

Research Article

Influence of Internal and External Recycle on Nitrogen Removal in Compact Bioreactor

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Abstract: Internal Recycle ratios (IR) were alternated and operated to determine its efficiency on nitrate removal within a SMALL FOOTPRINT bioreactor. Determining a suitable recycle ratio is essential to justify the prerequisites required for operative optimization. In order to achieve considerable nitrogen reduction, the reactor was designed with primary (pre) and secondary (post) anoxic chambers, combined aeration chamber for nitrification and carbon removal and final settler to settle the biomass prior to discharge. The nitrate oxidized in aeration chamber was recycled back to the pre-anoxic chamber. The residual nitrate flows to the post anoxic chamber for denitrification. Each IR ratio of 6, 4 and 0, was operated with distinct influent Chemical Oxygen Demand (COD) to Total Kjeldahl Nitrogen (TKN) ratios of 18.9, 14.9 and 10.9, respectively. The IR of 6 with COD/TKN ratio of 18.9 attained maximum Total Nitrogen (TN) removal efficiency of 90.7%. The overall average total nitrogen (TN) = 4.0 mg/L in effluent was achieved, signifying an average of 9.5% efficiency more than the process without nitrate recycle, with average effluent TN = 7.7 mg/L.

Keywords: Compact, internal recycles, nitrogen, SMALL FOOTPRINT

INTRODUCTION

Regulatory authorities are increasingly becoming conscious of the pressure on growing pollution due to indiscriminate discharge of nutrients to the aquatic environment, with resultant consequences becoming eminent on public health and the environment. This discharge of nutrients sets in eutrophication and aquatic toxicity (Daigger and Lim, 2011; LaPara and Ghosh, 2006). For instance, the ammonia compound is toxic to fish and other aquatic life and the microbial growth increases the biological oxygen demand and decreases dissolved oxygen concentrations within the aquatic environment. This creates “dead zones” caused by lack of dissolved oxygen in the water and is very detrimental to aquatic life (Salama *et al.*, 2014).

Exposures of nitrate for short and long-term can cause major health complications to humans when polluted drinking water is consumed. Drinking water contamination from short-term exposure can cause methemoglobinemia (blue baby syndrome) in infants (LaPara and Ghosh, 2006). The highly soluble nitrates and nitrites attach to the hemoglobin in the blood can result in deficiency of oxygen in the blood causing oxygen deprivation, which within only a few days can be fatal if unchecked (LaPara and Ghosh, 2006). On the other hand, exposures to long-term with nitrates and nitrites can cause diuresis, which is an enlarged starchy buildup and hemorrhaging of the spleen (Aslan and

Cakici, 2007). Anthropogenic origins are the main sources of nitrate, nitrite and ammonia contamination in surface and groundwater. Agricultural run-off, fish canning wastes, refineries, tanneries, fertilizers and domestic wastewater are a few examples and all can reach watercourses to cause damaging effects to aquatic habitats, people and animals (Sabumon, 2007).

Environment Quality Regulation Act of 1974 in Malaysia under purview of the Department of Environment (DOE, Environmental Quality (Sewage) Regulations, 2009) to include stringent restrictions of ammonia and nitrate-nitrogen to a minimum of 5 and 10 mg/L, respectively (DOE, Environmental Quality (Sewage) Regulations, 2009). This informs the need for enhancing the removal of nitrogen compounds from Wastewater Treatment Plants (WWTP), as a significant step to meet up with the strict increasing environmental regulations.

Total Nitrogen (TN) comprises both organic and inorganic (ammonium, nitrate and nitrite) forms (Downing and Nerenberg, 2008). Nitrogen in municipal wastewater originates from human fecal matter, ground refuse and industrial waste particularly food processing waste. Influent nitrogen comprises of three main sources: approximately 60% of ammonium; 40% of organic nitrogen which consists of a complex mixture of organic compounds including amino acids, amino sugars and proteins; negligible amount of nitrate, normally less than 1% (Sedlak, 1991). Bacterial

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decomposition of protein and hydrolysis of urea readily convert the organic nitrogen in wastewater to ammonium (Tchobanoglous *et al.*, 2003; Sedlak, 1991). Nitrogen removal in municipal wastewater is a vital process before discharging into natural water causes.

In this regard, the reduction from domestic wastewater treatment plants is largely mandatory to the complete environmental sustainability. The process to remove TN can be accomplished through sequential nitrification and denitrification processes (Tchobanoglous *et al.*, 2003). The bacteria for nitrification being nitrifiers are slow growers (Schmidt and Belser, 1982), hence high sludge age is necessary to ensure high removal efficiency and low operating tendencies (Ohashi *et al.*, 1995; Schmidt and Belser, 1994). The solids retention time (SRT), otherwise referred to as mean cell residence time is the time the biomass remain in activated sludge system before being wasted, remains is an important design parameter in activated sludge process (Kutty *et al.*, 2011).

Investigating the practical internal recycle ratio is necessary to optimize the system performance and evaluate cost related expenditure to operate on SMALL FOOTPRINT bioreactors.

