JOBIMB, 2022, Vol 10, No SP2, 29-39
https://doi.org/10.54987/jobimb.v10iSP2.726

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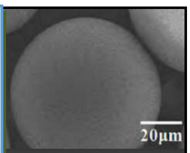

JOBIMB VOL 10 NO SP2 2022
ZnO nanoparticle

Effect of HRTs on COD and Nutrient Removal in Sequencing Batch Reactor (SBR) Process

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HISTORY
Received: 27 Jul 2022
Received in revised form: 26 Sep 2022
Accepted: 10 Dec 2022

KEYWORDS

COD
Dissolved oxygen
nutrient removal
hydraulic retention time (HRT)
sequencing batch reactor (SBR)

ABSTRACT

An effective wastewater treatment is a must to prevent water resources from being polluted. In this research, the method used was biological treatment with sequencing batch reactor (SBR) as the reactor to treatment synthetic wastewater. There were four stages involved in operation of SBR, which were fill, react, settle, and draw. Synthetic wastewater is being used as influent with C:N ratio = 500:50. Three hydraulic retention time (HRT)being tested, which were 24 h, 12 h, and 8 h. ORP, DO and pH were monitored online and its relationship with nutrient removal (ammonium, nitrate, nitrite, and phosphate) was observed. HRT 12 h and 8 h achieved similar performance among the three HRTs being tested while HRT 24 h achieved lowest percentage removal of nutrient.

INTRODUCTION

Wastewater pollution can be recognized by high concentration of biochemical oxygen demand (BOD), COD and the nutrient content of the water [1]. Degradation of the organic matter requires oxygen and the content organic matter in a sample of water can be estimated by the amount of oxygen necessary for the oxidation of this organic matter. The concentration of COD for extremely contaminated industrial wastewater can be higher than 100,000 mg/L [2].

Meanwhile, nutrient in wastewater consists of nitrogen and phosphorus. Nitrogen in wastewater consists of ammonium, nitrate, and nitrite. Nitrogen can be removed by nitrification and denitrification process. During nitrification, ammonium will be oxidized to nitrite and the resultant nitrite will be oxidized further to nitrate [3,4]. For denitrification process, nitrate will be reduced to nitrite and then reduced further to nitrogen gas in anoxic condition [5]. While for phosphorus, Phosphorus occurs mostly as phosphates (PO_4^{3-}), which are classified as orthophosphates (reactive phosphates), condensed phosphates (polyphosphates), and organic phosphates. Orthophosphates are the main constituent of fertilizers used for agricultural and residential purposes [3,5]. They are found in natural water and provide a good estimation of the amount of phosphorus available for algae and plant growth. This is the form of phosphorus that is most readily utilized by biota. Orthophosphates can be carried into streams and lakes through runoff [1].

In contrast, condensed (inorganic) phosphates are phosphorus compounds that contain salts or metals such as sodium, potassium, and calcium in various structures and chains [6]. This type of phosphate is used in industry and can be used as food additives. The third type of phosphate, namely organic phosphates, is formed primarily through biological processes. Organic phosphates enter sewage via human waste and food residues. These phosphates can be formed from orthophosphates in biological treatment processes or by biota in receiving waters [5,6].

Both elements play an important role in algae growth but the excessive amount nitrogen and phosphorus significantly contributed to eutrophication. Therefore, removal of the nutrients, organic contaminants and pathogens from wastewater is of paramount importance to prevent eutrophication, oxygen depletion and toxicity [7]. Various advanced processes had been developed to treat this contaminant which one of them is biological wastewater treatment. It is an attractive technology to treat this type of pollution due to economic advantages it offers in terms of operation cost and efficiency [8,9]. 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. [8-10].

Thus, alternatives have been introduced such as the sequencing batch reactor (SBR). The SBR is an activated sludge process that utilizes a fill and draw sequence and can be operated in just one tank [1,6]. It works as an equalization, neutralization and biological treatment and secondary clarifier in a single tank through a timed control sequence, which makes it environmentally friendly technology [8,9]. Operation of SBR consists of four stages, which are fill, react, settle, and draw. Anaerobic, aerobic, and anoxic process can be carried out in SBR to remove nutrient contained in the wastewater [2]. SBRs are used successfully to treat both municipal and industrial wastewater [10-11]. Among the advantages of SBR method is required less area compared to conventional treatment and can be controlled easily using computer [11]. In addition, SBR can achieve high nitrogen removal and secondary sedimentation tank is not required. From economic aspect, since the area required is lesser compared to conventional treatment, the less maintenance cost is required [5].

It should be noted that the application of SBRs in wastewater treatment has been investigated extensively [8]. However, to our knowledge, limited of the reported studies have reported on the performance evaluation of a SBR for simultaneous COD and nutrient removal of wastewater. The SBR system is selected on the basis that the settling and reaction phase takes place in the same vessel, which makes it easy to operate and economically attractive [11]. Thus, the aim for this study is to determine the performance of different hydraulic retention time (24 h, 12 h, and 8 h) to the percentage removal of COD and nutrient. Furthermore, the findings of the study will provide wastewater-producing industries with practical and technical reference information to reduce environmental pollution in water-receiving bodies effectively.

