The effect of static mixer on the properties and performance of aerobic granules under different organic loading rates in treating synthetic textile wastewater

To cite this article: S Suryati *et al* 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **682** 012032

The effect of static mixer on the properties and performance of aerobic granules under different organic loading rates in treating synthetic textile wastewater

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Abstract. Biogranulation is considered a promising technology in biological wastewater treatment due to its high effluent treatment quality, strong ability to withstand organic loading, strong microbial structure and high capability to remove organics, nitrogen and phosphate. Organic loading rate (OLR) is known as one of the significant factors in biogranulation process. Aerobic granules can be developed under different OLR conditions. Microorganisms are starved at low OLR while microbial growth accelerates at high OLR. The main objective of this study was to investigate the effect of various OLRs on the physical characteristics and treatment performance of aerobic granules in treating synthetic textile wastewater. Two reactors named as R4Y and R4N were used, where R4Y was a reactor with static mixer and R4N was without the static mixer. The OLR of 2.0, 2.5 and 3.0 kg/m^3.day were examined during the post development study. The study demonstrated that OLR affected the performance of biogranules. The physical characteristics of biogranules and removal efficiencies of the reactor with static mixer seemed to be better as compared to the reactor without static mixer with increasing of OLR. The granules of R4Y had better physical strength with IC of 19.6% and more excellent settling ability with SV of 82.7 m/h and SVI of 24.6 mL/g. The findings proved that static mixer had a positive influence in biogranulation system and therefore, will lower the energy consumption and operational cost.

1.0 Introduction

Biogranulation technology is considered as one of the novel advanced biological treatment technologies developed for wastewater treatment. Biogranulation process involves cell-to-cell attachment in which granules are formed through self-immobilization of microorganisms. Most aerobic granules have been cultured in sequencing batch reactors (SBRs). Several conditions such as organic loading rate (OLR), composition of substrate, settling time, hydraulic retention time (HRT), reactor configuration, volume exchange ratio (VER), mineral cations, cell hydrophobicity, extracellular polymeric substances (EPS), dissolved oxygen and hydrodynamic shear force affect the formation of the granules. Organic loading rate is one of the crucial factors in any biological system. It was reported in many previous studies that aerobic granules were able to withstand OLR range 2.5 to 15 kg/m^3.day [1, 2, 3, 4]. The low OLR probably did not enhance the granulation as many researchers have pointed out [5,6]. A moderate OLR was found to favor the development of stable aerobic granules [7]. It has been reported that high OLR is beneficial for accumulating biomass by secreting more EPS [8]. Thus, this study sought to investigate the effects of granules properties and reactor performance under combination of various OLRs with the addition of static mixer into the reactor system. A static mixer was introduced in the reactor to enhance the hydrodynamic shear force even at low SAV. The findings would provide a cheaper promising alternative for aerobic biogranulation system.

2.0 Materials and Methods

2.1 Wastewater Composition

The reactors were fed with synthetic textile wastewater to ensure consistent loading conditions. A synthetic wastewater having the composition reported by Muda et al. [9] was used as feed during the study. Trace solution used was 1 mL/L and the elements were based on the composition recommended by Smolders et al. [10]. The composition of synthetic textile wastewater is shown in Table 1. Mixed azo dyes of Reactive Blue 4, Reactive Black 5 and Disperse Red 13 from Sigma-Aldrich with a total concentration of 50 mg/L were used in this study. These azo dyes represent some of the dyestuffs that are commonly used in textile industry.

Table 1. Components of synthetic wastewater

Nutrient Component	Concentration (g/L)	Trace elements	Concentration (g/L)
NH_4Cl	0.16	H_3BO_3	0.15
KH_2PO_4	0.23	$FeCl_3.4H_2O$	1.5
K_2HPO_4	0.58	$ZnCl_2$	0.12
$CaCl_2.2H_2O$	0.07	$MnCl_2.4H_2O$	0.12
$MgSO_4.7H_2O$	0.09	$CuCl_2.2H_2O$	0.03
EDTA	0.02	$NaMoO_4$	0.06
		$CoCl_2.6H_2O$	0.15
		KI	0.03

2.2 Seed Sludge

A fresh sludge obtained from the aeration tank of IWK Sewage Treatment Plant at Taman Harmoni was used for biomass seeding. The seed sludge was light brown, loose and fluffy and was sieved twice with a mesh of 1.0 mm to remove large debris before inoculation. Each of new experimental stage used the fresh sludge taken from the sewage treatment plant.

