PERFORMANCE OF SEQUENCING ANOXIC/ANAEROBIC MEMBRANE BIOREACTOR (SAM) SYSTEM IN HOSPITAL WASTEWATER TREATMENT AND REUSE

Mohammed Ali I. Al-Hashimia, Prof. Dr.

Department of Building and Construction Engineering,

University of Technology, Baghdad, Iraq

Talib R. Abbas, Dr.

Environment and Water Directorate,

Ministry of Science and Technology, Jaderia, Baghdad, Iraq

Yaser I. Jasema

Department of Building and Construction Engineering,

University of Technology, Baghdad, Iraq

Abstract

In this study, a lab scale SAM system is studied to treat a hospital wastewater to remove organic mattar as well as nitrogen and phosphorus under a different internal recycling time mode. During the operation period, the BOD_5 and COD removal efficiency is higher than 98 and 90%, respectively regardless of change of operational conditions. In addition, the results show excellent removal of pathogen and turbidity with average of 98.33 and 99.5%, respectively. The change of Ax/An ratio representing the internal recycling time mode significantly affecting nitrogen and phosphorus removal. As increasing Ax/An ratio nitrogen removal efficiency has increased but phosphorus removal efficiency has decreased. The Ax/An ratio of 2/2, achieving optimal nitrogen and phosphorus removal efficiency of 93% and 83%, respectively. In addition, the SAM system produces high quality effluent which can achieve the Iraqi limits for irrigation purpose for all measured parameters.

Keywords: SAM, MBR, Nitrogen removal, Phosphorus removal

Introduction

The membrane bioreactor (MBR) has been gaining great attention in wastewater treatment as membrane filtration promises a complete solid-liquid separation, prevents failure of biological system due to biomass loss and/or bulking and maintains high mixed liquor suspended solids (MLSS) in the reactor [Cicek et al, 1998]. For this reason, MBR has been widely applied to remove organic pollutants as well as nutrient in wastewater [Cicek, 2003]. A novel MBR process that remove nitrogen and phosphorus simultaneously, so called, sequencing anoxic/anaerobic membrane bioreactor (SAM) is introduced and shows its superior abilities on phosphorus removal over the MLE (modified Luzack-Ettinger) type MBR system [Ahn et al, 2003]. The track study for SAM verifies that the phosphorus release and denitrification happen only by the intermittent recycling of the mixed liquor. Several bench-scale studies on the effects of parameters affecting nitrogen and phosphorus removal, such as hydraulic retention time (HRT), recycling time, recycling rate, solids retention time (SRT) and different carbon sources are conducted and reported that the parameters have influenced nitrogen and phosphorus removal, directly or indirectly [Song et al, 2009].

Nowadays, nutrient removal has attracted great attention in wastewater treatment for reuse. [Tatiana et al., 2011]. Wastewater reuse can both reduce the demand on fresh water supplies and minimise the discharge of treated water to the environment [Qadir et al, 2010]. Iraq area is characterized by arid to semi arid climate with low rainfall. As the population has grown against a background of decreasing freshwater resources, so the water available to individuals has fallen dramatically. Wastewater reuse is an important approach to help overcome the water scarcity problem of Iraq. Moreover, since current local wastewater treatment units in various hospitals are not capable to meet Iraqi standards (especially in terms of nutrient and pathogen removal), this study is designed to evaluate the performance of the SAM process for nutrient removal in hospital wastewater under different internal recycling time modes to achieve optimal nutrient removal. Moreover, to produce recycled water that is suitable for irrigation purposes.

Materials and methods

Laboratory-scale experiment

The lab-scale SAM system is composed of sequencing an anoxic/anaerobic zone and aerobic zone where the flat-sheet UF membrane module is immersed, as shown in Fig. 1. The PVDF (Polyvinylidene fluoride) membrane module has an effective filtration area of 0.8 m^2 and its nominal pore size is 0.08 μm. The membrane module was fully immersed and symmetrically placed in the system. An airlift was installed underneath the membrane module at a rate to maintained DO concentration of approximately 4.2 ± 0.3 mg/L. The constant flux of 13 $L.m^{-2}.h^{-1}$ is maintained and the transmembrane pressure is monitored. The membrane was operated intermittently to minimize membrane fouling; 12 min suction and 3 min rest. The hospital wastewater is continuously fed into the sequencing zone with a flow rate of 312 L/d. In the aerobic zone through membrane filtration, the effluent could be generated continuously regardless of the sequencing zone condition.

