Effect of recirculation ratio on the performance of modified septic tank in treating office building wastewater

Vandith Va[1], *Ahmad Soleh* Setiyawan[1], *Prayatni* Soewondo[1], and *Dyah Wulandari* Putri[1]

[1]Study Program of Environmental Engineering, Faculty of Civil and Environmental Engineering, Institute of Technology Bandung, St. Ganesha 10 Bandung 40132

Abstract. Higher concentration of nutrients has been characterized from office buildings compared to domestic wastewater. A Modified Septic Tank (MST), which consists of anoxic conditions followed by a Moving Bed Biofilm Reactor (MBBR) is proposed to treat office wastewater. This research investigated the effect of Recirculation Ratio (RR) on organic and nutrient removal in MST. The synthetic wastewater with COD: TN: TP (252:85:3), which is similar to actual office wastewater was used. The experimental data were obtained from three RR values (2, 3 and 4). The results showed COD, TN, NH_4, and TP removal ranged from 88% to 90%, 64% to 78%, 68% to 86%, and 56% to 64%, respectively. The effluent concentrations of COD and NH_4 ranged from 21 to 30 and 9 to 23 mg/L after applying RR and from 19 to 24 and 27 to 29 mg/L without RR, respectively. RR had the significant effect on organic and nutritional removal (p <0.05). It suggested increasing RR could improve nutrient removal in MST and the stability of NH_4 in the effluent needs to be considered.

1. Introduction

The wastewater from office building is different from the characteristic of domestic wastewater. It has specific characteristics with a high concentration of nutrient and low organic matter as it contained 106 to 432 mg COD/L, 41 to 114 mg N/L, and 0.99 to 8.21 mg P/L with the average COD:TN:TP ratio of 84:28:1, while the typical domestic wastewater contained 250 to 800 mg COD/L, 20 to 70 mg N/L and 4 to 12 P mg/L [1-19]. Typically, the quantity of mixed wastewater from office building varied over time from 7 am to 5 pm and from Monday to Friday and it ranged from 39.61 to 49.93 l/p/d with the peaking factor of 1.83 [1-19]. Therefore, there is a need to improve the traditional septic tank to treat this kind of wastewater.

Septic tanks (ST) can be used alone or in combination with other raw sewage treatment processes prior to discharge into an underwater infiltration system. Conventional Septic Tank (CST) is the most popular primary treatment method for on-site domestic wastewater treatment. A septic tank contains three zones: a layer of scum that forms a crust on the surface of the liquor; wastewater from which solids settle; and a lower sludge layer of the deposited material. The treatment of household wastewater by CST had been conducted, but the treatment performance is not sufficient in terms of organic and nutrient removal [2, 16,17,18]. Moreover, Bouted and Ratanatamskul (2018) [3] conducted research on a new isolated anaerobic filter (IAF) system incorporating waste heat input for wastewater treatment for buildings, but the performance of organic and nutrient removal from this system is still low.

ST removes most solids and functions that can be regulated as an anaerobic system that encourages the digestion of some organic matters [4]. Conventional on-site domestic wastewater treatment systems are not effective at removing nutrients and reducing pathogens [5]. ST effluents need further processing for better treatment performance to meet effluent standard of domestic wastewater, which will increase the cost of construction, operation, and maintenance of the system.

CST is insufficient for the performance of organic and nutrient removal in treating office buildings wastewater when the centralized wastewater treatment system is unavailable. To improve the quality of treated wastewater, a Modified Septic Tank (MST), which consists of anoxic conditions and Moving Bed Biofilm Reactor (MBBR) followed by sedimentation compartment is proposed for better organic and nutrient removal. The water circulation from sedimentation to anoxic compartments effectively removes nutrients, and the water circulation ratio is a key factor of biological nutrient removal. The effect of recirculation of ratio was investigated based on organic and nutrient removal in MST of this research.

2. Material and Method

The location and period of research, lab-scale reactor setup, the synthetic wastewater preparation, and experimental design and reactor operations of MST had been described in this part.

* Corresponding author: vandith_va@yahoo.com

2.1 Location and Period of Research

This research has been conducted in the water quality laboratory of the study program of environmental engineering at Institute of Technology Bandung (ITB) with a duration of 4 months from December 2018 to March 2019.