MATERIALS AND METHOD

Sequencing Batch Reactor (SBR) and Operational Parameter Set Up

The experiments were carried out in a 1300 mL SBR with a reaction volume of 1000 mL, headspace of 300 mL and exchange volume of 50%. A scheme of the reactor is shown in **Fig. 1**. The ORP, pH and DO electrode were placed in the reactor and monitored online. The signal from electrodes would be transfer to interface card and the data would be recorded using computer

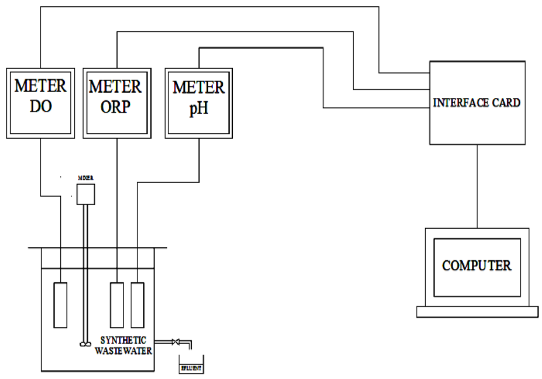

Fig. 1. Schematic Diagram of SBR

Following are the stages of the SBR that were operated in this study: Filling: filling was the stage where the wastewater that would be treated was added into the SBR reactor; Reaction: the reaction was operated anaerobically and aerobically, which aimed to produce a good percentage of total N removal; Settling: at this stage the treated wastewater would be separated from the activated sludge by sedimentation/settling; Draw: after passing through the settling stage, the treated effluent or wastewater was ready to be taken and tested; Idle: this stabilization stage aimed to make the reactor effluent ready to enter the next cycle. Each hydraulic retention time (HRT), 24 h, 12 h, and 8 h was operated in 3 cycles, with the stage times of each cycle were presented in **Table 1**. The performance of the SBR system was evaluated by estimating removal efficiency of each parameter (COD, NH_3-N) by comparing the concentration in the feed with that in reactor outlet at the end of each HRT h.

Table 1. Time distribution of each stage for one operational cycle.

Stage	8 Time (min)	12 h Time (min)	24 h Time (min)
filling	15	15	15
anaerobic reaction	120	180	360
aerobic reaction	50	450	900
settling	10	40	80
draw	15	15	15
idle	5	20	70

Synthetic Wastewater

The reactors were fed with the same composition of synthetic wastewater from previous literature studies which made by 25 mg/L $(NH_4)_2SO_4$, 25 mg/L KNO_3, 52.7 mg/L $MgCl_2.6H_2O$, 0.28 mg/L $MnCl_2.4H_2O$, 0.28 mg/L $Fe_2(SO_4)_3.5H_2O$, 4.30 mg/L $CaCl_2.2H_2O$ and 5 mg/L KH_2PO_4. C:N ratio for this synthetic wastewater in this study was maintained in 500:50 as presented in **Table 2**. The composition of the synthetic wastewater used as shown in **Table 2** contained organic carbon, essential nutrients, ammonia, and minerals to simulate the characteristics of raw domestic wastewater as also studied by the previous researcher [12]. COD and total nitrogen concentrations of the feed water were approximately 250 and 25 mg N/L, respectively

Table 2. Composition of synthetic wastewater and concentration of stock solution.

Types of Chemicals	Concentration of Stock Solution (g/L)	Composition of Synthetic Wastewater (mg/L)
Glucose	50.0	500.0
$(NH_4)_2SO_4$	20.0	25.0
KNO_3	10.0	25.0
$MgCl_2.6H_2O$	8.0	52.7
$MnCl_2.4H_2O$	1.0	0.28
$Fe_2(SO_4)_3.5H_2O$	0.04	0.28
$CaCl_2.2H_2O$	0.3	4.30
KH_2PO_4	4.0	5.0

Parameter Analysis

Chemical oxygen demand (COD) was measured spectrophotometrically by a spectrophotometer (DR3900 HACH, USA) using test kits according to the manufacturer's instruction. The ammoniacal nitrogen content was determined using Nessler reagent followed with the spectrophotometer reading. Samples of wastewater were taken during influent, effluent and between the HRTs period to study nitrification and denitrification process in the reactor.

Data Analysis

For data credibility, sampling during each sampling period were triplicated to minimize the experimental errors. The removal efficiency of COD and Nitrogen for the SBR system was calculated using Equation (1) as below:

$$Removal\ efficiency\ (\%) = \frac{C_0 - C_f}{C_0} x\ 100 \qquad \text{Eq.1}$$

where C_0 and C_f are the substrate concentrations (mg/L) in the SBR influent and effluent streams, respectively

RESULTS AND DISCUSSION

COD Removal

Fig. 2 and **Fig. 3** illustrates the results of COD removal for HRT 24 h, 12 h, and 8 h based on the concentration of biomass (mg/L). As presented in Fig2, the percentage removals of COD for HRT 24 h, 12 h and 8 h were 90.3%, 95% and 96.4% respectively. Average of percentage of COD removal was around 94.1%. Percentage of COD removal for HRT 24 h was the lowest among the three HRTs being tested because bacteria inside reactor still need more time to adapt to the surrounding inside reactor. Once the bacteria already adapted to the surrounding inside the reactor, percentage of COD removal would be higher, like the cases for HRT 12 h and 8 h. **Fig. 3** showed the relationship between percentage of COD removal and concentration of biomass where the of percentage of COD removal increases with increasing concentration of biomass. According to [9-13], the presence of microorganism in high concentration reduces the treatment duration and increase the percentage removal of COD.

Concentration of COD is one important measurement in wastewater analysis because degradation of organic compound content in the wastewater required oxygen. Therefore, total organic compound content in the wastewater can be determined by determined the oxygen required for degradation [12,14]. There are several factors that will affect the COD removal such as types of microorganisms, aeration condition, temperature, pH and HRT. Longer HRT period, better performance on COD removal [16-17].