The sequencing anoxic/anaerobic conditions are controlled by the intermittent recycle of the mixed liquor directly from the aerobic zone to sequencing zone. In time of recycling, the anoxic conditions could be induced and nitrate is reduced to nitrogen gas by denitrification process. No recycling causes oxygen and nitrate deficiency in the sequencing reactor to create the anaerobic condition for phosphorus release then the released orthophosphate is synthesized into the cell in the aerobic reactor under aerobic condition. Finally, the phosphorus is removed from the system by withdrawing the excess sludge directly from the aerobic reactor. Table 1 shows the characteristics of the influent.

Operation condition

The operation condition of the lab-scale experiment is listed in Table 2. Temperature, pH, HRT and MLSS ranges are 18-27 °C, 6.8-8, 8.3 h and 7700-8300 mg/L, respectively. The internal recycle is maintained at the rate of 300% of the influent flow rate. To investigate the effect of the internal recycling time mode on nutrient removal, runs 1, 2 and 3 are operated a at different internal recycling time mode. The internal recycling time mode determines Ax/An ratio, which represents relative time length of anoxic period to anaerobic period.

Analytical method

Biochemical oxygen demand (BOD) is measured using the WTW OxiTop control system, Germany. Chemical oxygen demand (COD) is measured using CSB/COD-Reactor (AL32 AQUALYT- IC, Germany). Ammonium, nitrate, nitrite and ortho-P are measured using the spectrophotometer (WTW Photo Flex, Germany). Dissolved oxygen concentration and pH are measured using the Do meter (YSI, Model 556, USA). The measurement of mass liquor suspended solids (MLSS) and total suspended solids (TSS) follow standard (APHA, 2005).

Table 1: Typical composition of the influent wastewater

Parameters	Unites	Range	Typical
BOD_5	mg/l	440 – 840	620
COD	mg/l	558 – 980	750
Orthophosphate PO4-P	mg/l	9.05 - 48	18.5
Ammonium NH4-N	mg/l	76.3 – 232.8	154.74
Nitrate NO3-N	mg/l	0 – 16.4	4.68

Nitrite NO2-N	mg/l	0.1 – 0.58	0.331
TSS	mg/l	100 - 254	170
Oil and Grease	mg/l	120 - 210	164.3
pH		7.2 – 7.68	7.4± 0.29
Coliforms	MPN/100 ml	460 - 1100	780
Fecal coliforms	MPN/100 ml	460 - 1100	780

Table 2: The operation conditions of the SAM experiment

Parameters	**Unites**	**Average value**		
		Run 1	**Run 2**	**Run 3**
Flux	$L.m^{-2}.h^{-1}$	15.12	15.12	15.12
SRT	day	58.5	66	116
COD/P		38.65	29.3	27
Operation time	day	13	15	14
Internal recycle rate	L/h	39	39	39
Ax/An	h	4/2	2/2	2/4

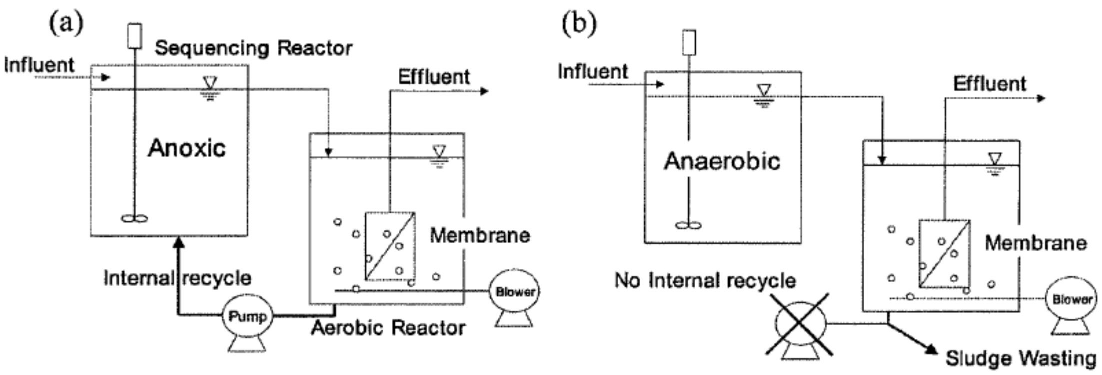

Fig 1: System configurations of the SAM process at anoxic phase (a) and anaerobic phase (b).