BIOLOGICAL NITROGEN REMOVAL

Biological Nitrogen Removal (BNR) offers removal total nitrogen (both organic and inorganic

nitrogen) through action of a variety of microorganisms under different environmental conditions (Tchobanoglous *et al.*, 2003). This is accomplished by either assimilation to form cells or by conversion of nitrogen contents to nitrogen gas liberated to the atmosphere (Tchobanoglous *et al.*, 2003; Sedlak, 1991). Basically, biological processes could operate as suspended growth or attached growth processes, or combination of both (Grady Jr. *et al.*, 2012). The focus of this study is suspended growth process, where the microorganisms are retained in suspension in the bioreactor, under aerobic condition with dissolved oxygen concentration of above 2 mg/L and anoxic condition without dissolved oxygen, which could inhibit denitrification performance (Tchobanoglous *et al.*, 2003; Metcalf and Eddy *et al.*, 2013).

Nitrification and denitrification are the two fundamental biological processes used in achieving nitrogen removal in municipal wastewater (Tchobanoglous *et al.*, 2003). During nitrification process, ammonium is oxidized to nitrite and then to nitrate in two steps, while denitrification converts nitrate to nitrogen gas. Nitrogen gas is released to the atmosphere from the wastewater in the anoxic chamber. These two processes are dependent on several factors such as pH, temperature, dissolved oxygen, alkalinity, toxicity, etc. (Jeyanayagam, 2005; Tchobanoglous *et al.*, 2003).