2.3 Reactor Set-up

A schematic diagram representation of the reactor set-up is given in Figure 1. Experiments were performed in a reactor system that was designed based on Muda et al. [9]. In this study, two sets of reactors comprised of a cylindrical column with no water jacket was constructed using acrylic. The cylindrical columns used had a working volume of 1.5 L with internal diameter and total height of 8 and 100 cm, respectively. The reactors were operated with intermittent phase in a 16 hours cycle time which consisted of filling (5 min), anaerobic (700 min), aerobic (240 min), settling (5 min), idle (5 min) and decant (5 min). The automatic timers were used to control the sequence operation of the SBR. Feeding, wastewater withdrawal and recirculation operations were controlled by peristaltic pumps. Fine air bubbles were introduced by a diffuser placed at the bottom of reactor at SAVs of 1.4 cms^{-1}. The wastewater influent was pumped into the reactor from the port located at the bottom of the reactor and the effluent was discharged through the port positioned at 15 cm from the bottom which gives the volumetric exchange ratio as 50%. Fine air bubble diffuser located at the bottom of the column boosted the aeration process by creating air bubbles. A 100 cm long metal rod is placed at the centre of the reactor with attached 6 blades (40 mm), placed head down at 45ºC and arranged alternately left and right was fixed for static mixing.

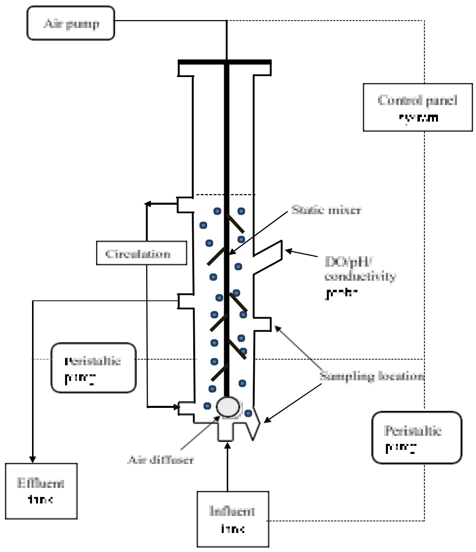

Figure 1. The schematic diagram of bioreactor system

2.4 Experimental Set-up
In order to investigate how stable granules would perform under a different loading rate, different concentrations of OLR were applied to the system. It has been reported in previous studies that biogranules are able to withstand OLR range of 2.5 to 15 kg/m^3.day. The disintegration of granules was reported at high OLR of 18 kg/m^3.day. Therefore, the OLR of 2.0, 2.5 and 3.0 kg/m^3.day were examined during the study. The OLR was increased stepwise to 2.5 kg/m^3.day in stage II and 3.0 kg/m^3.day in stage III while HRT was kept as 16 hours. Both reactors were operated continuously for 115 days according to the phases listed in Table 2 and the duration of each stage is also shown.

Table 2. Reactor operational conditions for R4N and R4Y in post development under various OLR and HRT at 16 hours

Stage	I	II	III
Operation day (days)	0-40	40-78	78-112
SAV (cm/s)	1.4	1.4	1.4
HRT (hours)	16	16	16
OLR (kg/m^3.day)	2.0	2.5	3.0