Results and discussion

Organic matter removal

All the results presented in this study are obtained from the laboratory-scale reactor at steady-state conditions. Fig. 2 and Fig. 3 present the variation of influent and effluent of BOD_5 and COD and their removal efficiency, respectively. Despite the fluctuations in the influent quality, the SAM is very stable and effective in achieving approximately 98.5%

BOD_5 and more than 90% COD removal for all runs, corresponding to the average 9.2 and 67 mg/L in the effluent, respectively. This improved performance of the SAM would be explained by the higher MLSS of the MBR system and the enhanced removal by membrane separation. These results are in a good agreement with the previous study [Tadkaew et al., 2010], who report that the removal of organic matter varies between 90% and 99%.

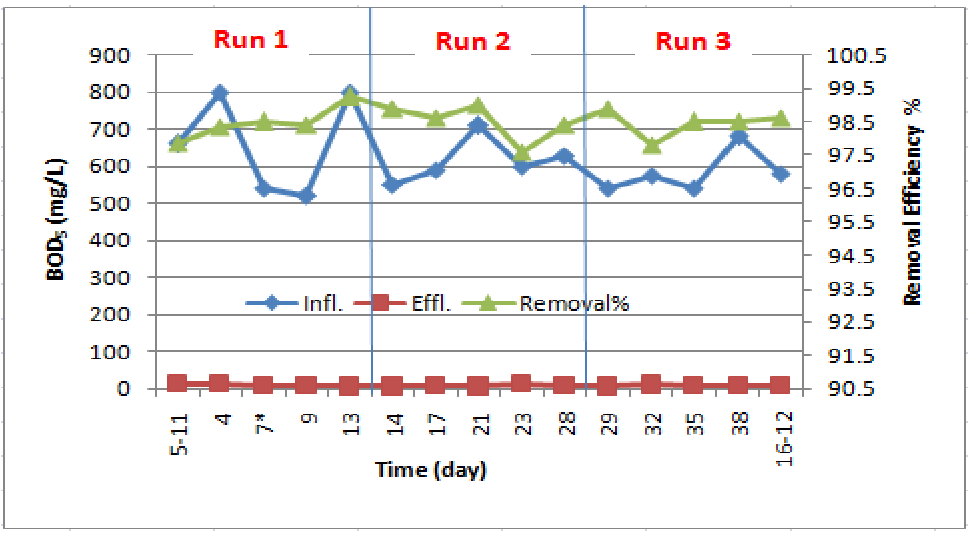

Fig. 2: The influent and effluent BOD_5 concentrations and removal efficiency of the SAM system. (*) means rainy day

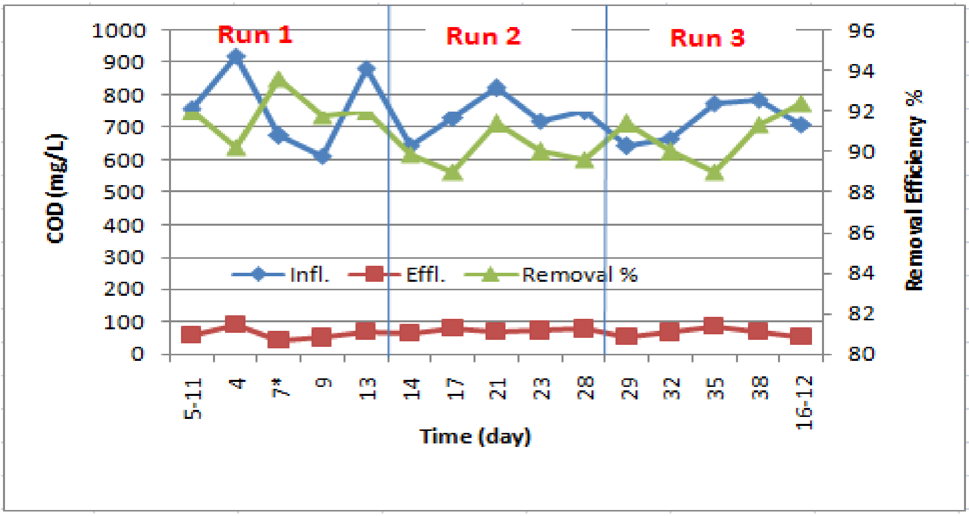

Fig. 3: The influent and effluent COD concentrations and removal efficiency of the SAM system. (*) means rainy day