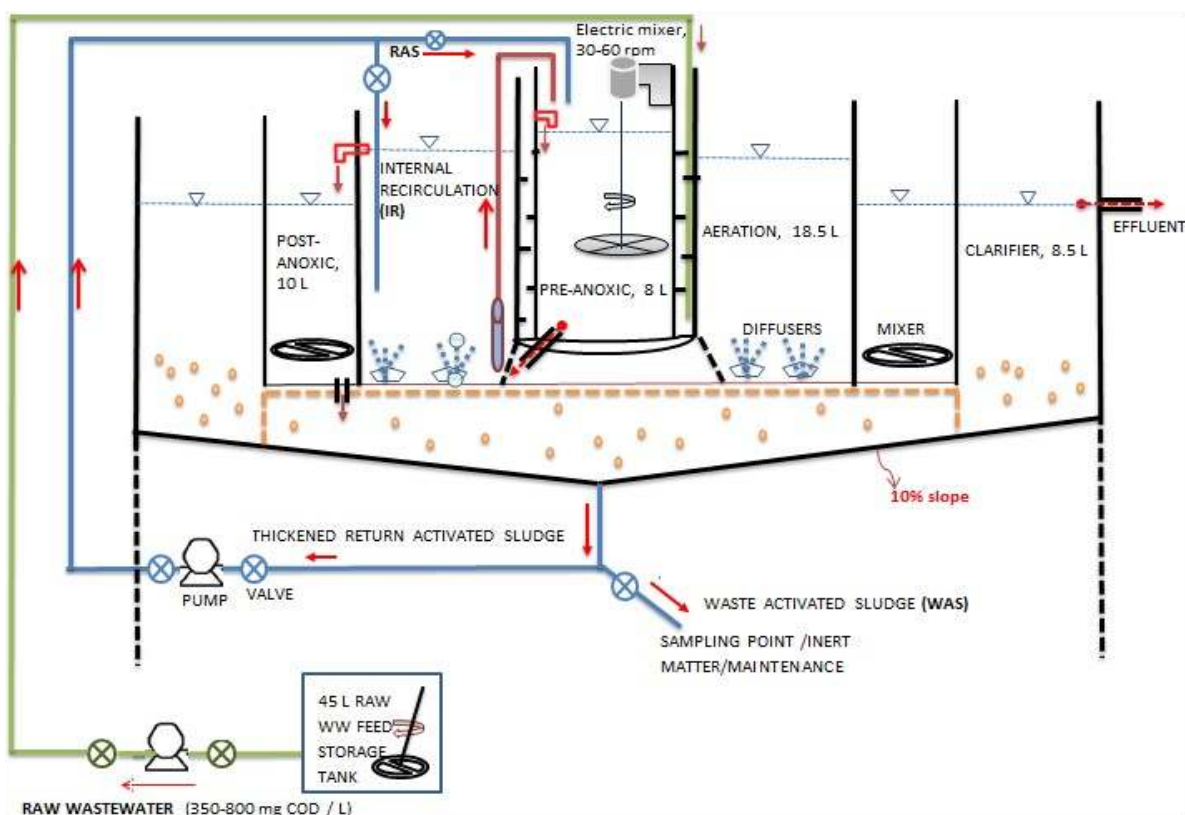


Fig. 1: Cross section of bench-scale SMALL FOOTPRINT bioreactor process

MATERIALS AND METHODS

Description of experimental setup: Figure 1 illustrates the cross section of the continuous flow reactor used for this experiment. The reactor consists of pre-anoxic (8 L), aeration (18.5 L), post-anoxic (10 L) and final settler (15 L). Influent as raw carbon source is set to enter into the pre-anoxic and flow to aeration chamber, while ensuring adequate detention time maintained by fitted narrow baffles. The aeration chamber has adequate air diffusers providing fine bubbles through supplied air by compressor, maintaining dissolved oxygen between 2.0-3.0 mg/L. A submersible pump with programmed timer is fitted inside the aeration chamber to return nitrate produced back to the pre-anoxic chamber for denitrification. The residual nitrate passes through the post-anoxic chamber for denitrification, using endogenous carbon source from aeration chamber. The biomass is recycled to pre-anoxic and aeration chamber to keep the concentration of biomass within the system. The anoxic chamber mixing is provided slowly to ensure biomass does not settle, while degradation proceeds accordingly. Daily wastage of sludge was carried out to avoid excess growth of biomass. The reactor configuration resembles Bardenpho process (Ilies and Mavinic, 2001; Tchobanoglous *et al.*, 2003; Sattayatewa *et al.*, 2009).

Influent wastewater characteristics for the experiment: Synthetic substrate was prepared by grinding to fine particles, a balanced diet cat's food with the addition of macro and micronutrients for required growth of microbes according to Table 1. The C:N:P ratio of 100:5:1 was reported as minimum to offer an enabling environment for growth of bacteria to degrade organic matter (Baeza *et al.*, 2004; Kutty *et al.*, 2012). The concentration of the ammonium chloride was altered accordingly to achieve the desired experimental goals.

Bioreactor operating conditions: The process to evaluate the internal recycle was performed after the reactor has fully stabilized (seeding, acclimatization and biomass build up achieved) within 35 days after the start-up. The MLSS concentration was maintained in the bioreactor through daily wasting (Al-Malack, 2006; Amin *et al.*, 2012). The sludge age of 40 days was maintained during the period of the experiment. The operational conditions for the process are presented in Table 2.

Analytical procedure: Grab samples after attaining full reactor HRT were obtained from the influent, exit of pre-anoxic, exit of aeration, exit of post-anoxic, exit of RAS and effluent from clarifier. The samples were in triplicates and analysed 3 times per week. The procedure follows American Public Health Association

Table 1: Composition of synthetic wastewater

Component	Concentration (mg/L)
Cat's premium feed	1500
Ammonium chloride (NH ₄ Cl)	55/85/110
Magnesium chloride (MgCl ₂ .7H ₂ O)	78.0
Sodium chloride (NaCl)	69.0
Potassium di hydrogen phosphate (KH ₂ PO ₄)	65.0
Calcium chloride (CaCl ₂ . 2H ₂ O)	35.0
Iron Sulphate (FeSO ₄ . 7H ₂ O)	1.70
Zinc sulphate (ZnSO ₄ .7H ₂ O)	1.70
Manganese sulphate (MnSO ₄ .7H ₂ O)	1.10
Copper sulphate (CuSO ₄ .5H ₂ O)	0.86
Yeast extract	0.86

Table 2: Operational conditions

Parameter	Value
Inflow, (I ₀)	20 L per day
Return Activated Sludge, (RAS) = 1.5* I ₀	30 L per day
Internal recycle flow, (IR ₀)	120/80/0 L per day
Internal recycle ratio, (IR) = IR ₀ / I ₀	6/4/0
Hydraulic retention time,	
Pre-Anoxic, $\Theta_{preanox}$	9.6 hours
Aeration, Θ_{aer}	22.2 hours
Post-Anoxic, $\Theta_{postanox}$	12.0 hours
SRT, Θ_c	40 days
pH	7.0 – 7.8
Temperature	25 - 28 °C
Dissolved oxygen,	
DO in Pre-anoxic	0 mg/L
DO in Aeration	2.0 – 3.0 mg/L
DO in Post-anoxic	0 mg/L

(APHA), standard methods (Federation and Association, 2005) according to Table 3.

Experimental design: Total of nine experiments were conducted. Each influent ammonia-nitrogen dosage and internal recycle ratio were combined according to Table 4. Therefore, each set of experiment was completed three times and nine times for the whole procedure.

The nitrate recycle design for the reactor was according to the provision of the nitrate transfer at six times the influent flow rate to the anoxic zone for denitrification (Tchobanoglous *et al.*, 2003). Therefore, peak internal recirculation of 600% can be operated to achieve substantial nitrate reduction (Cervantes *et al.*, 2006; Grady Jr. *et al.*, 2012). However, higher recycle could increase in subsequent economic cost due to energy requirements associated to pumping and may inhibit anoxic performance due to the tendencies of introduction dissolved oxygen (Baeza *et al.*, 2004; Ding *et al.*, 2013).

