 mg $CaCl_2.2H_2O$/L. All reagents used in this study were purchased from Sigma-Aldrich, UK.

2.2. Setup and operation of the laboratory SBR system

The SBR system used in this study is shown in Fig. 1. Its capacity is 6.5L and the working volume is 5L; it was filled with 1-2L of bacteria (biomass) and 3-4L of synthetic wastewater. The parameters of pH, DO, temperature and ORP were monitored online via sensors installed in the SBR reactor. The SBR reactor was operated continuously for three months, and the samples were taken from the reactor and analysed for influent and effluent concentration to measure the removal efficiency and find the relationship between the parameters of pH, DO and ORP with the treatment conditions.

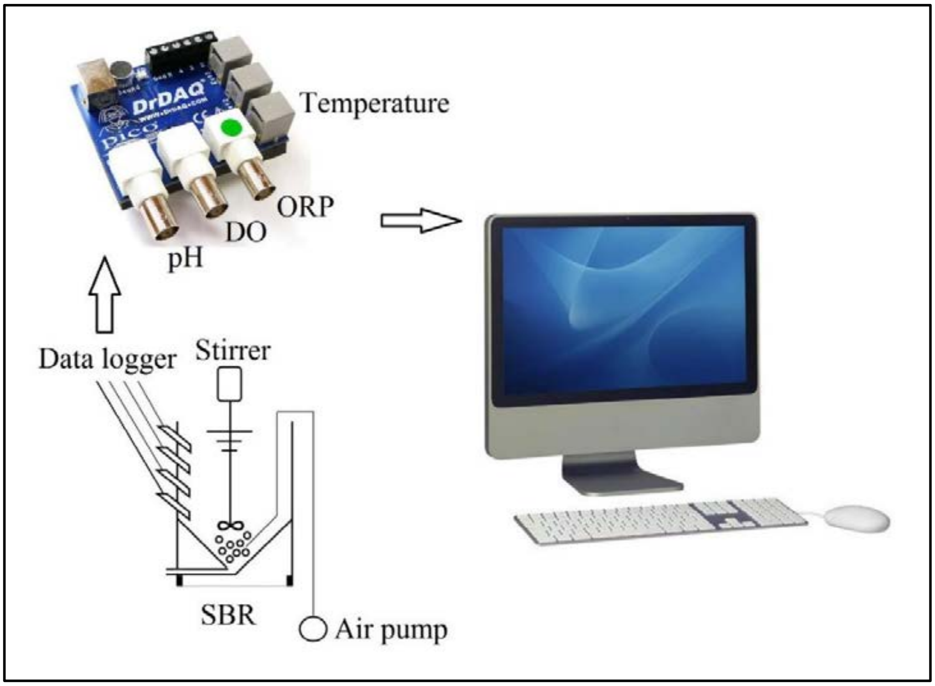

Fig. 1. a) Lab-scale SBR system.

2.3. Analytical methods

The influent and effluent samples were collected from the SBR reactors before and after the treatment cycle using a peristatic pump, and then the samples were filtered using a vacuum pump containing 0.45 μm filter paper, and then analysed for the concentrations of COD, ammonia-N and nitrate-N, and these measurements were performed according to the standard methods [13]. The parameters of pH, DO, temperature and ORP were recorded automatically on the computer through a data logger (Fig. 2) that transferred the data from the probes to the computer. The probes and the software were provided by Pico Technology, UK.

3. Results and discussion

The SBR system was operated continuously for three months in the following cycle: 30 minutes anoxic fill, 240 minutes react, 60 minutes settle, and 60 minutes draw and idle. The parameters of pH, DO and ORP were continuously monitored online to determine the variation of these parameters in the biological process and relate this to nutrient removal.