Nitrogen and phosphorus removal

In order to determine the optimal time mode in lab-scale SAM, R-1, 2, 3 are operated at a different internal recycling time mode. The internal recycling time mode determines Ax/An ratio, which represents relative time length of anoxic period to anaerobic period of sequencing anoxic/anaerobic reactor. AS shown in Fig. 4(a), despite the fluctuations in the influent quality, the NH_4-N is almost completely (100%) eliminated within the SAM system, indicates that complete nitrification has occurred in the aerobic zone and all the influent NH_4-N entered in to aerobic bioreactor is completely oxidized into nitrate and nitrite.

Run-1 of highest Ax/An ratio (4/2) shows high level of denitrification process developed in the anoxic bioreactor with the effluent nitrogen compounds account for less than 9% of its in the influent as evident in Fig.'s 4(a, b, c), achieving 91% removal efficiency of nitrogen as evident in Fig. 4(d). While limiting phosphorus removal efficiency is achieved (61% as evident in Fig. 5(b)). The same observation is also reported by Puig et al., [2008]; Monclus et al., [2010]. R-3 compared to R-1, operated at lowest Ax/An ratio (2/4) showed the highest phosphorus removal efficiency of 80% while worst in nitrogen (only 55%). This result is in a agreement with the previous study [Song et al., 2010].

R-2 is operated at Ax/An ratio of (2/2), shows a more stable effluent concentration of nitrogen compounds accounting for 7% of its concentration in the influent as evident in Fig.'s 4(a, b, c), indicating high level of denitrification process developed in the anoxic bioreactor achieving high nitrogen removal efficiency of 93% as evident in Fig. 4(d). The relatively higher nitrogen removal efficiency of the SAM system for this run (93%) with the lower anoxic period of 2 h compared to 91% for run 1 with the higher anoxic period of 4 h does not agree with the previous study [Song et al., 2010]. This may be explained by that the denitrifying phosphorus accumulating organisms (PAOs) are known as being able to reduce nitrate together with the absorption of phosphorus, while utilizing the accumulated substrate as an electron donor. This process is reported to perform slower than ‘‘conventional’’ heterotrophic denitrification as being suggested by Raymond et al., [2004] therefore more time be required to accumulate.

As shown in Fig.'s 5(a, b), despite the fluctuations in the influent quality, the SAM system has shown excellent performance on phosphorus removal, achieving approximate 83% averagely, corresponding to the average 3.66 mg /L in the effluent. The relatively higher phosphorus removal efficiency of the SAM system for R-2 (83%) with the lower anaerobic period of 2 h compared to 80% for R-3 with the higher anaerobic period of 4 h does not agree with the previous study [Song et al., 2010]. This unexpected result, which may be attributed to two reasons: first, relatively low COD/P ratio of R-3 (27) compared to (29.3) for R-2. COD/P ratio is critical for PAOs to grow, function, and take up phosphorus from solution. Phosphorus removal efficiencies exhibit an increase trend with the increasing of influent COD/P and a linear positive relationship is found between COD/P and phosphorus removal, [Wang et al., 2009]. Second, long SRT of R-3 compared to R-2 (116 versus 66 day) result in secondary release of phosphorus through endogenous decay of PAOs and release it into solution. [Song et al., 2010], report that there is a strong link between SRT and phosphorus removal in enhanced biological phosphorus removal process. As SRT increase, the percentage of phosphorus in MLVSS increases because the decay rate of PAOs is relatively lower than that of normal heterotrophic organisms, while the sludge wasting rate decreases.

Optimal time mode

As shown in Fig. 6, R-2 represents the optimal phase of SAM system ,which is operated under internal recycling time mode of 2 h anoxic followed by 2 h anaerobic, corresponding to the Ax/An ratio of 2/2, achieving optimal simultaneous nitrogen and phosphorus removal efficiency of 93% and 83%, respectively.