RESULT AND DISCUSSION

Properties of synthetic wastewater and effluent parameters: Influent wastewater characteristic that was maintained during the experimental studies is contained in Table 5. The different compositions of ammonia-nitrogen concentration dosage in influent as 15, 23 and 30 mg/L, yielded C/N/ P ratios of 100/5/3, 100/7/3 and 100/9/3, respectively. Therefore, sample 1,

Table 3: Federation and Association (2005) analytical procedure

S. No	Parameter	Method	Equipment	Volume of sample (mL)					
				I	ANX-1	AER	ANX-2	CLR	E
1	MLSS/MLVSS	Gravimetric method	Digital analytical balance (MAX 2000G), Oven (103-105°C), muffle furnace (ashing at 550°C), vacuum suction pump	X	10	10	10	2	X
2	Ammonia-nitrogen	Nessler, method 8039	Spectrophotometer DR2800, 10/20 mL cuvette, Digestion vessel DRB200, Heating block, micro fiber glass filter paper to filter for soluble COD	10	10	10	10	X	10
3	Nitrate-Nitrogen	Cadmium reduction, method 8039		30	30	30	30	X	30
4	Total Phosphorus	Acid persulfate Digestion, Method 8190		5	X	X	X	X	5
5	COD	Reactor Digestion, Method 8000		6	6	6	6	X	6
6	Total Nitrogen	Persulfate digestion: 10072		X	6	6	6	X	X
7	TKN	Buchi Auto Kjeldahl Method, Digestion, distillation and titration	Buchi Auto Kjeldahl Method	30	X	X	X	X	30
8	BOD ₅	Membrane Electrode Method: 5 days Incubation at 20°C and Membrane Electrode Method for DO (mg/L)	DO meter model YSI 5100	5	10	10	20	X	50
11	pH and Temperature	HACH pH Sensor +, PH3 and probe		50	50	50	50	X	50

I: Influent, ANX-1: Pre-anoxic, AER: Aeration, ANX-2: Post-anoxic, CLR: Clarifier, E: Effluent, COD: Chemical Oxygen Demand, TKN: Total Kjeldahl Nitrogen, pH: Power of Hydrogen, MLVSS: Mixed Liquor Volatile Suspended Solids, MLSS: Mixed Liquor Suspended Solids

Table 4: Experimental design for the operational procedure

Experimental design					
Experiment	Set	COD/TKN Ratio	Ammonia-nitrogen dosage (mg/L)	IR rate	Nomenclature
1	1	18.9	15	6 I _Q	Set 1_15 mg/L ammonia-nitrogen with IR at 6 I _Q
2			15	4 I _Q	Set 1_15 mg/L ammonia-nitrogen with IR at 4 I _Q
3			15	0	Set 1_15 mg/L ammonia-nitrogen with IR at 0
4	2	14.9	23	6 I _Q	Set 2_23 mg/L ammonia-nitrogen with IR at 6 I _Q
5			23	4 I _Q	Set 2_23 mg/L ammonia-nitrogen with IR at 4 I _Q
6			23	0	Set 2_23 mg/L ammonia-nitrogen with IR at 0
7	3	10.9	30	6 I _Q	Set 3_30 mg/L ammonia-nitrogen IR with 6 I _Q
8			30	4 I _Q	Set 3_30 mg/L ammonia nitrogen with IR at 4 I _Q
9			30	0	Set 3_30 mg/L ammonia-nitrogen with IR 0

I_Q: Influent flow rate (L/d), IR: Internal recirculation

Table 5: Influent wastewater characteristics and effluent parameters

Parameter	Influent concentration (mg/L)			Effluent concentration (mg/L), IR = 6/4/0								
	Sample 1	Sample 2	Sample 3	Set 1			Set 2			Set 3		
COD	500	500	500	48.0	48.0	48.1	47.4	47.4	47.3	47.2	47.2	47.0
TN	27.4	34.6	47.0	2.50	3.50	5.40	4.40	5.70	7.70	6.30	8.80	10.5
NH ₄ ⁺ -N	15.0	23.0	30.0	2.20	3.20	3.70	4.00	4.30	4.80	5.70	7.20	7.40
Norg-N	11.6	10.6	15.8	0.10	0.10	0.20	0.20	0.00	0.10	0.10	0.10	0.30
NO ₃ ⁻ -N	0.70	1.00	1.20	0.20	0.30	1.20	0.20	1.40	2.60	0.50	1.30	2.40
TKN	26.6	33.6	45.8	2.30	3.30	4.00	4.20	4.40	4.90	5.80	7.30	7.70
PO ₄ ³⁻ -P	15.0	15.0	150	12.1	11.9	11.8	12.0	11.8	11.6	11.9	11.7	11.6

IR: Internal Recirculation

sample 2 and sample 3 had equivalent set 1, set 2 and set 3 values obtained in the effluent in Table 4. These ratios for the influent feed are above the minimum recommended for biological wastewater treatment