3.1. pH profile during COD, Ammonia-N and Nitrate-N removal

The pH profile is shown in Fig. 2. The pH value declined during the anoxic fill at the beginning of the treatment cycle and it continued to decrease during the first 30 minutes of the react stage. The decrease in pH during the anoxic fill could be due to the release of acid fermentation and the further decrease in pH profile during the first 30 minutes of the react stage is related to the ammonia nitrification, which consumes alkalinity. The fall in pH value continued until the point that the ammonia-N was converted to nitrate-N and nitrite-N. About 75% of the ammonia could be removed from the SBR system at this pH profile point. This break point for the ammonia, which is called the ammonia “valley” [14,15], could be significantly used to modify the aerobic phase duration according to the ammonia-N influent concentration. After achieving the ammonia valley, the pH rose rapidly during the next 3.5 h of the reacting stage, and this could be because the C2 was stripped from the SBR system. Fig. 2a shows the COD removal, and it can be seen that COD was completely removed after 4 hours of the react stage. Fig. 2b shows the ammonia-N removal, which increased slightly during the conversion of COD to ammonia, and then it began to degrade and it was completely removed after 5 hours of SBR operation. Fig. 2c shows the nitrate-N removal, which started to decrease from the beginning of the SBR cycle, and then, during the anaerobic environment, some of the nitrite was converted to nitrate, which increased the nitrate value, and then the degradation of the nitrate-N started again, and it was removed during the second cycle of the treatment. Fig. 2d shows the pH profile during the 24 h cycle. After monitoring the pH profile for the whole period of study, it can be stated that it could significantly reflect the anaerobic biological respiration of the SBR system. Thus, the pH profile can be used to establish control strategy of nutrient removal in the SBR system which could contribute to this growing area of research by minimising the cost of operation.

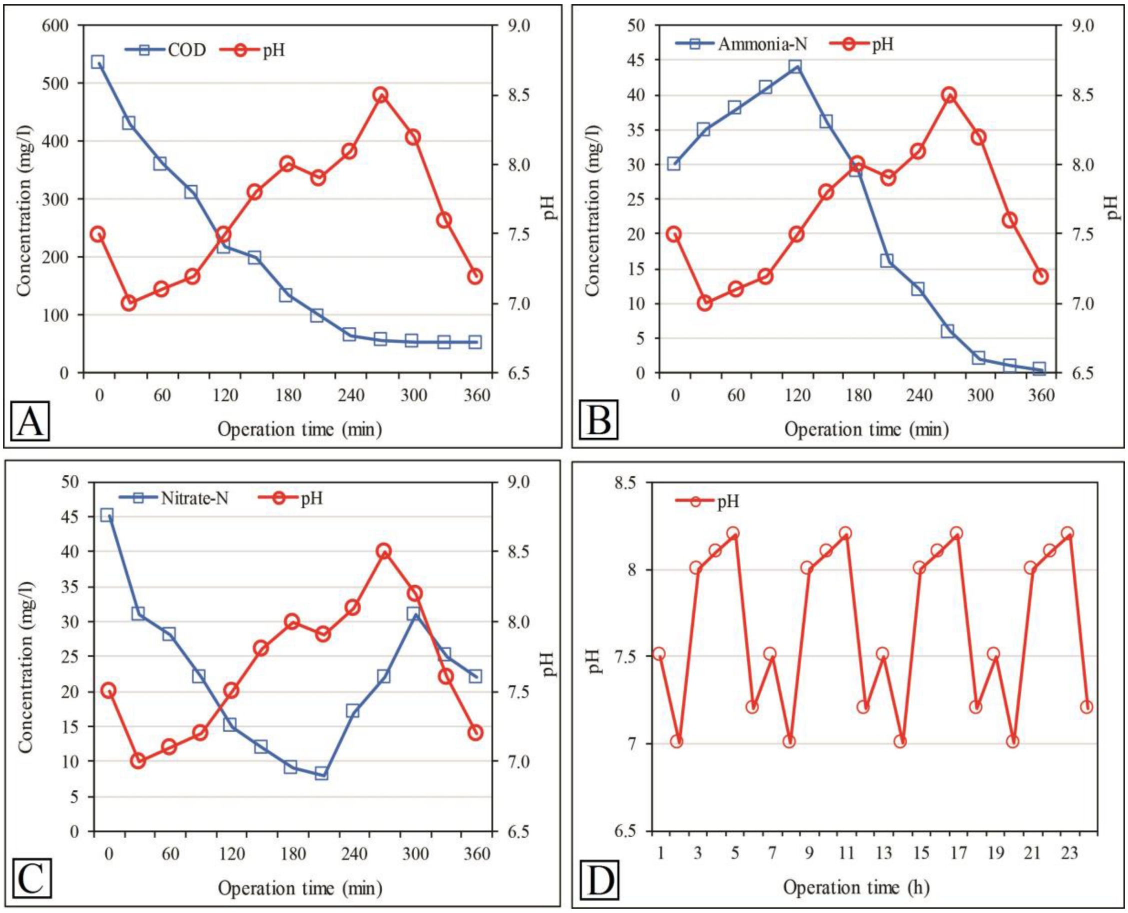

Fig. 2. pH profile during a) COD removal, b) Ammonia-N removal, c) Nitrate-N removal. d) pH profile during the 24 h cycle.