To find out the suitability of effluent water from SAM system with the irrigation limits, the measured parameters are compared with the Iraqi limitations for wastewater reuse for agricultural irrigation No. 3, 2012 [ILWRA No.3, 2012]. The SAM system shows a good performance to meet the requirements of the (INLWRA No. 3, 2012) for all measured parameters.

Pathogen removal and turbidity

The membranes serve as microbial barriers that can capture most of the biomass inside the bioreactor. Therefore, the MBR system produces excellent removal efficiency of pathogen (in terms of coliforms and fecal coliforms) with 98.33%, corresponding to the average effluent of 13 cell/100 ml. This result is slightly less than that presented by a previous study [Mahvi et al., 2009] who report that the rate of fecal coliforms removal has been reported 99.96% in Hamadan (west of Iran) hospital. This result is probably due to pollution of the system or due to mistake in sampling, where the ultrafiltration membrane which has a pore diameter smaller than the size of bacteria and parasitic microorganisms.

It is generally accepted that MBR provides excellent treated water turbidity (Melin et al., 2006). In this study, the turbidity removal efficiency of SAM system is between 99% and 100% for all runs. Furthermore, despite the TSS value of the influent fluctuate between 100 mg/L and 254 mg/L, the effluent turbidity remains less than 0.3 NTU and all recorded data are below 0.5 NTU as shown in Fig. 7. The excellent removal efficiency of turbidity illustrates the effectiveness of the membrane. The same observation is also reported by [Noah et al., 2009].

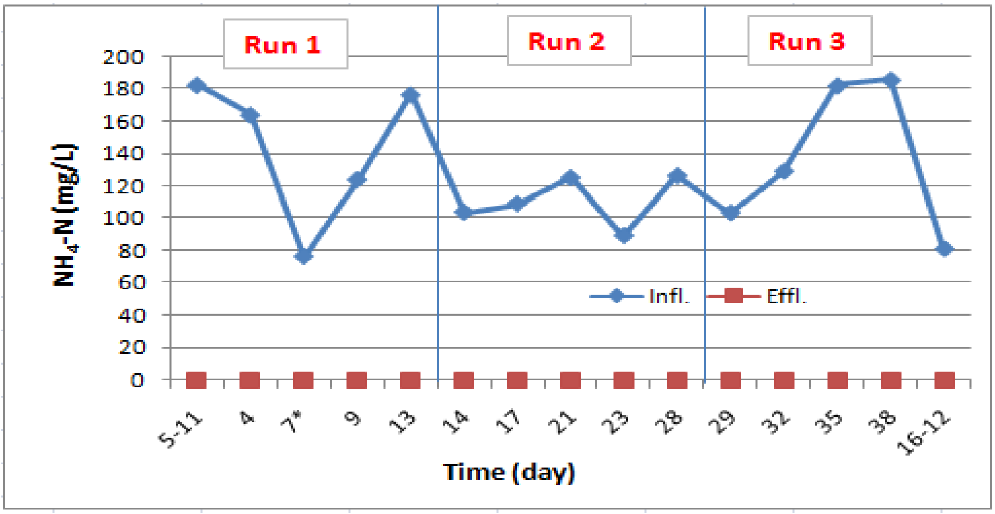

Fig. 4(a): The influent and effluent NH_4-N concentrations for the SAM experiment. (*) means rainy day