2.2 Lab-scale Reactor Setup

The lab-scale of the modified septic tank consists of four compartments: anoxic 1, anoxic 2, Moving Bed Biofilm Reactor (MBBR) and sedimentation compartment (see Fig 1 and Fig 2 for illustration) while the conventional septic tank has only anaerobic compartment. To feed synthetic wastewater to this system, the feed tank is set at the front of the system and there is a peristaltic pump to pump wastewater to the anoxic 1, continuously to the operation time of 10 hours per day from 7 am until 5 pm between Monday until Friday according to the working time of people in office building. The air flowrate was controlled at 20 L/minute and the air stone is placed at the bottom of the aerobic compartment. The airflow was controlled by the air flowmeter to supply the oxygen inside the compartment for aerobic microorganism growth. The working volume of the overall reactor is 91.15L. Anoxic 1 has a working volume of 30.4 L with filling ratio 30% of bio ball and the features of this media are 19 mm diameter and 378 m^2/m^3. Anoxic 2 has 16.75L of working volume with filling ratio 60% of bio ball. Moreover, MBBR has 31L of working volume with filling ratio 20% of kaldness media used as moving bed biofilm media and cylindrical carrier made of polyethylene with a density of 0.123 g / mL and a diameter of 10 mm with a cross inside as it has high surface area for better microorganism growth. Finally, sedimentation compartment has 13L of the working volume where the sludge was settled before the treated water was discharged to the environment. In order to promote the denitrification process, the recycled water was pumped from the sedimentation compartment to anoxic 1 continuously.

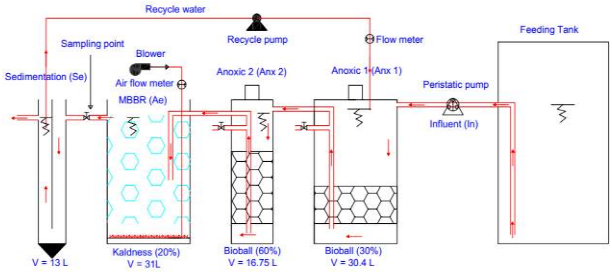

Fig1 Schematic of lab-scale model of MST with cubic shape.

Fig 2 Real lab-scale model of MST installed at water quality laboratory of study program of environmental engineering at ITB.

2.3 Synthetic Wastewater Preparation

The synthetic wastewater, which was characterized according to the characteristics of the office building wastewater was used in this experiment. [19]. The synthetic wastewater compositions used were glucose ($C6H_{12}O_6$), ammonium chloride (NH_4Cl), potassium nitrate (KNO_3) and sodium nitrite ($NaNO_2$) and potassium dihydrogen phosphate (KH_2PO_4) used as a source. of COD: TN: TN: TP (252: 85: 3), respectively [6-19].

2.4 Experimental Design and Reactor Operation

To start up MST, the sludge was collected in a septic tank of an office building used for inoculation with 3802 mg of VSS/L. To make anaerobic condition, N_2 was flushed in these compartments for 15 minutes. Glucose, ammonium chloride, and potassium dihydrogen phosphate were added to the reactor as the food for microorganisms [7]. After the operation of six weeks, the significant biomass was grown in the media, especially in MBBR and sustainable feeding of synthetic wastewater began constant feed concentration to the reactor. Based on Table 1, this system was supplied synthetic with the recirculation ratio of 4, 3 and 2. The time of each trial depends on the steady-state. In the experiment, the sampling points were carried out in the feeding tank and effluent of the sedimentation compartment for analyzing COD, TN, and TP every day before and after reaching a steady state. Moreover, COD, TN, NH_4, NO_2, NO_3, PO_4, and TP were measured after they reached a steady state in each compartment of the system. The pH, DO, and temperature were measured weekly in each compartment to determine the environmental conditions of biological wastewater treatment before and after MST reached a steady state.

Table 1 Experimental design and reactor operation in this research.

Run	COD mg/L	TN mg/L	TP mg/L	HRT h	RR
I	252	85	3	36	4
II					3
III					2

HRT: Hydraulic Retention Time, RR: Recirculation Ratio

2.5 Basic Calculations in MST

The basic calculation of removal efficiency, recirculation ratio and statistical analysis had been described in MST.