3.2. DO profile during COD, Ammonia-N and Nitrate-N removal

The DO profile during the degradation of COD, ammonia-N and nitrate-N is shown in Fig. 3. It can be clearly seen that the profile increases during the react stage due to the aeration provided to the system and it declines during the settle, draw and idle stages because the aeration and mixing were turned off. Fig. 3d shows the DO profile during the 24 h cycle. The DO concentration could be considered one of the most significant parameters that affect the treatment operation in the SBR system. In the react stage, two activities are performed: the first one is the substrate degradation, in which the organic matter is removed, and the second activity is starvation, which happens after all the organic matter has been removed from the system so the bacteria become more hydrophobic, which results in microbial adhesion [16]. The DO concentration is significantly related to the microbial activity. The bacteria utilised the DO in the system to oxidise the COD and ammonia. The DO peak occurs when ammonia concentration is depleted and it could indicate the end of the nitrification process [17]. After the degradation of the organic matter, the bacterial respiration decreased and this could increase the DO concentration. The removal of COD and ammonia could result in a significant increase in the DO profile. Thus, the DO profile can predict accurately the removal of COD and ammonia and consequently determine the transfer of operation stages the SBR technology through the online monitoring system.

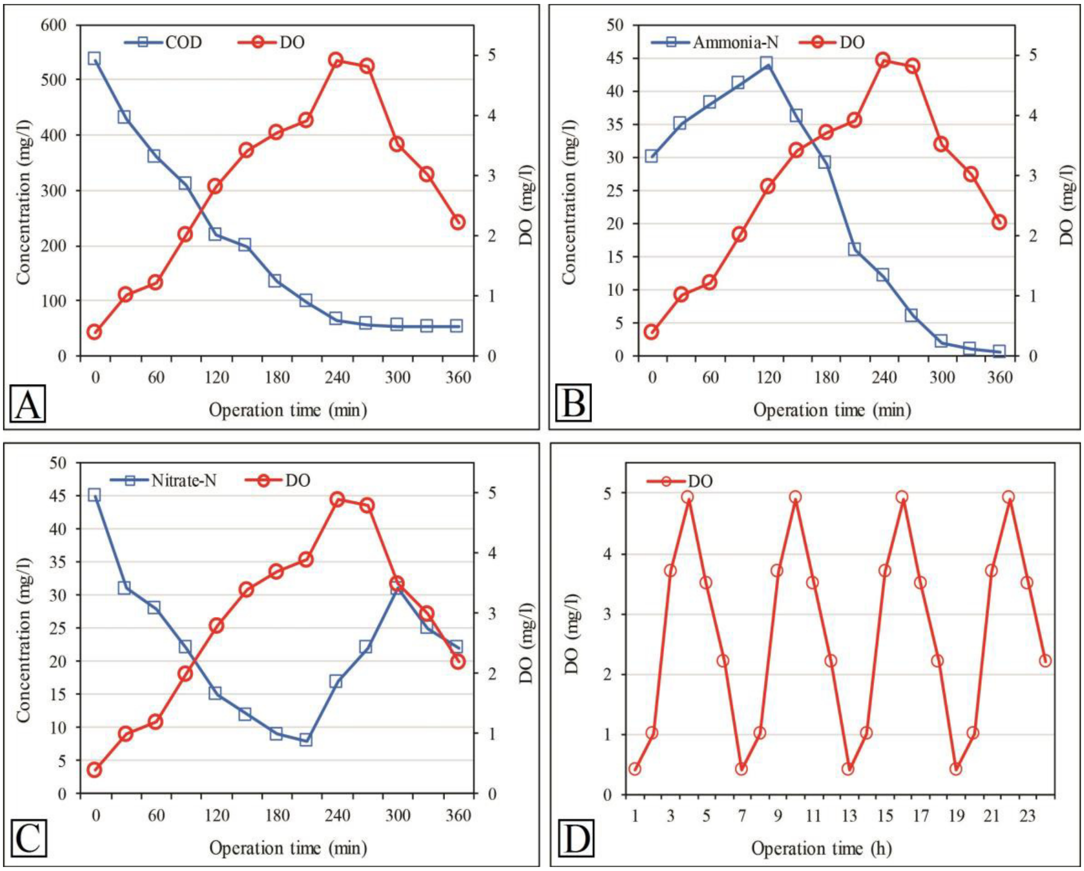

Fig. 3. DO profile during a) COD removal, b) Ammonia-N removal, c) Nitrate-N removal. d) DO profile during the 24 h cycle.