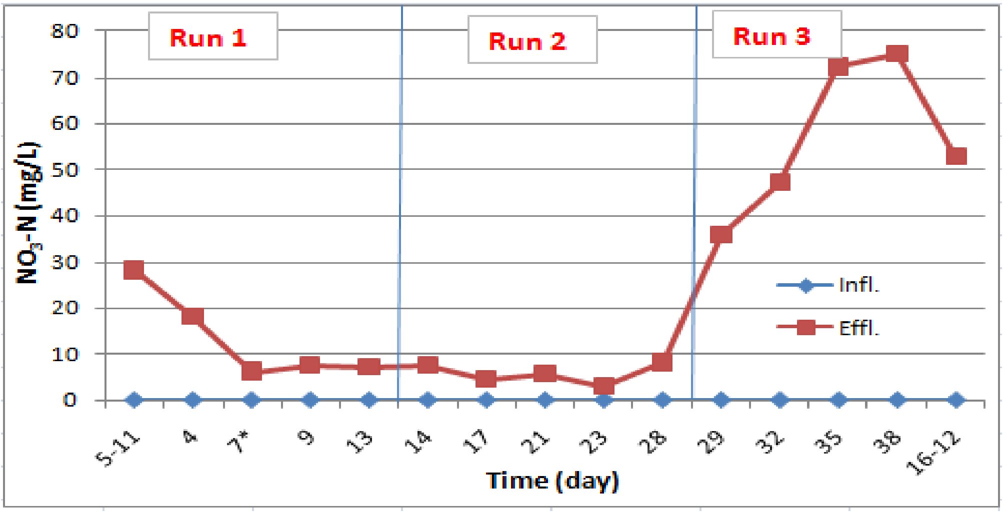

Fig. 4(b): The influent and effluent NO_3-N concentrations for the SAM experiment. (*) means rainy day

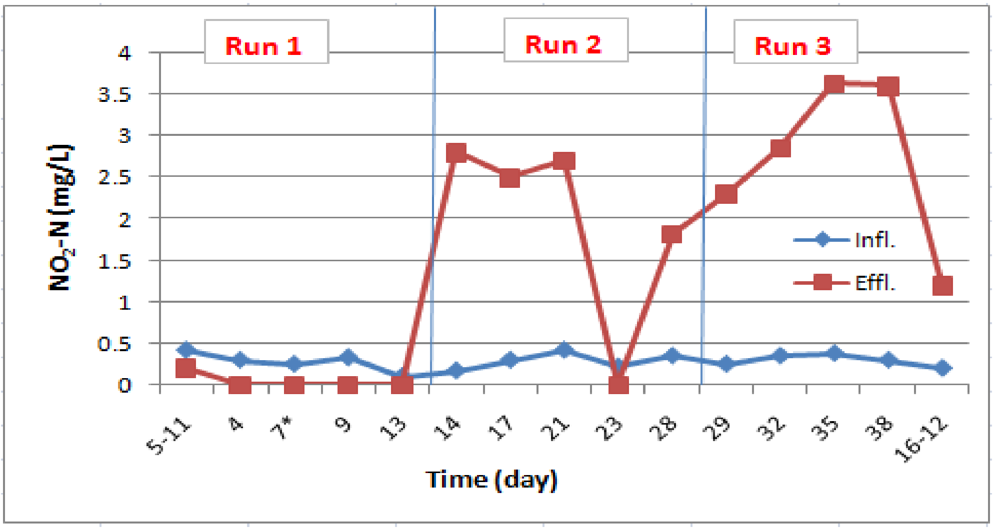

Fig. 4(c): The influent and effluent NO_2-N concentrations for the SAM experiment. (*) means rainy day

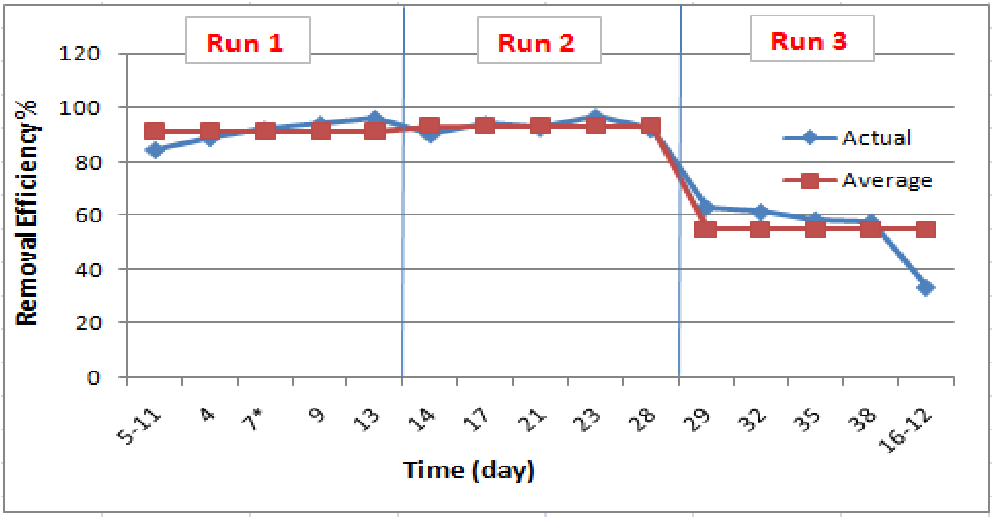

Fig. 4(d): Nitrogen Removal Efficiency for the SAM experiment. (*) means rainy day