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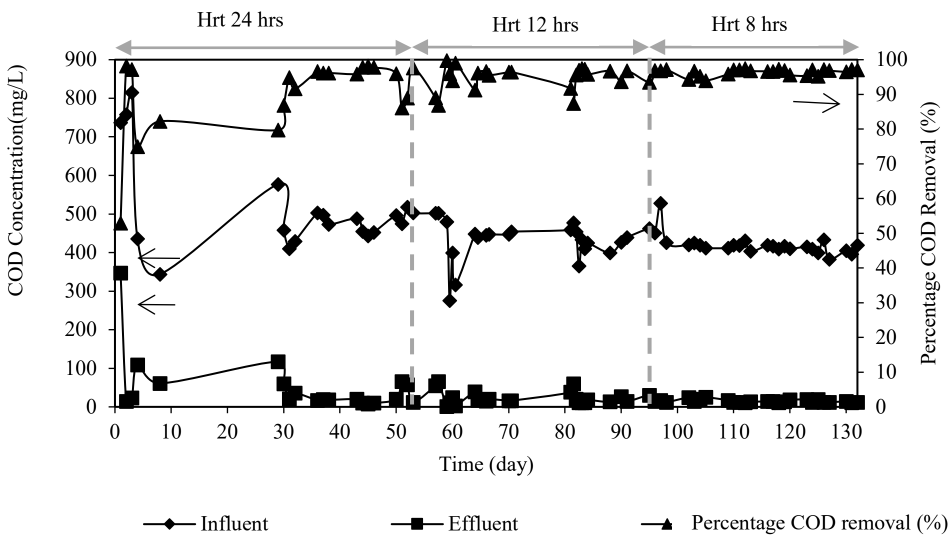

Fig. 2 COD and its removal percentage.

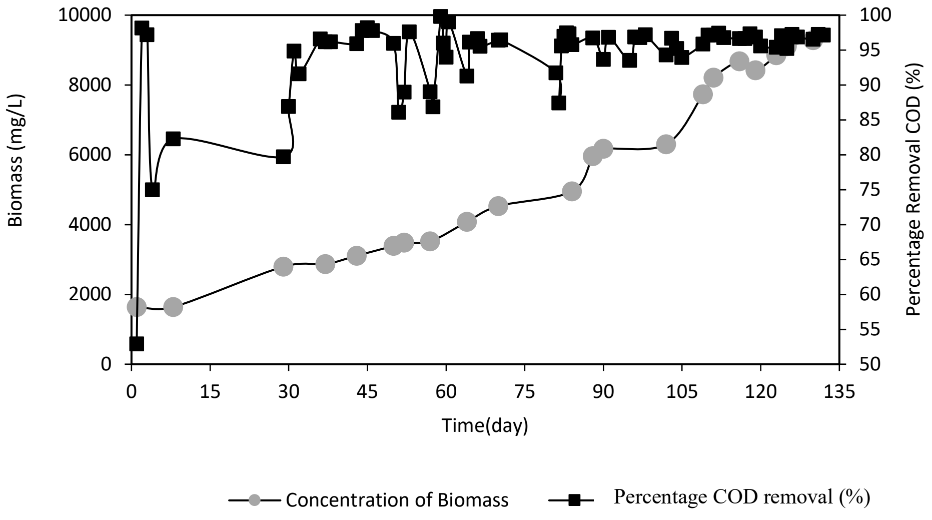

Fig. 3. Relationship between the percentage of cod removal and biomass.

Nutrient Removal

The biological nutrient removal process mainly involves two steps, nitrification, and denitrification. According to [8-9] nitrification requires strictly aerobic environment which is achieved through aeration in an SBR tank. The second step, denitrification, involves the heterotrophic bacteria which are anaerobic and utilize complex organic compounds for their carbon requirements and nitrate serves as the electron acceptor under anoxic or anaerobic conditions, which in turn forms nitrogen gas that leaves the aqueous phase [6]. In a simple word, nitrification is a biological process that converts ammonia to nitrite and nitrite to nitrate before denitrification process convert nitrate to nitrogen gas [5].

Fig. 4 and Fig. 5 showed the percentage removal for ammonium and nitrate respectively. As presented in **Fig. 4,** trend for ammonium removal is not stable due to value fluctuation which means that the toxicity of synthetic wastewater had a negative impact on microbial degradation potential which in turn effects the efficiency of ammonium removal. Study by [19] also shows similar trend of unstable ammonium removal efficiency due to the toxicity of paper mill effluent. Hence, the suggestion is to prolong the exposure period of HRT up to a few days instead of only 24 h to improve the performance of ammonium removal using SBR system. The percentage removals of ammonium for HRT 24 h, 12 h and 8 h were 80.7%, 93.7% and 84.2% respectively. Average percentage removal for ammonium was around 86.8% and Percentage removal of ammonium achieved lowest value on the first day of treatment. This is due to insufficient aeration inside reactor. On the first day of treatment, the aeration inside reactor is in the range between 0.1 – 0.2 mg/L only. So, the condition inside reactor is not suitable for nitrification process and as a result, percentage removal of ammonium only achieved by 15%.

The removal efficiency of nitrate was presented in **Fig.5**. From **Fig. 5**, percentage removals of nitrate for HRT 24 h, 12 h and 8 h were 60.7%, 77% and 89.2% respectively. Average percentage removal of nitrate was around 76%. Besides, from **Fig. 5**, on third day, concentration of nitrate was higher in effluent compared to influent. This is due to denitrification process could not occur because concentration of DO too high. According to [13], the main factor which influences the process of denitrification is the organic content in the reactor. The organic matter available within the medium/reactor is only source of nutrition for the bacteria. Therefore, the bacteria require a source of readily available organic matter such as glucose in the reactor to enhance the denitrification process and at the same time the removal of nitrite will be increasing. In addition, according to **Fig. 5**, there was a sharp increase of nitrate concentration in influent, which was on day-81. This sharp increase is due to accumulation of nitrate inside the reactor.

The composition of nitrite in the reactor is presented in **Fig. 6**. Nitrite is the intermediate product between nitrification and denitrification processes. Ammonium will be oxidized to nitrite during nitrification process and the resultant nitrite will be oxidized further becomes nitrate [18-19] Meanwhile, **Fig. 7** shows the percentage removal of phosphate for HRT 24 h, 12 h and 8 h were 98.5%, 95.6% and 96.7%. respectively. Average percentage removal was around 96.5%. All the three HRTs gave almost similar performance in terms of phosphate removal. In addition, as shown in **Fig. 7**, phosphate concentration in influent decreasing from time to time due to disturbance of other ion when conducting analysis [1,6].