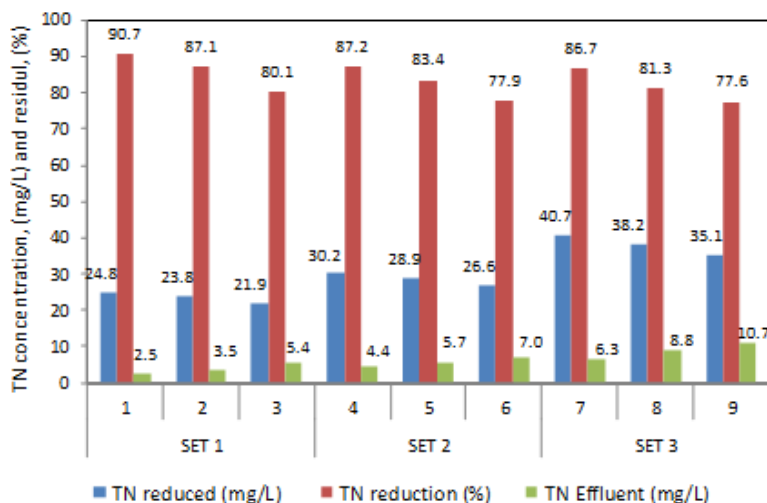


Fig. 2: Removal efficiency of total nitrogen in CEAR

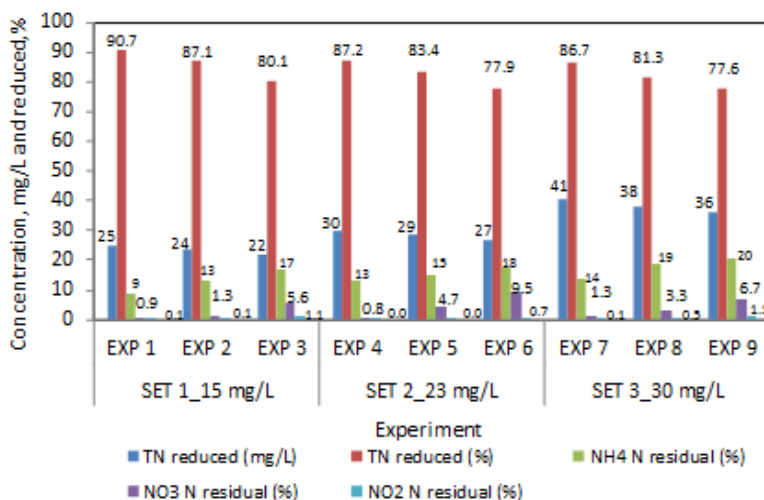


Fig. 3: Contribution of residual nitrogen components in effluent

process to occur (Diez *et al.*, 2002; Marrot *et al.*, 2006). Hence, satisfactory biological process for carbon oxidation, nitrification and denitrification in the biological reactor was compliant. Previous treatment processes were accomplished by similar C/N/P ratios (Ammary, 2004; Diez *et al.*, 2002).

The COD and phosphorus removal in the operational recycle ratios were very insignificant during the entire experiment. It can be seen that the carbon required for denitrification is comes from the raw influent. The removal of phosphorus will require anaerobic process in order for actual removal and treatment to be achieved.

Effect of internal recirculation on Total nitrogen removal: The determination of removal efficiencies for the nitrogen compounds was determined according to (1):

$$N_{removed}(\%) = (N_{Influent} - N_{Effluent}) / N_{Influent} * 100 \quad (1)$$

$N_{influent}$ and $N_{effluent}$ is evaluated for all the nitrogen forms; organic and inorganic in influent and effluent, respectively. The nitrogen forms have been explained earlier in section 1. Figure 2 shows total nitrogen reduced and its corresponding reduction in the percentage from influent. The reductions are determined based on (1). Figure 3 shows various components for total nitrogen for the experiments carried out that remained as residual components. Out of which residual contribution of the remainder contributed by each component in effluent is presented. The maximum removal occurred during set 1 in the first experiment, with removal of 24.8 mg/L (90.7%) and minimum removal was achieved in set 3 during experiment 9, with removal of 36.4 mg/l (77.6%). It can be observed that least removal occurred without internal recycle. However, only the return sludge to keep the biomass concentration in the bioreactor.