2.5.1 Removal Efficiency

The removal efficiency (E) is the performance of microorganisms in degrading pollutants in the wastewater. It can be calculated by the following formula for evaluating the treatment performance of organic and nutrient removal in MST.

$$E = \frac{S_0 - S}{S_0} \times 100\% \quad (3)$$

Where S_0 is an initial concentration (mg/L) and S is the final concentration (mg/L).

2.5.2 Recirculation Ratio

The recirculation ratios mean the volume of recirculating water from the effluent to that of influent shown in Eq.4 [8],

$$RR = \frac{Q_R}{Q_{In}} \quad (4)$$

RR : Recirculation Ratio
Q_R : The flowrate of recycling water L/h
Q_{in} : Inlet flowrate of water, L/h

2.5.3 Statistical Analysis

At 95% confidence interval, a one-way analysis of variance (ANOVA) has been used for statistical comparisons between recirculation ratios by using Microsoft Office Excel 2016. Data from various operations measured after MST stability in each recirculation ratio are used in ANOVA. The one-way ANOVA result means that there is a significant difference between removal efficiency in the experimental run if P-value is lower than 0.05.

2.6 Analytical Analysis

The parameters measurement were carried out according to the standard method for the examination of water and wastewater: APHA-4500-H^+-B-2017 by pH meter CT-6022, APHA-4500-DO by DO meter (DO-5512SD), B-2017, APHA-5220-COD-B-2017 by closed reflux method, APHA-4500-N-B 2017 by destruction, destination and titration method, APHA-4500-NH_4-B-2017 by destination and titration method, APHA-4500-NO_2-B-2017, APHA-4500-NO_3-E-2017, APHA-4500 -P-J-2017, and APHA-4500-PO_4-D-2017 have been measured by JENWAY 6305 spectrophotometer [9].

3. Result and Discussion

This part is discussed about the effect of RR on COD, TN and TP removal in MST.

3.1 Effect of RR on COD, TN and TP Removal

Effect of RR on COD, TN and TP removal was inves in this part.

3.1.1Effect of RR on COD Removal in MST

The system was operated with different recirculation ratios of 4, 3 and 2 with initial concentration around 250 mg COD/L and HRT 36h for 82 days. The average COD removal was 90%, 89% and 88% when the system was operated with recirculation ratio of 4, 3 and 2, respectively shown in Fig 3, To investigate the effect of recirculation ratio on COD removal in MST, one-way ANOVA was performed, and it gave the significant difference on COD removal in MST and maximum removal of COD can be achieved 90% at RR of 4 (P value = 2E-05 < 0.05). A little effluent COD concentration increased with decreasing the recirculation

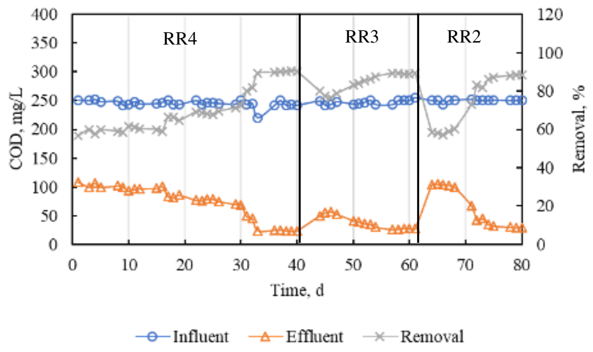

Fig 3 Influent COD, effluent COD and COD removal at different RR values in MST.

ratio. In this case, the concentration increases in the effluents are due to the initial accumulation due to the decrease dilution rate of influent concentration from the anoxic compartment and also because of the initial shock of microorganisms to sudden changes in the environment. This shows that changes in structure with the environment cause-related variables in microorganisms to change quickly and often significantly. Because microorganisms can experience difficulties and try to recover, COD accumulates in the reactor due to slow metabolic action, so it creates a rise in COD concentration [10].