2.5 Analytical Method
Mixed liquor suspended solid (MLSS) was measured by collecting the sample from reactors. The dissolved oxygen (DO) and pH were continuously monitored and recorded by a pH/DO meter (Orion 4-Star Benchtop pH/DO Meter). The granules developed in the SBR column were periodically collected and analysed for their physical characteristics including SVI, SV, granules diameter and strength. The SVI procedure was carried out according to the method suggested by de Kreuk et al. [11]. The settling velocity was determined using a measuring cylinder. A granule was placed at the top and the time taken for the granule to settle through a certain distance in the cylinder was recorded. The granular strength was expressed as integrity coefficient (IC) and was determined following the procedures described by Ghangrekar et al. [12]. Sludge morphology and size distribution of the developed granules were characterized using a stereo microscope equipped with digital image analyser (I-Solution Premium). The removal efficiencies were calculated as percentage reduction between influent and effluent samples of the main typical parameters. The values of COD concentration were measured using HACH DRB 200 digester and HACH DR5000 spectrophotometer. Two mL of sample was added to the COD digestion reagent vial (High Range) and was heated at 150ºC for 2 hours in COD digester. Then the sample was allowed to cool at room temperature and COD reading was determined using DR5000

Spectrophotometer. Color intensity was also measured using HACH DR5000 spectrophotometer Procedure No. 1660. The result was expressed in terms of American Dye Manufacturing Index (ADMI).

3.0 Results and Discussion

3.1 Biomass Profile

The variation in MLSS concentrations is shown in Figure 2. With the increase of OLR, overall profile of MLSS of R4N and R4Y were rising in stage I to III, which R4N reached 5.34 g/L of MLSS and R4Y reached 5.73 g/L at the end of operational days. It seemed that the enhanced OLR promoted the cells to produce greater amounts of EPS. The biomass concentration in the two reactors both showed an increasing tendency due to the increase of OLRs and relatively larger granules was obtained at relatively higher OLRs, which in line with the study by Nguyen et al. [6]. This result is similar to that of Deng et al. [13] and Liu and Tay [5]; who found that high OLR is beneficial for biomass accumulated by secreting more EPS. The MLSS concentration present in R4Y was higher than that of R4N. The static mixer enhances the hydrodynamic shear force to induce more EPS production which is favorable for granulation and therefore accumulate biomass and retain more granules.

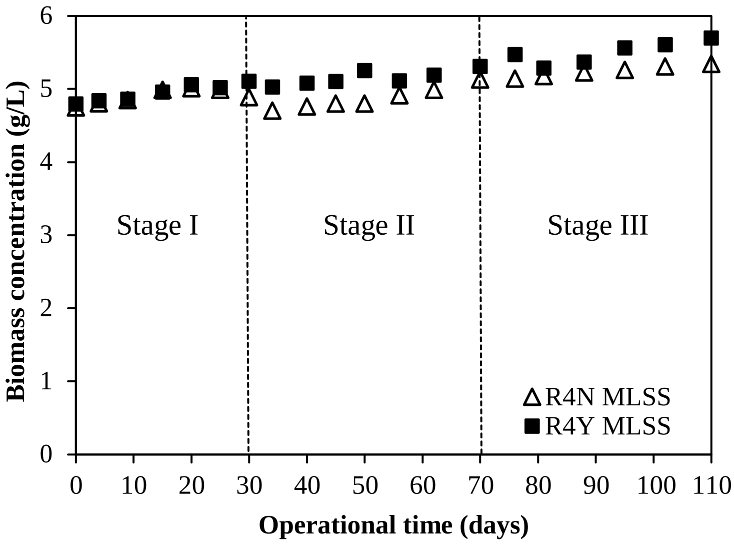

Figure 2. Biomass profile of the granules in the system

3.2 Granule Strength

The IC value reduced as the OLR increased at stage I to III for both reactors R4N and R4Y as can been seen in Figure 3. The low mean score of IC represents the high ability of biogranules to withstand rough abrasion and shear. The IC values for R4Y was significantly lower than in R4N which demonstrated that high shear force provided from static mixer was beneficial to strengthen the bond that linked the microorganisms in the granules. It has been believed that appropriate level of EPS contributed to a strong structure of the granules [14,15].