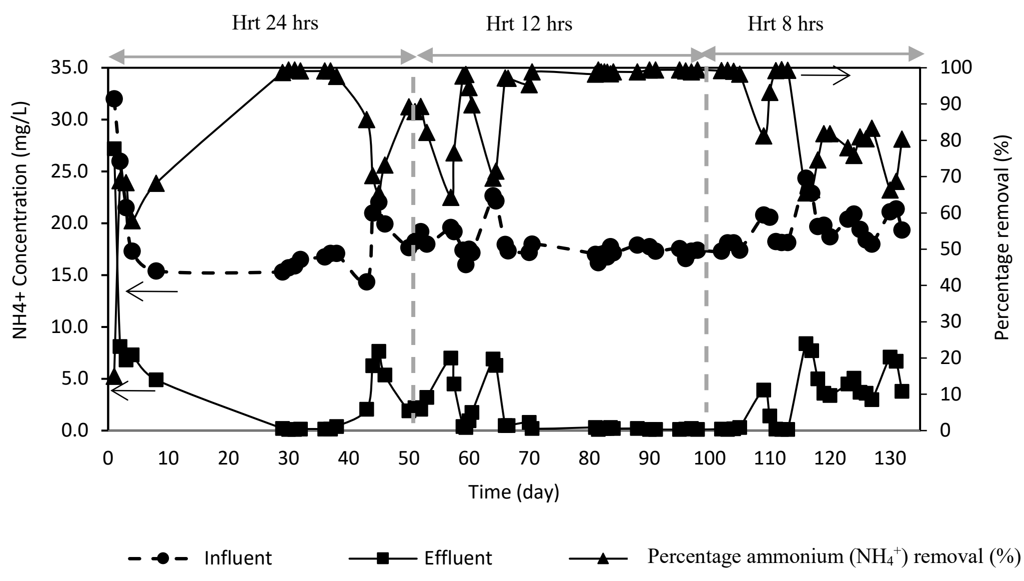

Fig. 4. Percentage removal of ammonium (NH_4^+).

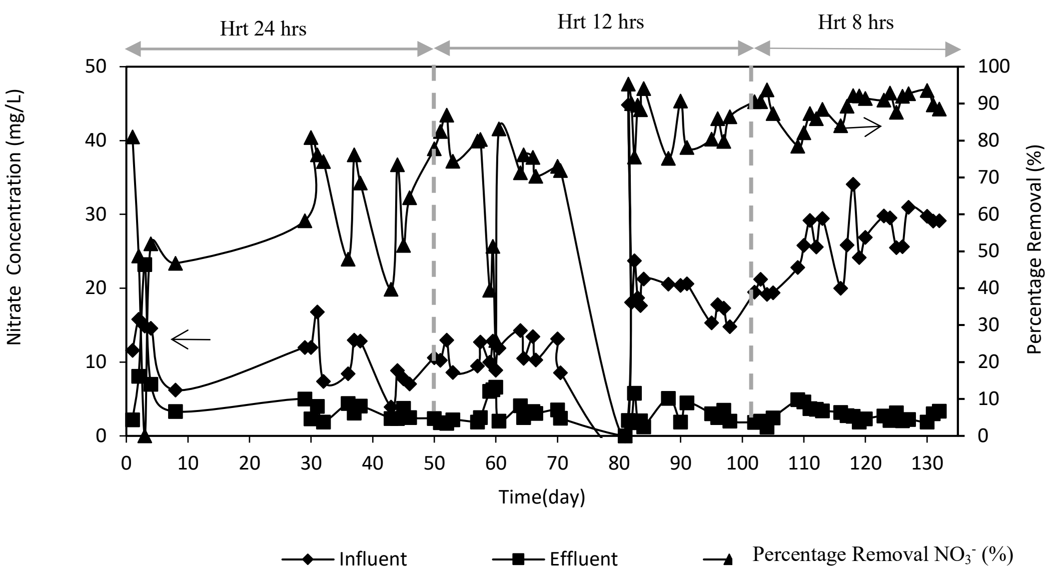

Fig. 5. Percentage Removal of Nitrate.

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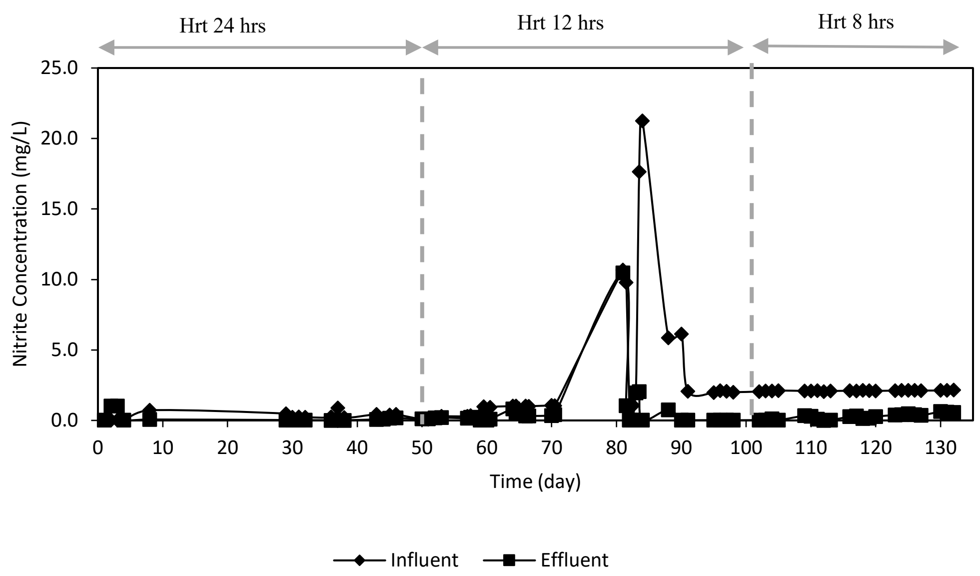

Fig. 6. Nitrite (NO_2^-) Concentration.