3.1.2 Effect of RR on TN Removal in MST

The system was operated with different recirculation ratio of 4, 3 and 2 with initial concentration around 83 mg N/L and HRT 36h for 82 days. The average TN removal was 79%, 72% and 66% when the system was operated with recirculation ratio of 4, 3 and 2, respectively shown in Fig 4. To identify the effect of recirculation ratio on the removal of TN in MST, one-way ANOVA was applied, and it gave the significant difference on TN removal in MST as a maximum removal of TN can be achieved 79% at recirculation ratio of 4 (P value = 3E-07 < 0.05). This indicated that increasing higher recirculation ratio could improve the denitrification process resulting in better total nitrogen removal. Effect of recirculation ratio on nitrification and denitrification processes were investigated. In lab-scale of modified septic tank, increase hydraulic retention time was effective for organic removal, However, TN removal efficiency was not increasing

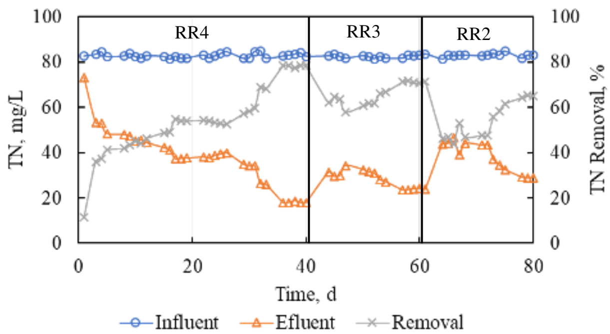

Fig 4. Influent TN, effluent TN and TN removal at different RR values in MST.

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because of nitrite and nitrate remaining in the effluent. Because the nitrification and denitrification rate was high, the effluent concentration of TN should depend on both nitrification and denitrification simultaneously. Meanwhile, lower recirculation ratio decreased the dilution rate of influent wastewater in the anoxic compartment and increased TN concentration in the inlet water of the aerobic compartment in MST.

3.1.3 Effect of RR on TP Removal in MST

The system was operated with different recirculation ratios of 4, 3 and 2 with initial concentration of around 2.8 mg/L and HRT 36h for 82 days. The average TP removal was 66%, 63%, and 59% when the system was operated with recirculation ratio of 4, 3 and 2, respectively showed in Fig 5. To evaluate the effect of recirculation ratio on the performance of TP removal in MST, one-way ANOVA was applied, and it gave the significant difference on TP removal in MST as the maximum removal of TP can be achieved 66% at recirculation ratio of 4 (P value = 5E-04 < 0.05). The higher the recirculation ratio, the higher the TP removal efficiency can be achieved in MST.

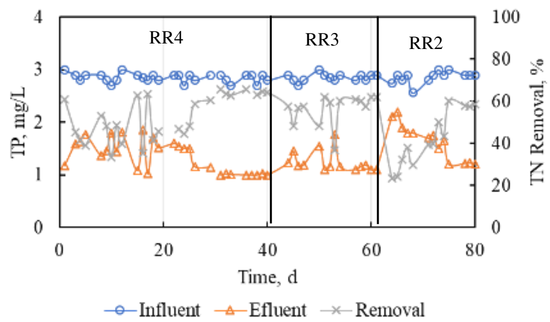

Fig 5. Influent TP, effluent TP and TP removal at different RR values in MST.

3.2 COD Removal Characteristics in MST

The COD removal rate of the MST with different recirculation ratio is shown in Fig 6. Experimental results indicate a slight decrease in the efficiency of COD removal with a decrease in recirculation ratio. COD removal efficiency ranges between 88% to 90%, while the effluent concentration ranges from 24 to 30 mg/L. The removal efficiency of COD in the individual compartments was also analyzed. The efficient removal of COD in anoxic 1, anoxic 2, and aerobic compartments was 45% to 48%, 7% to 11%, and 75% to 77%, respectively. Similar results were observed in the research carried out by Nam et al. (1998) [12] where the COD removal efficiencies ranged from 90 % to 97% from another research. Su and Ouyang (1996) also observed about 87% to 91%. COD removal efficiency in a combined process with activated sludge and fixed biofilm at HRT 8 to 2 h [15]. The COD removal occurs due to a population of attached and suspended anoxic bacteria in the anoxic compartment, and in the anoxic compartment due to the denitrification process. Finally, the remaining COD removal has been observed in the aerobic compartment due to organic matter

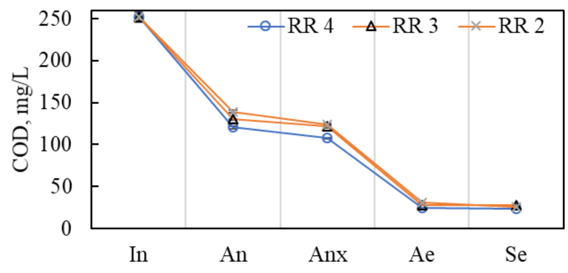

Fig 6. COD removal in each compartment of MST with different RR values in MST.

oxidation by heterotrophic bacteria as shown in Fig 6 in MST.