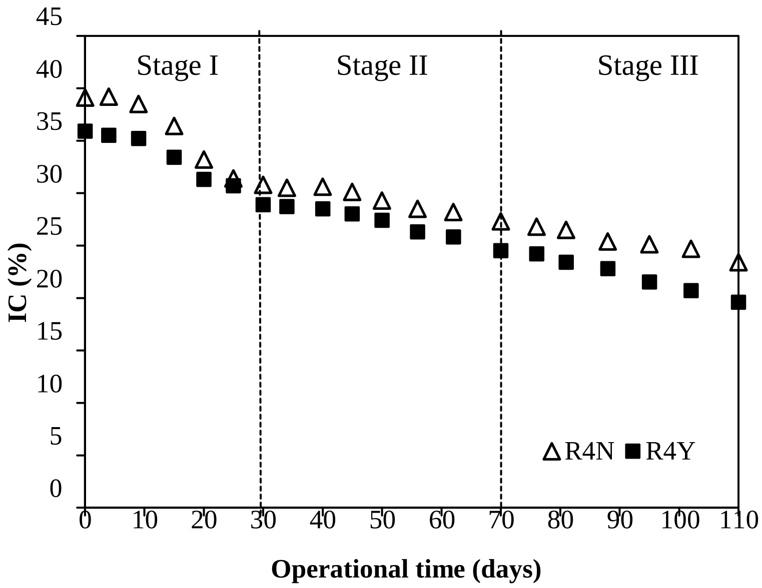

Figure 3. The trend in granules strength in the system

3.3 Settling Ability

As shown in Figure 4, the SV values improved from 71.3 to 77.2 m/h for R4N and 77.5 to 82.7 m/h for R4Y. Subsequently, an increase of the OLR to 3 kg/m^3.day in stage III contributed to an increase of SV, which indicates that the settleability of the granules improves with the OLR increase. The same finding was also revealed in other study by Truong et al. [16] which reporting that the settling ability of granules was increased with increasing OLR. High OLR promoted metabolism and production of EPS to adhere cells together and therefore improve the granules settling ability. The SV value for R4Y is higher that of R4N. This indicates that the hydrodynamic shear force created by the addition of static mixer was the factor for the better SV.

The settling ability of granules also increased as shown by the decrease of SVI in stage III. A higher OLR contributed to a much lower SVI with better settling granular sludge, where a decreased from 35.2 to 30.4 mL/g in R4N and 28.7 to 24.6 mL/g in R4Y at OLR of 3 kg/m^3.day (Figure 5). These results were consistent with observations made by Abdullah et al. [17] in SBR system treating agro-based wastewater, where the SVI decreased when the OLR was increased from 1.5 to 3.5 kg/m^3.day. It appears that there was a significant difference between R4N and R4Y. The reason that biogranules in R4Y was having better SVI than those in R4N is the addition of static mixer, which produced stronger hydrodynamic shear force with SAV of 2.4 cm/s. At the same time the high OLR promoted more secretion of EPS to bridging cells within the biogranules together which promoted the settleability of biogranules [16,18,19].