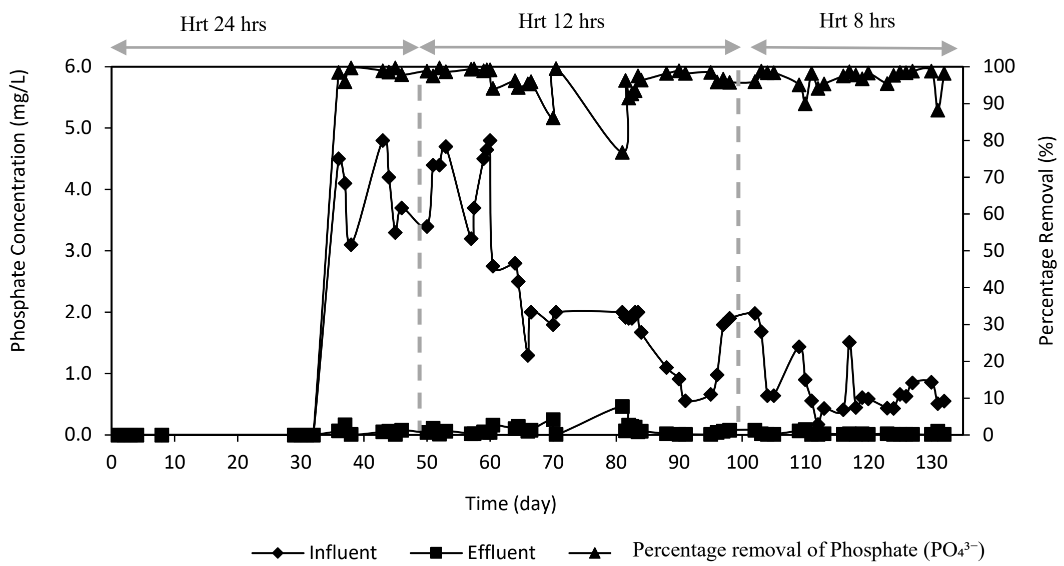

Fig. 7. Percentage Removal of Phosphate (PO_4^{3-})

Relationship Between Online Parameter and Analysis In-situ

Treatment of wastewater by means of biological process has been widely implemented from urban to industrial wastewaters [7]. However, biological treatment systems are effective and efficient for treating biodegradable wastewaters, if good process control is ensured [13]. Oxidation reduction potential (ORP), dissolved oxygen (DO) and pH were used as controlling factor because all these parameters have close relationship with reaction condition [20]. **Figs. 8, 9** and **10** illustrated the relationship between online parameter and nutrient removal for HRT 24 h, 12 h, and 8 h respectively. From these Figures, similar trend could be observed.

ORP value has close relationship between activity microorganism and nitrification and denitrification processes [7-21]. Anaerobic/anoxic and aerobic can be well distinguished by the means of ORP profile. The parameter ORP also reflects the concentration of DO. When ORP increases, DO increases too [20-21]. During nitrification process, ORP value will increase and moves toward positive value. However, when denitrification process occurred, OPR value will decrease and moves toward negative value [20-21]. From **Fig. 8, 9** and **10**, we can observe that denitrification process occurred first followed by nitrification process. During denitrification process, ORP value decreases until one point known as Nitrate Valley [20-22].

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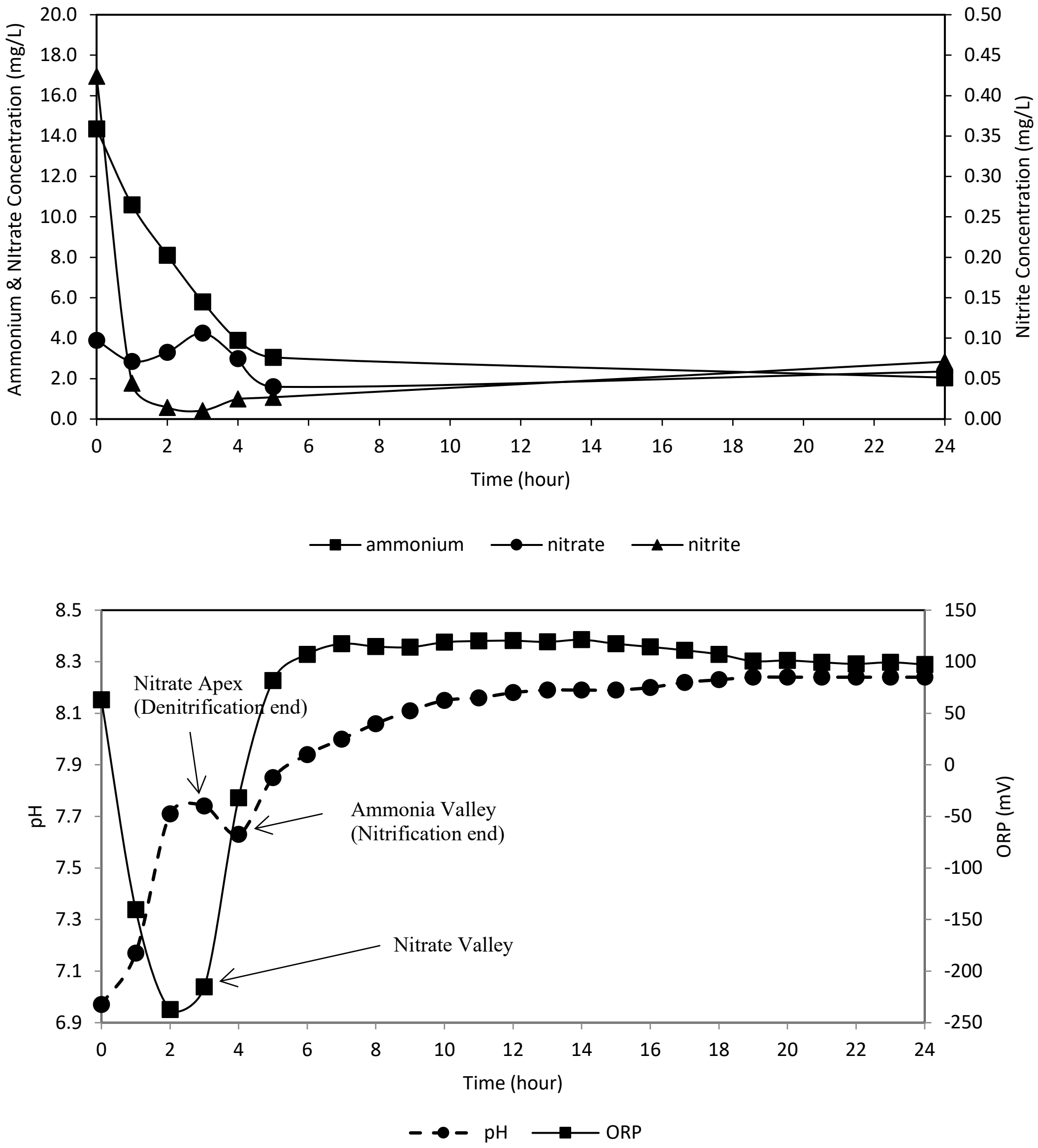