3.3 Nitrogen Removal Characteristics in MST

Fig 7(c) shows the concentrations of NH_4 in each compartment of MST. The influent NH_4 concentration was about 69 mg/L throughout the study. The effluent NH_4 concentration and its removal efficiency of the anoxic compartment were 33 to 43 mg/L and 42% and 55%, respectively. Dilution by the external recirculation from the sedimentation compartment and by adsorbed cells from cell layers by anoxic bacteria and attached biofilm on the surface of the media could cause NH_4 reduction in the anoxic 1 [11-12]. Similarly, the effluent NH_4 concentration and its removal efficiency in anoxic 2 were 18 mg/L to 28 mg/L and 34 % to 45%, respectively, which is the effect of external recycle dilution and cell synthesis, partly in the anoxic

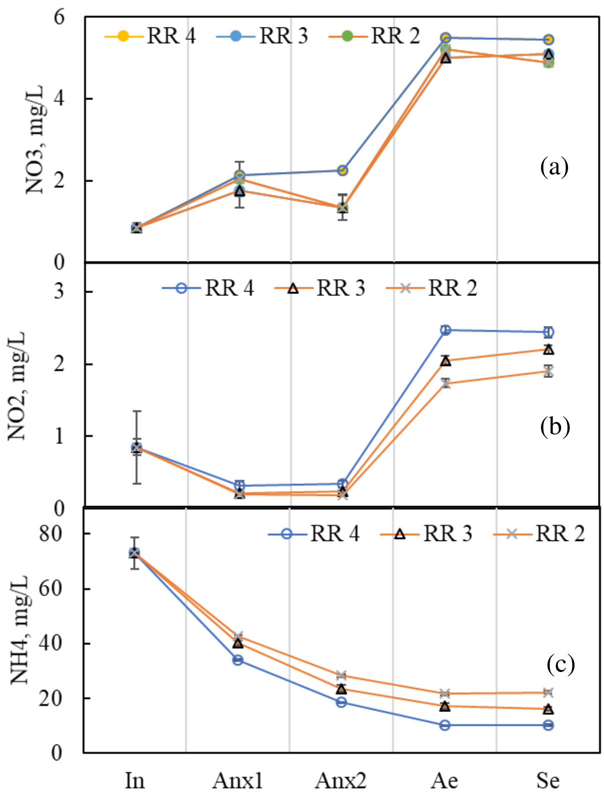

Fig 7. (a): NO_3 content in each compartment at different RR values in MST, (b): NO_2 content in each compartment at different RR values in MST and (c): NH_4 content in each compartment at different RR values in MST.

compartments. Most of NH_4 removal takes place in the aerobic compartment and the fraction of NH_4 removal is caused by nitrification of nitrifiers and assimilation by carbonaceous bacteria and nitrifiers in the aerobic compartment as NO_3 and NO_2 gave a sharp increase in Fig 7(a, b). The NH_4 concentration in the effluent of the aerobic compartment resulted in 10 mg/L to 22 mg/L and its removal efficiency was 24% and 44%, respectively. Moreover, the overall NH_4 removal ranged from 70% to 86% and the effluent concentrations ranged from 9 to 29 mg/L in MST throughout the study.