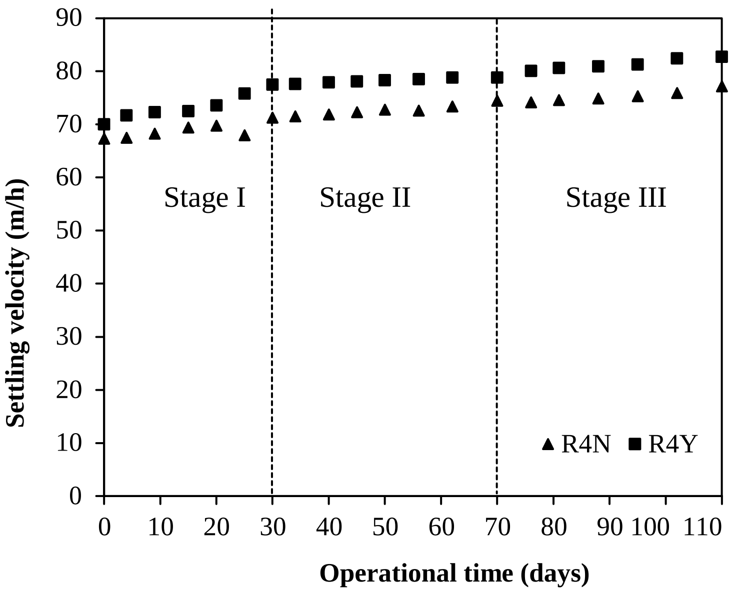

Figure 4. Changes of settling velocities of the granules

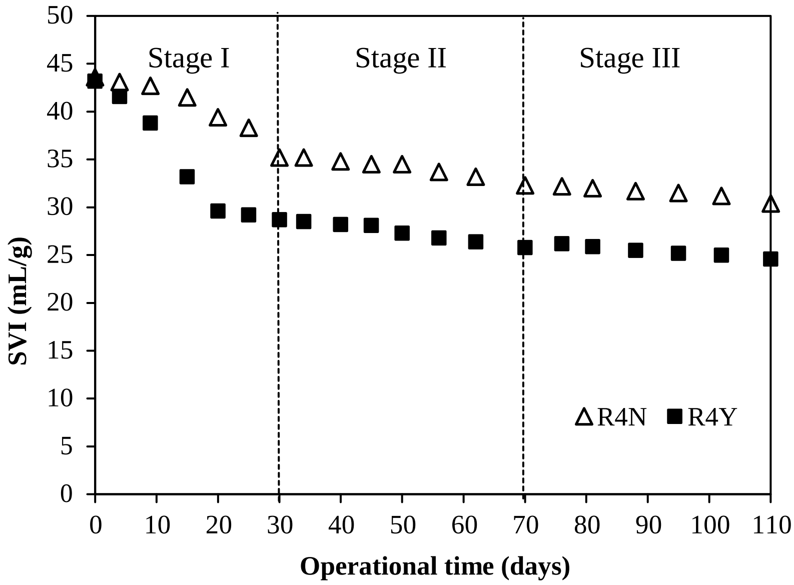

Figure 5. The variation of SVI of the granules during the operational time

3.4 Removal Performance

The performance of the SBR in terms of COD and color removal efficiencies was monitored during the 115 day experimental period. The removal of COD as a function of the SBR operational time is shown in Figure 6. The high value of COD removal presented good performance were achieved in both reactors. The COD removal efficiencies at the end of both experimental runs were not considerably affected and found to be in the range of over 90%. However, biogranules in R4Y showed slightly excellent COD removal efficiency compared to R4N. This result indicates that in the presence of static mixer, excellent biological activity could be attained during the degradation of the wastewater and therefore increased the COD removal efficiency.