3.3. ORP profile during COD, Ammonia-N and Nitrate-N removal

The ORP profile during the degradation of COD, ammonia-N and nitrate-N is shown in Fig. 4. During the anoxic fill stage, the ORP decreased rapidly as the sludge was mixed with the organic matter. However, its value started to increase during the react stage and, at the end of the react stage, the ORP value had reached its maximum. Then the ORP decreased during the settling stage. The ORP increased sharply when the nitrate concentration decreased and this could indicate the end of the denitrification process. During denitrification, the organic matter is degraded under the anaerobic environment, which will lead to a decrease in the ORP value. The significant increase in the ORP profile after the removal of COD proves that the COD is removed completely. The increase of the ORP profile after the end of the nitrification process might be because of the rise in the DO profile. Thus, the ORP profile can be used to establish control strategy of nutrient removal in the SBR technology through the online monitoring system.

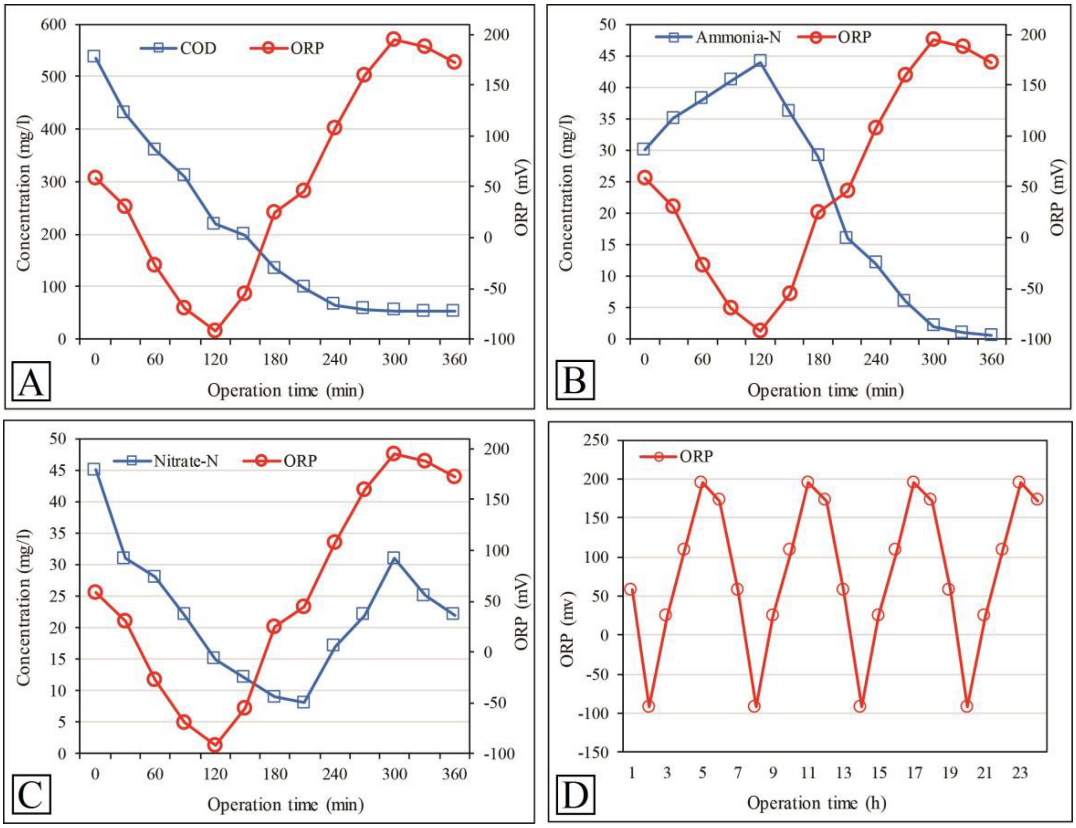

Fig. 4. ORP profile during a) COD removal, b) Ammonia-N removal, c) Nitrate-N removal. d) ORP profile during the 24 h cycle.

4. Conclusion

The online monitoring of pH, DO and ORP using an SBR system was studied. Using the pH profile, the end of the nitrification process was significantly indicated under aerobic conditions and the ammonia valley was found in the pH profile. In the same vein, the nitrate valley was found in the ORP profile and the denitrification process was completed under anoxic conditions. Therefore, these points indicate that the reactions in the SBR were completely understood and the removal of different nutrients can be easily estimated. In the SBR system, pH and ORP are more related to the anaerobic stage, while DO is related to the aerobic stage. Thus, instead of analysing the parameters of COD, ammonia-N and nitrate-N offsite, which is costly and time-consuming, a control system using online monitoring of the pH, DO and ORP could accurately detect the removal time for these parameters and could estimate the end of the treatment cycle. These findings fills a gap in the literature by proving that the online monitoring can be applied successfully in the SBR system, and this contribution to the body of knowledge will result in a reduction of the operation cost.