3.4. Phosphorus Removal Characteristic in MST

Fig 8 shows the changes in the total phosphorus (TP) content. The removal efficiency of TP ranged between 59% to 66%, while the effluent concentrations ranged from 1.01 to 1.22 mg/L. The maximum TP removal efficiency of 66 % in Run 1 was observed in the recirculation ratio of 4. The TP removal efficiency in the anoxic 1, anoxic 2 and aerobic compartments was 14% to 20%, 36% to 46%, and 22% to 26%, respectively. For the recirculation ratio of 4, the TP concentration in anoxic 1 was high on an average, which could be from the recycled water which contains adsorbed phosphorus in it, leading to an increase in concentration in the anoxic 1 and thus less TP removal. However, TP removal efficiency in anoxic 2 and aerobic compartments was about 28% and 24%, respectively. During the anaerobic process, due to the water recirculation from the sedimentation tank, the phosphorus gets released into the liquid by phosphorus-accumulating bacteria like the Acinetobacter species, thereby increasing phosphorus content in the sample of the anaerobic reactor [13]. In the anaerobic compartment, the microorganisms consume carbon from the influent feed and store it as poly hydroxyl butyrate (PHB). In the subsequent anoxic and aerobic compartments, the degradation of these stored PHBs occurs for glycogen restoration and thus phosphorus is removed in MST [14]. Moreover, the

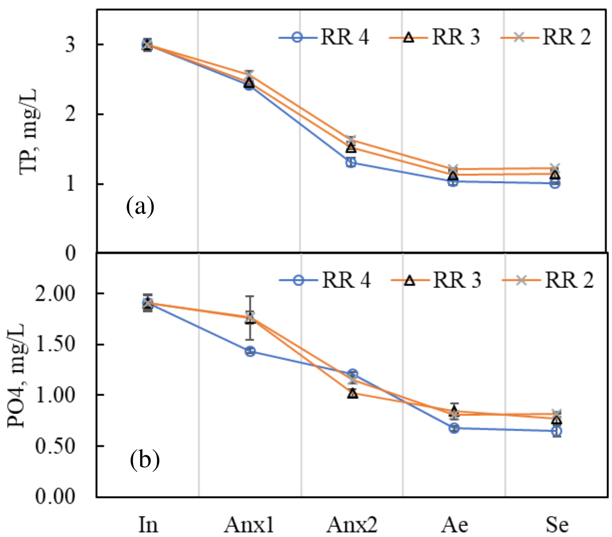

Fig 8. (a): TP removal content in each compartment of MST at different RR values and (b): PO_4 removal content in each compartment of MST at different RR values.

overall PO_4 removal ranged from 57% to 64% in this MST throughout the study.

3.5 Performance Evaluation of MST

The removal ratio of COD, TN, NH_4 and TP from the MST of this research ranged from 87% to 90%, 66% to 79%, 70% to 86%, and 59 to 71%, with the effluent concentration 24 to 32 mg/L, 18 to 29 mg/L, 9 to 22 mg/L, and 0.88 to 1.22 mg/L, respectively. The result of performance of organic and nutrient removal in this research has been compared to other studies of conventional systems. The results show the better performance than CST, SBST, TBST, PST, and AF from the previous studies in terms of COD, NH_4, TN and TP with the different experimental runs of recirculation ratio in MST. Table 2 shows that this MST significantly could increase the treatment performance of conventional ones and it may have the potential to be applied in treating the office building wastewater to meet the effluent standard of domestic wastewater in Indonesia.

Table 2 Comparison of the performance of COD, NH_4, TN and TP removal from MST and COD, NH_4, TN and TP removal from previous studies about CST, SBST, TBST, PST, and AF.

STT	HRT h	Item mg/L	Influent mg/L	Effluent mg/L	Removal %	PERMEN LHK 68/2016
CST [26]	24 48 72	**COD**	**960**	**334**	**38-65**	**100**
		NH_4,	**26.2**	**28**	**4-7**	**10**
		TN	71	52.3	17-26	-
		TP	4.44	3.14	25-29	-
SBST [16]		COD	817-1184	266-396	55-72	10
TBST [16]		COD	817-1185	248-380	57-74	
PST [16]		COD	817-1186	221-359	56 - 68	
PST [17]	50	**COD**	**651**	**111**	**83**	**10**
AF [218]	24 48 72	**COD**	**187-252**	**40-126**	**32-81**	**100**
		NH_4	**27-30**	**17-20**	**31-36**	**10**
		TN	29-34	18-22	30-41	-
		TP	3-6	2-3	12-48	-
MST**	36h	**COD**	**247**	19-24	**82-92**	**100**
		NH_4	**69**	27 -29	**45-61**	**10**
MST*	36	**COD**	**242-252**	**24-32**	**88-90**	**100**
		NH_4	**65-73**	**9-22**	**70-86**	**10**
		TN	81-85	18-29	66-79	-
		TP	2.73-3	0.88-1.22	59-71	-

Note: AF: Anaerobic Filter, CST: Conventional Septic Tank, MST: Modified Septic Tank, PST: Packed Septic Tank, SBST: Single Baffle Septic Tank, TBST: Two Baffle Septic Tank, STT, Septic Tank Type, * This research, and **This research without recirculation ratio.