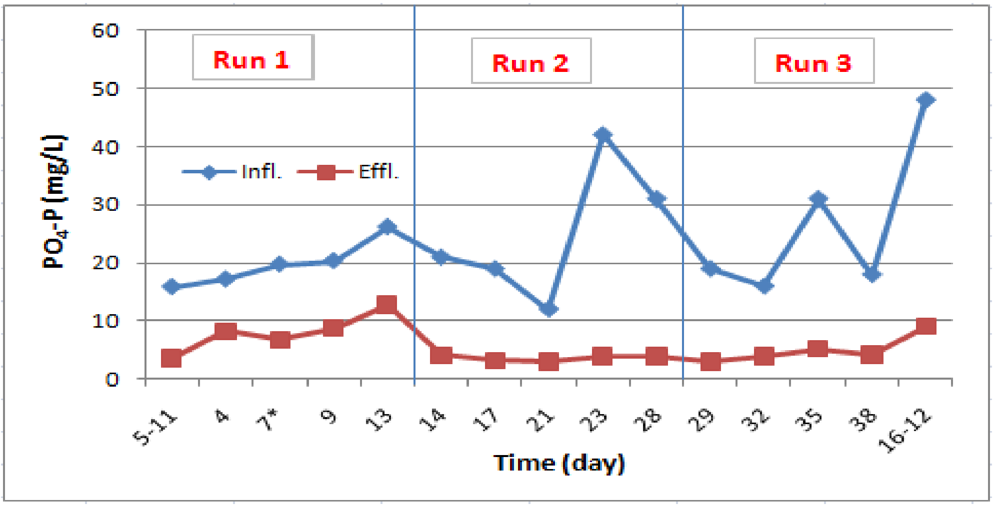

Fig. 5(a): The influent and effluent PO4-P concentrations for the SAM experiment. (*) means rainy day