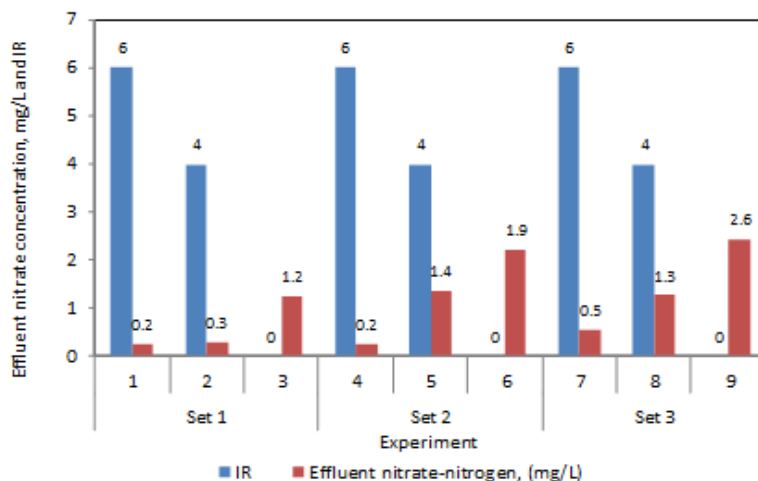


Fig. 4: Nitrate-nitrogen reduction for set of experiments

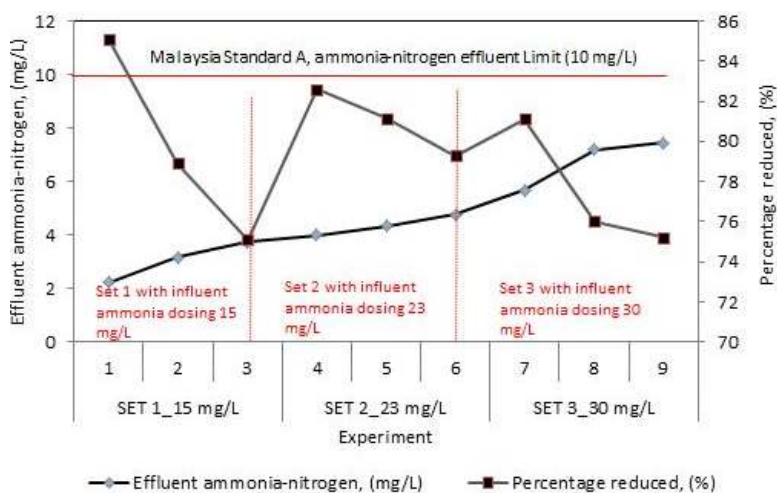


Fig. 5: Ammonia-nitrogen reduction for set of experiments

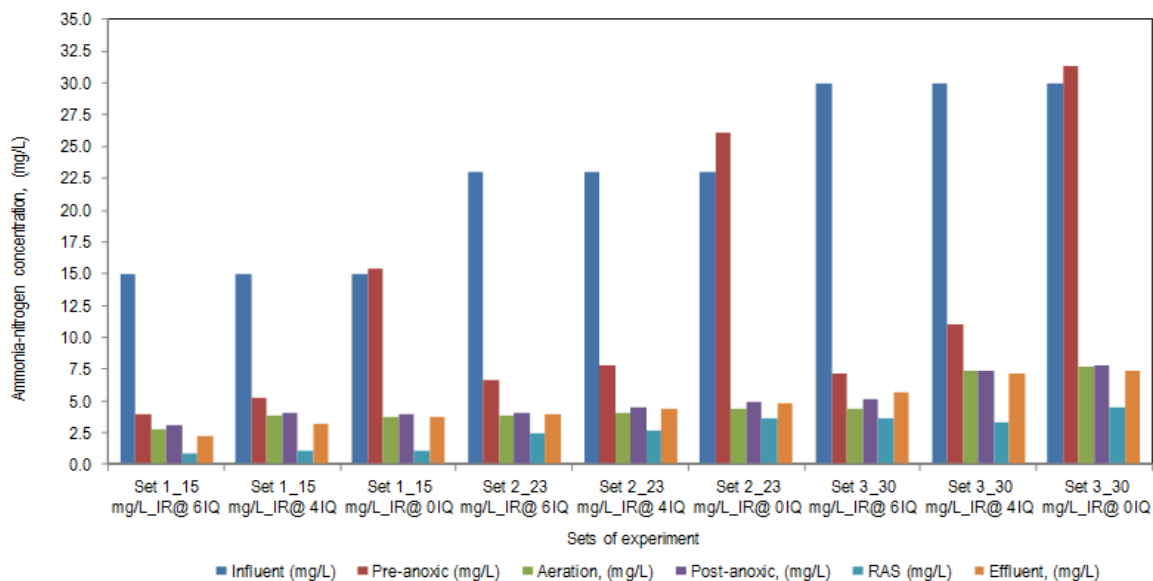


Fig. 6: Fingerprint profile for the serial reduction of ammonia-nitrogen

The recycle could probably mean that microbial species responsible for organic matter degradation are activated to increase efficiency of the treatment process due to contact time. The lowest removal occurred during highest dosing of ammonia-nitrogen concentration (30 mg/L) in the influent. In contrast, maximum removals occurred during highest recycle with the least dosing of the ammonia-nitrogen of 15 mg/L. Therefore, concentrations of ammonia in influent and internal recycle are fundamental and could possibly be an important consideration. The maximum removal in TN efficiency with recycle were observed; in set 1 at 10.6%, followed by 9.3% in set 2 and 9.1% in set 3.

Effect of internal recycle on denitrification: The trend for the nitrate sequence with operational internal recycle at the rates of 6, 4 and 0 are presented in Fig. 4. The effluents with least nitrate concentration were recorded and both had common internal recycle of 6, with concentrations of 0.2 mg/L during experiments 1 and 4. The highest effluent nitrate concentration was recorded during experiment 9 (2.6 mg/L), without internal recycle. In comparing the effluent nitrate concentration from the individual sets of the experiments, it is obvious that a serial reduction due to influence of internal recycle was detected. However, ammonia-nitrogen concentration in the influent could be a controlling factor in determining the effluent quality, especially if in high concentration. The nitrate limits for the entire ammonia-nitrogen dosage tested at internal recycle of 4 could still meet up with the regulatory requirements. The incorporation of the post-anoxic chamber for denitrification influenced nitrate removal, even without operating internal recycle. Though, the nitrate source in the pre-anoxic chamber is that supplied from the return activated sludge only. This could be another economic consideration with the limits already attained through the RAS operated at $1.5I_Q$ without internal recycle. This might be practical for high wastewater flows.