4. Conclusion

The laboratory-scale of modified septic tank consists of anoxic compartments followed by MBBR was found to be a technically feasible process for organic and nutrient removal from synthetic wastewater, which has been characterized from actual office building wastewater by varying the recirculation ratio. Variations of recirculation ratio have been evaluated and it had a significant effect on COD, TN, and TP removal and the optimum condition can be achieved 90% of COD, 79% of TN and 66% of TP at recirculation ratio of 4. Increasing the recirculation ratio could increase COD, TN and TP removal in MST. COD, TN, NH_4, and TP removal efficiency ranged from 87% to 90%, 66% to 79%, 70% to 86%, and 59% to 71% while the concentrations of COD, TN, NH_4 and TP in the effluent ranged from 24 to 32, 18 to 29, 9 to 22, and 0.88 to 1.22 mg/L, respectively. This system is proved to be a good alternative for the treatment of office building wastewater, compared with the conventional septic tank. The perspective of this study in the scale-up should be with HRT of 36h and operation of RR of 4 to enhance the performance of organic and nutrient removal.

5. Acknowledgment

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6. References

[1].V,Va A.S. Setiyawan, P. Soewondo. Int.J.Goemate, **1** (2), 199-214 (2018).
[2] F.A Nasra, and B. Mikhaeila. Environ. Technol, **34**,16, 2337-2343 (2003).
[3] C. Bouted and C. Ratanatamsku. J Environ Manage, **206**, 697-706 (2018).
[4] D. Les and G. Ashantha. Environ Geol, **44**, 467–477 (2003).
[5] D.R Cullimore and T. Viraraghavan. Environ Technol, **15**,165–173 (2008).
[6] A. Akbari, A. A. L. Zinatizadeh, P. Mohammadi, Y. Mansouri, M. Irandoust, and M. H. Isa. Water Sci Technol, **9**, 371-378 (2012).
[7] S.M. Borghei, M. Sharbatmaleki, P. Pourrezaie and Borghei. Bioresour. Technol **99**, 1118–1124 (2008)
[8] G.Nakagawa, Y. Ebie, S. Tshuneda, M. Matsumura. K. Q. Xu and Y. Inamori. Japanese Journal of Water Treatment Biology **3**(2), 134-149 (2007).
[9] APHA (2012). *Standard Methods for the Examination of Water and Wastewater, 22nd editions, Washington*, DC 20001-3710.
[10] A. Hirata, T. Takemoto, K. Ogawa, J. Auresenia and S. Tsuneda. Biochem Eng Journal, **5**, p. 165–171 (2000).
[11] K. H. Lee, J.L. Lee and T. J. Park. Korean J Chem Eng **15** (1) (1998).
[12] H.U.Nam, J.H, Y.O. Kim, Y.G. Kim and T. J Park, .Korean J Chem Eng **15** (4), 429–433 (1998)
[13] J. Kerrn-Jespersen. Water Res **28** (5), 1253–1255 (1994).
[14] D.S. Manu and A.K. Thalla. Water Sci Technol **77**(1), 248-259, (2018).
[15] J.L. Su and C. F. Ouyang. Water Sci Technol, **34** (1–2) (1996).
[16] Nasra, F, A and Mikhaeila, B.Env. Technol, **34** (16), 2337-2343 (2013)
[17] M. K. Sharma and A.A. Kazmi. Ecol eng **75** 457–461 (2015).
[18] J. L. C. Ladu and X. LÜ. Water Sci Technol, **7**(2): 168-182 (2014).
[19] V,Va A.S. Setiyawan, P. Soewondo, *SIBE 2017. MATEC Web of Conferences* 147, 04004 (2018).