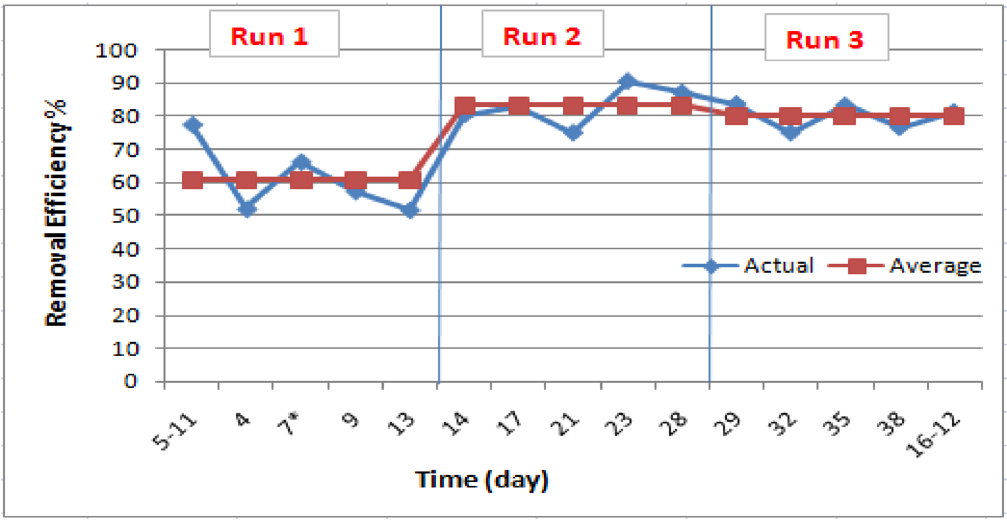

Fig. 5(b): PO4-P Removal Efficiency for the SAM experiment. (*) means rainy day

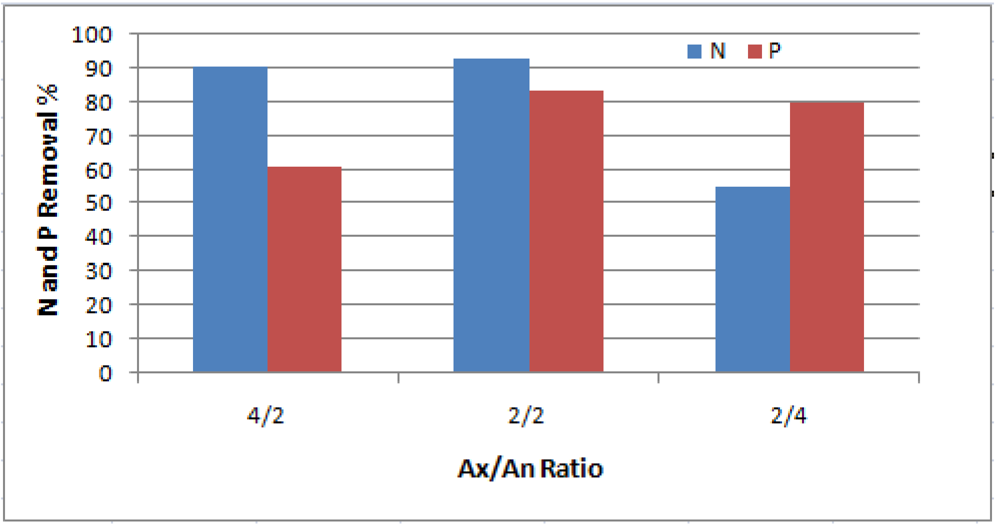

Fig. 6: Nitrogen and Phosphorus Removal Efficiency at different Ax/An ratio for the SAM experiment.

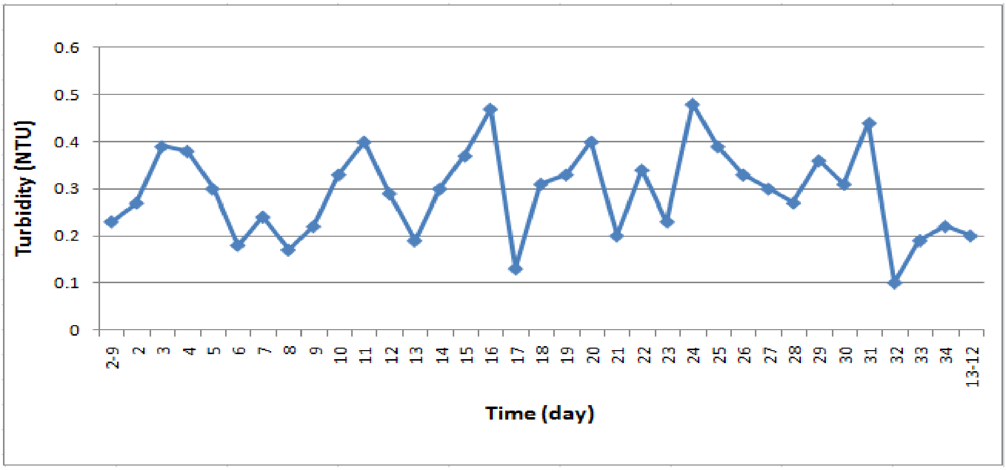

Fig. 7: The effluent turbidity for SAM experiments

Conclusion

Experiments investigating the influence of internal recycling time mode of SAM system on nutrient removal are conducted in this study. Nitrogen and phosphorus removal is strongly depended on Ax/An ratio controlled by internal recycling time mode. Highest Ax/An ratio, reveals the best nitrogen removal efficiency but worst phosphorus removal efficiency, while lowest Ax/An ratio shows the highest phosphorus removal efficiency. Compromizing between nitrogen percentage removal and PO4-P percentage removals, suggests that the Ax/An ratio that gives optimal nitrogen and phosphorus removal are 2-h anoxic and 2-h anaerobic. In addition, the SAM system provides appropriate treatment technology that is available to produce high quality effluent for reuse for irrigation purpose (unrestricted agriculture) which can significantly reduce the demand for fresh water.

Furthermore, it has superior feature compared with Anaerobic-Anoxic-Oxic (A2O) system by adopting two basins instead of three basins in A2O system.

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