Fig. 8. Relationship between online parameter and analysis in-situ for HRT 24 h.

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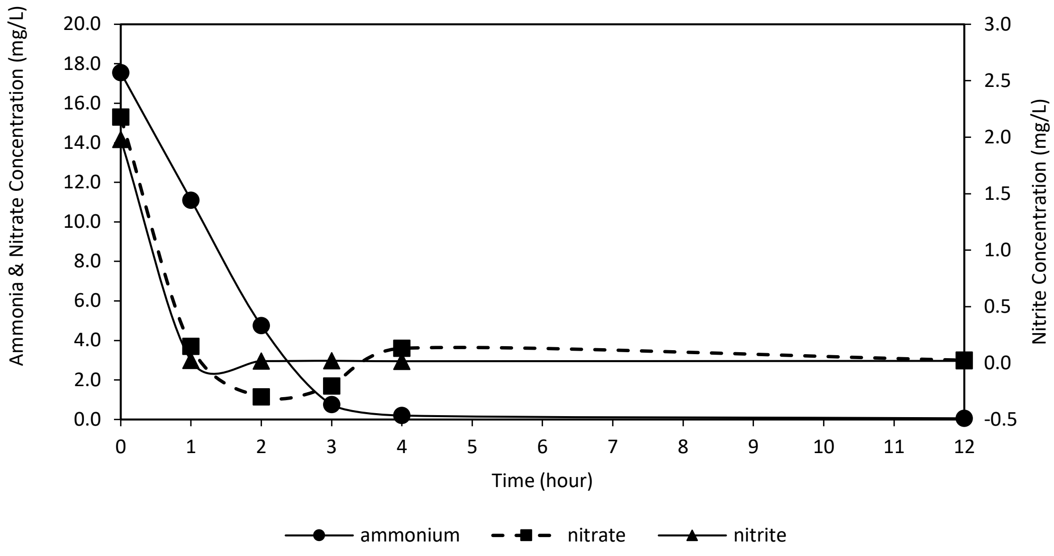