Several integrated reactors have experimented TN removal within smaller footprint bioreactors (Ding *et al.*, 2013; Meng *et al.*, 2013; Satoh *et al.*, 2004). Internal recycle rate could significantly influence on the TN removal efficiency (Ahmed *et al.*, 2007).

Effect of recirculation on effluent ammonia-nitrogen concentration: The ammonia-nitrogen removal efficiencies during the 9 experiments is highlighted in Fig. 5, while Fig. 6 illustrate the ammonia-nitrogen sequential reduction in the bioreactor. The elevated concentrations of ammonia-nitrogen in the anoxic zones during regimes without recycle were observed. However, source of ammonia remained steady from influent, without dilution effects from described sources. Hydrolysis could probably set in to produce ammonium from organic nitrogen. It can be observed in

each set of experiment, that effluent quality largely depends on the recycle ratio and specific influent ammonia-nitrogen concentrations. Hence, higher ammonia-nitrogen removal was achieved with recycle ratio of 6 in the entire experiments. The least influent ammonia-nitrogen concentration of 15 mg/L was in set 1 (experiment 1), where highest removal was observed at 2.2 mg/L (85.1%). The lowest removal was obtained in set 3 (experiment 9), where effluent quality of 7.4 mg/L (75.2%) was recorded. Similar observations were substantiated in previous work (Baeza *et al.*, 2004; Ding *et al.*, 2013).

CONCLUSION

This research has offered an informed assessment on the impact of variable nitrate recycle ratio on the removal efficiency of total nitrogen, within an integrated wastewater bioreactor. An increasing quality in the effluent nitrate was observed with increasing operational recycle ratios of 6, 4 and 0, respectively. Further ending observations are emphasized below:

- Evidence for the concept has been established that the innovative SMALL footprint bioreactor capable of nitrogen removal to meet DOE requirements.
- Average of 9.5% TN removal efficiency was achieved with IR of 6.
- Economic evaluation can be made with the informed operational data.
- The recycle ratio of 4 can still offer required quality of total nitrogen in effluent for the medium strength wastewater. However, the effluent quality could depend on the influent TN concentrations.
- Savings from cost of pumping due to power requirements can be minimized at recycle ratio of 4.
- Denitrification has been further achieved with larger post anoxic reactor volume of 10 L.
- CEAR as extended aeration system has offered prospects to waste less sludge, which could have incurred huge cost for its management.

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NOMENCLATURES

- I_Q : Inflow
 RAS : Return activated sludge
 IR_Q : Internal recycle flow, lpd
 IR : Internal recycle ratio

Greek symbols:

θ : Hydraulic retention time

θ_c : Solids retention time

Abbreviations:

CEAR : Compact extended aeration reactor

EQA : Environmental Quality Act

DoE : Department of Environment

TN : Total nitrogen

TKN : Total kjeldahl nitrogen

SRT : Solids retention time

IR : Internal recirculation

BNR : Biological nitrogen removal

MLSS : Mixed liquor Suspended Solids

DO : Dissolved oxygen

REFERENCES

Ahmed, Z., B.R. Lim, J. Cho and K.H. Ahn, 2007. Effects of the internal recycling rate on biological nutrient removal and microbial community structure in a sequential anoxic/anaerobic membrane bioreactor. *Bioproc. Biosyst. Eng.*, 30(1): 61-69.

Al-Malack, M.H., 2006. Determination of biokinetic coefficients of an immersed membrane bioreactor. *J. Membrane Sci.*, 271(1): 47-58.

Amin, M., S. Kutty, H. Gasim and M. Isa, 2012. Impact of petroleum refinery wastewater on activated sludge. *Proceeding of 5th WSEAS International Conference on Environmental and Geological Science and Engineering (EG)*. Vienna, Austria.

Ammary, B.Y., 2004. Nutrients requirements in biological industrial wastewater treatment. *Afr. J. Biotechnol.*, 3(4): 236-238.

Aslan, S. and H. Cakici, 2007. Biological denitrification of drinking water in a slow sand filter. *J. Hazard. Mater.*, 148(1): 253-258.

Baeza, J., D. Gabriel and J. Lafuente, 2004. Effect of internal recycle on the nitrogen removal efficiency of an anaerobic/anoxic/oxic (A²O) wastewater treatment plant (WWTP). *Proces Biochem.*, 39(11): 1615-1624.

Cervantes, F.J., S.G. Pavlostathis and A.C. Van Haandel, 2006. *Advanced Biological Treatment Processes for Industrial Wastewaters: Principles and Applications*. IWA Publishing, London, ISBN: 1843391147, pp: 345.

Daigger, G.T., and H.C. Lim, 2011. *Wastewater Treatment*. Vol. 63.

Diez, M., G. Castillo, L. Aguilar, G. Vidal and M. Mora, 2002. Operational factors and nutrient effects on activated sludge treatment of *Pinus radiata* kraft mill wastewater. *Bioresource Technol.*, 83(2): 131-138.

Ding, A., F. Qu, H. Liang, J. Ma, Z. Han, H. Yu and G. Li, 2013. A novel integrated vertical membrane bioreactor (IVMBR) for removal of nitrogen from synthetic wastewater/domestic sewage. *Chem. Eng. J.*, 223: 908-914.