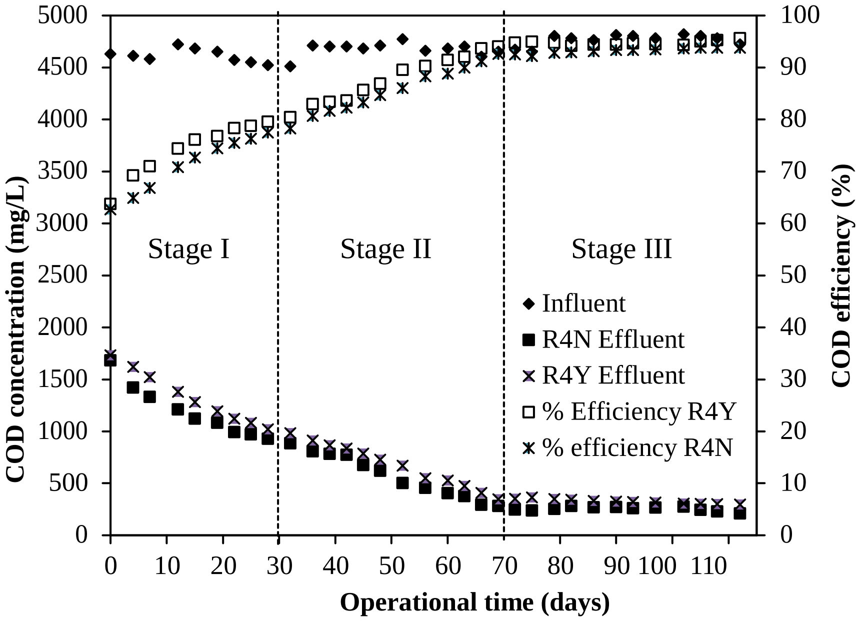

Figure 6. Profile of COD removal efficiency at different OLR

Figure 7 shows the removal of color for R4N and R4Y from the beginning of the experiment towards the end of the post development stage. In accordance with the present results, previous study by Ong et al. [20] have demonstrated that the percentage of color removal efficiency increased by 16% in anaerobic and 50% in aerobic SBR system when the OLR rate was increased from 2.66 to 5.32 kg/m^3.day. According to Pandey et al. [21], the rate of dye degradation is affected by the increase in organic loading. At the end of each phase, R4Y had slightly better color removal efficiency which depicted that the addition of static mixer supplied higher hydrodynamic shear force to increase the intimate contact between the granules and wastewater and resulting in better color removal efficiency.

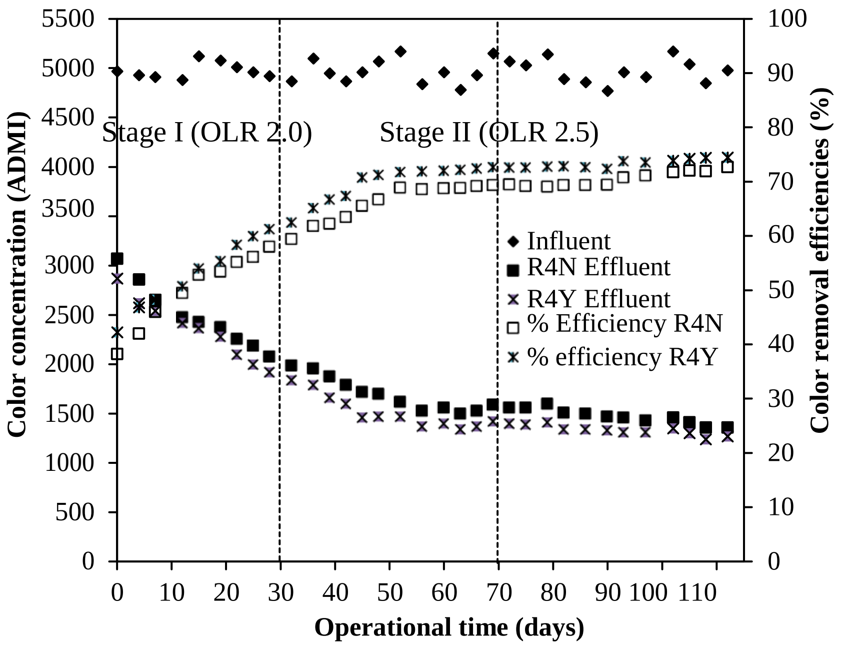

Figure 7. Profile of color removal efficiency at different OLR

4.0 Conclusion

The observation of this study showed that OLR had a great influence on the physical characteristics. Similarly, the granules strength of both reactors was raised with OLR increment. COD removal efficiencies above 90% were obtained in both reactors throughout all the experimental time. At the end of the experiment, the physical characteristics, settling ability and removal performance of the granules in R4Y were better than R4N at high OLR. The static mixer had a positive influence in the study. Due to that, OLR had affected the characteristics of the granules and it was proportionally related to the applied static mixer.

5.0 References

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Acknowledgement

The Authors would like to acknowledge the support, in undertaking this research to the Faculty of Civil Engineering Technology, Universiti Malaysia Pahang and School of Civil Engineering, Universiti Teknologi Malaysia.