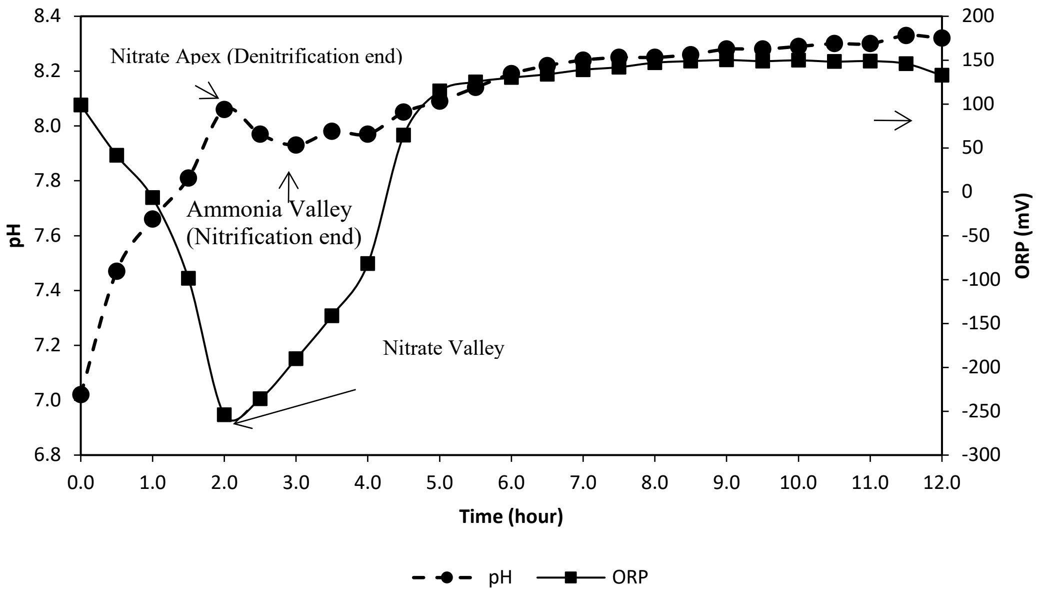

Fig. 9. Relationship between online parameter and analysis in-situ for HRT 12

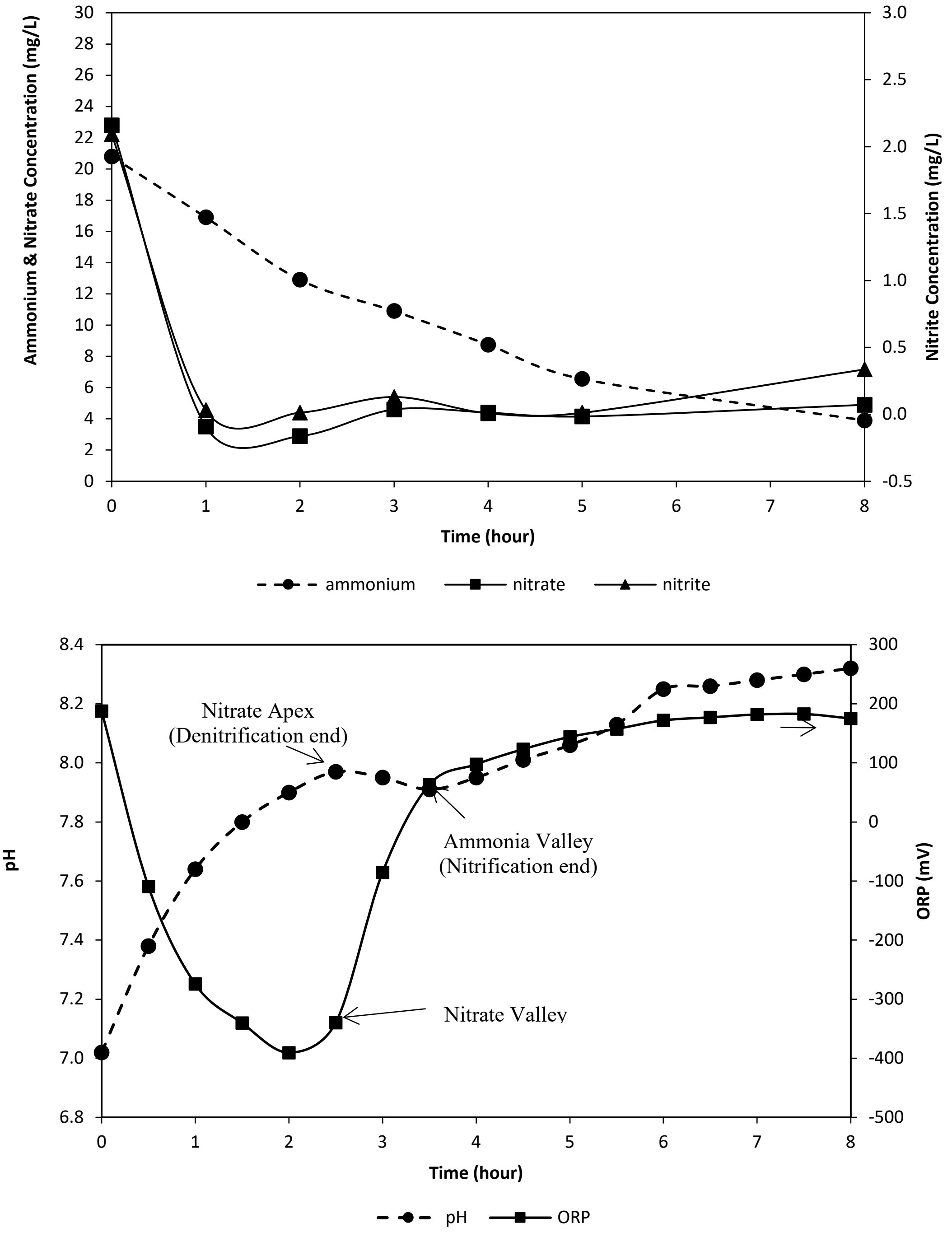

Fig. 10. Relationship between online parameter and analysis in-situ for HRT 8.

This point marks that nitrate concentration became minimum and denitrification process already completed as shown in **Fig. 8** to **10**. For nitrification process, ORP value increase and nitrate and nitrite concentration also increase as shown in **Fig. 8** to **10**. Values for nitrate valley for HRT 24 h, 12 h and 8 h were -237.2 mV, -254 mV and -390 mV respectively.

For pH profile, pH value will increase during denitrification process and decrease during nitrification process. In other words, pH value increases with decreases ORP and vice versa. According to [21], there are two important points in pH profile, which are ammonia valley and nitrate apex. Ammonia valley is the point that marks the end of nitrification process and located at the minimum curve in pH profile as shown in **Fig. 8** to **10**. Nitrate apex is the point that marks the end of denitrification process and located at the maximum curve in the pH profile as illustrated in **Fig. 8** to **10**. **Table 3** shows the summary for nitrate apex, ammonia valley and nitrate valley for three HRTs.

Table 3. Summary of Nitrate Valley, Nitrate Apex and Ammonia Valley.

	HRT 24 h		HRT 12 h		HRT 8 h	
	Time	Value	Time	Value	Time	Value
Nitrate Valley	2nd h	-237.2 mV	2nd h	-254 mV	2nd h	-390 mV
Nitrate Apex	2nd h	7.74	2nd h	8.06	2nd h	7.97
Ammonia Valley	4th h	7.63	3rd h	7.93	4th h	7.91

CONCLUSIONS

From the result obtained, we can conclude that sequencing batch reactor (SBR) is suitable approach to treat wastewater biologically. Percentage removals of COD for HRT 24 h, 12 h and 8 h were 90.3%, 95% and 96.4% respectively. Percentage removals of ammonium for HRT 24 h, 12 h and 8 h were 80.7%, 93.7% and 84.2% respectively. For nitrate, percentage removals for HRT 24 h, 12 h and 8 h were 60.7%, 77% and 89.2% respectively. Percentage removals for phosphate for HRT 24 h, 12 h and 8 h were 98.5%, 95.6% and 96.7% respectively. Among the three HRTs being tested, HRT 24 h achieved lowest percentage removal in terms of nutrient removals. HRT 12 h and 8 h achieved almost similar performance in nutrient removal. In addition, 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. 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. Thus, instead of analyzing 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 shows that the online monitoring can be applied successfully in the SBR system, and this application will result in a reduction of the operation cos while reduce the environmental pollution.