DOE, Environmental Quality (Sewage) Regulations, 2009. Environmental Quality Act, 1974. Environmental Quality (Control of Pollution from Solid Waste Transfer Station and Landfill) Regulations, Malaysia.

Downing, L.S. and R. Nerenberg, 2008. Total nitrogen removal in a hybrid, membrane-aerated activated sludge process. *Water Res.*, 42(14): 3697-3708.

Federation, W.E. and A.P.H. Association, 2005. *Standard Methods for the Examination of Water and Wastewater*. American Public Health Association (APHA), Washington, DC, USA.

Grady Jr., C.L., G.T. Daigger, N.G. Love and C.D. Filipe, 2012. *Biological Wastewater Treatment*. CRC Press, Boca Raton, FL.

Ilies, P. and D. Mavinic, 2001. Biological nitrification and denitrification of a simulated high ammonia landfill leachate using 4-stage Bardenpho systems: System startup and acclimation. *Can. J. Civil Eng.*, 28(1): 85-97.

Jeyanayagam, S., 2005. True confessions of the biological nutrient removal process. *Florida Water Resour. J.*, 1: 37-46.

Kutty, S., M. Isa and L. Leong, 2011. Removal of ammonia-nitrogen (NH₃-N) and nitrate by modified conventional activated-sludge system to meet new DOE regulations. *Proceeding of the International Conference on Environment and Industrial Innovation (IPCBE)*.

Kutty, S.R.M., S.G. Khaw, C.L. Lai and M.H. Isa, 2012. Removal of copper using Microwave Incinerated Rice Husk Ash (MIRHA) in continuous flow activated sludge system. *Proceeding of the International Conference on Civil, Offshore and Environmental Engineering (ICCOEE)*, 2012.

LaPara, T. and S. Ghosh, 2006. Population dynamics of the ammonia-oxidizing bacteria in a full-scale municipal wastewater treatment facility. *Environ. Eng. Sci.*, 23(2): 309-319.

Marrot, B., A. Barrios-Martinez, P. Moulin and N. Roche, 2006. Biodegradation of high phenol concentration by activated sludge in an immersed membrane bioreactor. *Biochem. Eng. J.*, 30(2): 174-183.

Meng, F., Z. Zhou, L. Li, R. Li, X. Jia and S. Li, 2013. A novel nearly plug-flow membrane bioreactor for enhanced biological nutrient removal. *AIChE J.*, 59(1): 46-54.

Metcalf and Eddy, G. Tchobanoglous, H.D. Stensel, R. Tsuchihashi and F. Burton, 2013. *Wastewater Engineering: Treatment and Resource Recovery*. 5th Edn., McGraw-Hill, New York.

- Ohashi, A., D.V. de Silva, B. Mobarry, J.A. Manem, D.A. Stahl and B.E. Rittmann, 1995. Influence of substrate C/N ratio on the structure of multi-species biofilms consisting of nitrifiers and heterotrophs. *Water Sci. Technol.*, 32(8): 75-84.
- Sabumon, P., 2007. Anaerobic ammonia removal in presence of organic matter: A novel route. *J. Hazard. Mater.*, 149(1): 49-59.
- Salama, Y., M. Chennaoui, M. Mountadar, M. Rihani and O. Assobhei, 2014. Influence of support media on COD and BOD removal from domestic wastewater using biological treatment in batch mode. *Desal. Water Treatment*, 54(4): 1-7.
- Satoh, H., H. Ono, B. Rulin, J. Kamo, S. Okabe and K.I. Fukushi, 2004. Macroscale and microscale analyses of nitrification and denitrification in biofilms attached on membrane aerated biofilm reactors. *Water Res.*, 38(6): 1633-1641.
- Sattayatewa, C., K. Pagilla, P. Pitt, K. Selock and T. Bruton, 2009. Organic nitrogen transformations in a 4-stage Bardenpho nitrogen removal plant and bioavailability/biodegradability of effluent DON. *Water Res.*, 43(18): 4507-4516.
- Schmidt, E.L. and L.W. Belser, 1982. Nitrifying Bacteria. *Methods of Soil Analysis. Part 2.* In: Page, A.L. *et al.*, (Ed.), *Chemical and Microbiological Properties.* American Society of Agronomy, Madison, pp: 1027-1042.
- Schmidt, E.L. and L.W. Belser, 1994. Autotrophic Nitrifying Bacteria. In: Weaver, R., J.S. Angle and P.J. Bottomely (Eds.), *Methods of Soil Analysis, Part 2. Microbiological and Biochemical Properties.* Soil Science Society of America, Madison, WI, pp: 159-177.
- Sedlak, R.I., 1991. *Phosphorus and Nitrogen Removal from Municipal Wastewater: Principles and Practice.* CRC Press, Boca Raton, FL.
- Tchobanoglous, G., F.L. Burton, H.D. Stensel, Metcalf and Eddy, 2003. *Wastewater Engineering: Treatment and Reuse.* McGraw-Hill, Boston, pp: 1819.