Acknowledgements

The financial support for the first author from the Ministry of Higher Education and Scientific Research, Iraq, and the University of Wasit is highly appreciated.

References

[1] United States Environmental Protection Agency, Onsite wastewater treatment technology fact sheet – 3. U.S. Environmental Protection Agency, Washington, D. C., 1999.

[2] Mata, A. M. T., Pinheiro, H. M. and Lourenço, N. D., Effect of sequencing batch cycle strategy on the treatment of a simulated textile wastewater with aerobic granular sludge. Biochemical Engineering Journal, 2015, 104, 106-114.

[3] Metcalf and Eddy, Inc., Wastewater Engineering: Treatment and Reuse, fourth ed. New York, NY: McGraw-Hill Higher Education, 2003.

[4] Hasan, H. A., Abdullah, S. R. S., Al-Attabi, A. W. N., Nash, D. A. H., Anuar, N., Rahman, N. A. & Titah, H. S., Removal of ibuprofen, ketoprofen, COD and nitrogen compounds from pharmaceutical wastewater using aerobic suspension-sequencing batch reactor (ASSBR). Separation and Purification Technology, 2016, 157, 215–221.

[5] Puig, S., Corominas, L., Vives, M.T., Balaguer, M.D., Colprim, J., Development and implementation of a real-time control system for nitrogen removal using OUR and ORP as end points. Indus. Eng. Chem. Res., 2005, 44 (9), 3367–3373.

[6] Ra, C.S., Lo, K.V., Shin, J.S., Oh, J.S., Hong, B.J., Biological nutrient removal with an internal organic carbon source in piggery wastewater. Water Res., 2000, 34, 965–973.

[7] Hao, J.O., Kim, H., pH and oxidation reduction potential (ORP) strategy for optimization of nutrient removal in an alternating aerobic–anoxic system. Water Environ. Res., 2000, 73 (1), 95–102.

[8] Chang, C.H., Hao, O.J., Sequencing batch reactor system for nutrient removals: ORP and pH profiles. J. Chem. Technol. Biotechnol, 1996, 67, 27–38.

[9] Kishida, N., Kim, J.M., Chen, M., Sasaki, H., Sudo, R., Effectiveness of oxidation–reduction potential and pH as monitoring and control parameters for nitrogen removal in swine wastewater treatment by sequencing batch reactors. J. Biosci. Bioeng., 2003, 96 (3), 285–290.

[10] Chen, K., Chen, C., Peng, J., Houng, J., Real-time control of an immobilized-cell reactor for wastewater treatment using ORP. Water Res., 2002, 36, 230–238.

[11] Holman, J.B., Wareham, D.G., COD, ammonia and dissolved oxygen time profile in the simultaneous nitrification/denitrification process. Biochem. Eng. J., 2005, 22 (2), 125–133.

[12] Shariati, S. R., Bonakdarpour, B., Zare, N. and Ashtiani, F. Z., The effect of hydraulic retention time on the performance and fouling characteristics of membrane sequencing batch reactors used for the treatment of synthetic petroleum refinery wastewater. Bioresource Technology, 2011, 102, 7692–7699.

[13] American Public Health Association (APHA), Standard methods for the examination of water and wastewater, 18th ed., Washington, DC, USA: APHA, 2012.

[14] Andreottola, G., Foladori, P., Ragazzi, M., Online control of a SBR system for nitrogen removal from industrial wastewater. Water Sci. Technol., 2001, 43 (3), 93–100.

[15] Yu, R.F., Liaw, S.L., Chang, C.N., Cheng, W.Y., Applying real time control to enhanced the performance of nitrogen removal in the continuous flow SBR system. Water Sci. Technol., 1998, 38 (3), 271–280.

[16] Tay, J.H., Liu, Q.S., Liu, Y., Microscopic observation of aerobic granulation in a sequential aerobic sludge blanket reactor. J. Appl. Microbiol., 2001, 91 (1), 168–175.

[17] Holman, J.B., Wareham, D.G., COD, ammonia and dissolved oxygen time profile in the simultaneous nitrification/denitrification process. Biochem. Eng. J., 2005, 22 (2), 125–133.