ACKNOWLEDGEMENT

The authors would like to thank Ministry of Higher Education, Malaysia for granting this project under FRGS/1/2019/TK02/UKM/01/1 and Universiti Kebangsaan Malaysia (UKM) for supporting this research work.

REFERENCES

1. Liu J, Yuan Y, Li B, Zhang Q, Wu L, Li X, Peng Y. Enhanced nitrogen, and phosphorus removal from municipal wastewater in an anaerobic-aerobic-anoxic sequencing batch reactor with sludge fermentation products as carbon source. Bioresour Technol. 2017; 244: 1158–1165.
2. Mojiri A, Ohashi A, Ozaki N, Kindaichi T. Pollutants removal from synthetic wastewater by the combined electrochemical, adsorption and sequencing batch reactor (SBR). Ecotoxicol Environ Saf. 2018; 161: 137–144.
3. Mohajeri P, Selamat MR, Aziz HA, Smith C. Removal of COD and Ammonia Nitrogen by a Sawdust/Bentonite-Augmented SBR Process. Clean Technol. 2019; 1(1): 125–140.
4. Hussain S, Aziz HA, Isa MH, AAdlan MN, Asaari FAH. Physioco-Chemical Method for Ammonia Removal from Synthetic Wastewater Using Limestone and GAC in Bath and Column Studies. Bioresour. Technol.2007; 98: 874-880
5. He Q, Zhang W, Zhang S, Wang H. Enhanced nitrogen removal in an aerobic granular sequencing batch reactor performing simultaneous nitrification, endogenous denitrification, and phosphorus removal with low superficial gas velocity. J Chem Eng. 2017; 326: 1223–1231.
6. Wang H, Song Q, Wang J, Zhang H, He Q, Zhang W, Song J, Zhou J, Li H. Simultaneous nitrification, denitrification, and phosphorus removal in an aerobic granular sludge sequencing batch reactor with high dissolved oxygen: Effects of carbon to nitrogen ratios. Sci Total Environ. 2018; 642: 1145–1152.
7. Hasan H A, Abdullah SSR., Kamarudin, SK, Kofli TN. Recognition of relevant ORP, pH, and DO bending points in ammonia removal from drinking water through online BAF system. Int J Chem React. 2010; 587032. 1-7
8. Chen W, Dai X, Cao D, Wang S, Hu X, Liu W, Yang D. Performance, and microbial ecology of a nitritation sequencing batch reactor treating high-strength ammonia wastewater. Sci Rep. 2016; 6.
9. Dutta A, Sarkar S. Sequencing Batch Reactor for Wastewater Treatment: Recent Advances. Curr Pollut Rep. 2015; 1(3): 177–190.
10. Akin BS, Ugurlu A. Monitoring, and control of biological nutrient removal in a Sequencing Batch Reactor. Process Biochem. 2005; 40: 2873-2878
11. Khumalo SM, Bakare BF, Tetteh EK, Rathilal S. Sequencing Batch Reactor Performance Evaluation on Orthophosphates and COD Removal from Brewery Wastewater. Ferment. 2022; 8(7).
12. Eljamal R, Kahraman I, Eljamal O, Thompson IP, Maamoun I, Yilmaz G. Impact of nZVI on the formation of aerobic granules, bacterial growth and nutrient removal using aerobic sequencing batch reactor. Environ Technol Innov. 2020; 19.
13. Sirivedhin T, Gray K. Factors Affecting Denitrification Rates in Experimental Wetlands: Field and Laboratory Studies. Eco Eng. 2006; 26(2): 167-181.
14. Wang J, Peng Y, Wang S, Gao Y. Nitrogen removal by simultaneous nitrification and denitrification via nitrite in a Sequence Hybrid Biological Reactor. Chin. J. Chem. Eng 2008; 16(5): 778-784
15. Chollom MN, Rathilal S, Swalaha FM, Bakare BF, Tetteh EK. Comparison of response surface methods for the optimization of an upflow anaerobic sludge blanket for the treatment of slaughterhouse wastewater. Environ Eng Res. 2020; 25(1): 114-122.
16. Ya;cob A, Zainol N, Aziz N.H. Application of response methodology for COD and ammonia removal from municipal wastewater treatment plant using acclimatized mixed culture. Heliyon. 2022; e09685
17. Yadu A, Sahariah BP, Anandkumar J. Influence of COD/ammonia ratio on simultaneous removal of NH_4^+-N and COD in surface water using moving bed batch reactor. J. Water Process Eng. 2018; 22: 66–72.
18. Ibrahim HTY. Study of Aeration Time Effect on COD and Ammonia removal by Sequencing Batch Reactor. *J. Univ. Babylon* Eng. Sci. 2017; 1(25): 276-283
19. Muhammad MH, Abdullah SRS, Hasan HA, Bakar SNHA. Multimedia-sequencing batch reactor in treating recycled paper mill effluent containing high level of

pentachlorophenol: long term performance, mechanism, and kinetic studies. J. Water Process Eng. 2020; 37: 101522
20. Hajsardar M, Borghei SM, Hassani AH, Takdastan A. Simultaneous ammonium, and nitrate removal by a modified intermittently aerated sequencing batch reactor (SBR) with multiple filling events. Pol J Chem Technol. 2016; 18(3): 72–80.
21. Alattabi AW, Harris C, Alkhaddar R, Alzeyadi A, Abdulredha M. 2017. Online monitoring of a sequencing batch reactor treating domestic wastewater. Proceedia Eng. 2017; 196: 800-807
22. Azis K, Ntougias S, Melidis P. $NH4^{+}$-N versus pH and ORP versus NO3−-N sensors during online monitoring of an intermittently aerated and fed membrane bioreactor. Environ. Sci. Pollut. Res. 2021; 28(26); 33837–33843.