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The Granular Sludge Properties and Performance Evaluation of Upflow Anaerobic Sludge Blanket Reactor as a Pre-Treatment for Domestic Wastewater

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Upflow Anaerobic Sludge Blanket (UASB) has traditionally being used in treating high strength wastewater to reduce the strength prior to the aeration treatment. The ability of UASB to reduce the strength of the wastewater via anaerobic mode help to reduce the aeration demand in the aerobic reactors, which in turn lower the energy demand for aeration. A pilot study of 131 m^3 working volume capacity bioreactor has been conducted to assess the potential and benefits of UASB as pre-treatment for domestic wastewater prior the aerobic biological treatment system. Based on monitoring assessment, the results showed that the integration with UASB performance as a pre-treatment able to reduce organic and solid loading from incoming influent (Chemical Oxygen Demand (COD) ~ 50 % removal and Total Suspended Solid (TSS) ~ 60 % removal). Consequently, the downstream aerobic biological system will be able to operate efficiently with less aeration requirement, hence save energy consumption for overall plant and produce better quality of effluent. Furthermore, the formation of anaerobic granular sludge is also observed in the UASB reactor. The analysis proved that granules with size between 0.3 to 0.6 mm were obtained in the sludge bed of the UASB reactor, and the highest amount (volume) was obtained from bottom part. Based on physical properties analyses, these granules have an excellent settling ability and compact sludge settleability (SVI_{30} 55–95 mL/g, SV 25–30 m/h). In conclusion, this study is significantly indicated that UASB can be deployed for enhancement of domestic wastewater treatment, by using anaerobic granular sludge as seed sludge for subsequent activated sludge process, thus will improve the overall sludge settleability performance of the plant.

1. Introduction

Domestic wastewater system in Malaysia is commonly treated by using aerobic treatment process (Sabeen et al., 2018). Aerobic treatment process in wastewater is a biological process that uses oxygen by aerating the wastewater and sludge mixture in order to breakdown the organic and other pollutants. The advantage of aerobic process is that it can meet the treated effluent discharge standard requirement. However, this will in turn resulting in higher cost and expenses of operating and maintaining the treatment plant which include requirement of aeration equipment and supply, electricity consumption, mechanical and electrical maintenance. Moreover, the aerobic treatment process also requires regular sludge wasting which in resulted into higher sludge treatment, management and disposal cost. Anaerobic treatment combines effective wastewater treatment with minimal operating costs and energy recovery. Other than that the advantages of the anaerobic treatment include the capacity to handle high COD loading and withstand with the influent fluctuations, production of biogas and quick and efficient treatment of wastewater (James and Kamaraj, 2022). Anaerobic digestion has been widely explored and used for the treatment of medium to high concentration of wastewater and known as the effective method in treating municipal solid waste (Nasir et al., 2012) and wastewater sludge (Appels et al., 2011). One of the popular anaerobic digester configuration is upflow anaerobic sludge blanket

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(UASB) (Khan et al., 2015). The ability of UASB to treat various types of wastewater has been investigated due to low electricity dependency, good treatment efficiency, adaptability, and energy output in term of the biogas generation and minimal sludge generation (Lu et al., 2015). The typical UASB reactor consist of a granular sludge bed, sludge blanket and 3 phase gas-liquid-solid separator, the cross section of UASB reactor is illustrated as in Figure 1.

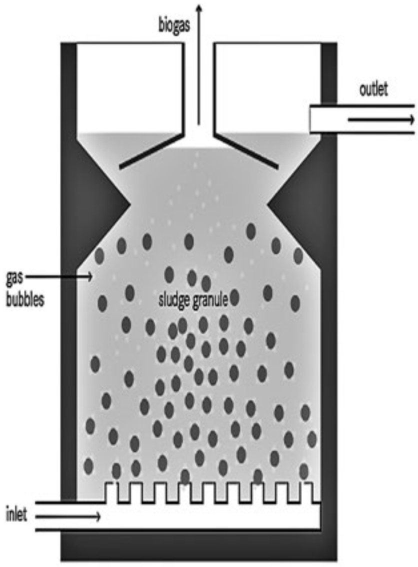


Figure 1: The cross section of UASB reactor

The UASB able to produce granular sludge which are diverse in microbial communities. Granulation plays a crucial role in how anaerobic reactors function, and it has a complex process that incorporates both biological and physiochemical mechanisms. Granular sludge can be defined as a biomass particle with a specific characteristic such as accelerated sedimentation velocity and methanogenic activity that are required for the breakdown of organic contaminants in wastewater. It is also relatively high in density and has excellent settleability element which will be able to avoid biomass washout and resistant to disintegration. Wang et al. (2018) mentioned that the stable operations of UASB reactor depends on the generation and maintenance of the granular sludge Hence, the granular sludge produced from the UASB reactor is a marketable by-product where it can be used as a seeding for a full-scale reactor or wastewater treatment system and to shorten the start-up time as well as to improve the sludge sedimentation process. Therefore, the objective of this study is to evaluate the performance of the current UASB operation in treating the domestic wastewater and apart from that, this study also aims to develop and characterize the anaerobic granular sludge developed from the UASB.

2. Research methodology

2.1 Research set-up and operational conditions

The baseline study was conducted by using pilot UASB reactor located at one of the local domestic wastewater treatment plant (WWTP) in Kuala Lumpur. The UASB working volume capacity is 131 m^3. The diameter of the reactor was 3.5 m with 14 m height. In comparison to other common UASB system at only 5 to 6 m height (Chernicharo et al., 2007), this reactor has a special features and advantage of smaller footprint. The reactor was seeded with approximately 70 m^3 of digested sludge from the nearest WWTP to accelerate the acclimation process of the reactor system. However there are a number of variables such as wastewater characteristics, seed sludge acclimatisation, pH, nutrient, existence of toxic compounds, loading rate, upflow velocity, hydraulic retention time, liquid mixing, and reactor design have an impact during the process of starting up the UASB reactor (Rizvi et al., 2015). The reactor was operated continuously at the ambient temperature with 30 min feeding and 30 min resting time.

2.2 Analytical methods

The performance of the UASB reactor was determined by analyzing the wastewater sample from the influent and effluent UASB reactor. The influent and effluent samples were collected and directly analysed at IWK laboratory after the sampling was done. The samples were analyzed for parameter include chemical oxygen demand (COD), biochemical oxygen demand (BOD), Total Suspended Solid (TSS) and ammoniacal nitrogen (NH_3N). The sampling frequency for the monitoring parameters that reflects to the reactor performance tabulated was conducted once a week. Analysis was conducted following to the APHA standard method for water and wastewater analysis. Other than that, the TSS for the sludge blanket also sampled once a week. The granules were also sampled from top, middle and bottom of reactor at the end of monitoring period and physical characterization was carried out. To prepare the samples, 1000 mL of granules were sieved over 0.3, 0.6 and 1.0 mm mesh size. Then, the retained granules on each sieve sizes were collected and it is ready to be analysed. The standard method was used to analyse granules characteristics include MLSS, MLVSS, SVI_{30}, and settling velocity (Rodger et al., 2017). A Leica EZ4W stereomicroscope (5-megapixel camera) to determine the granules' size and used to capture the photo.

3. Results and discussion

3.1 UASB operational conditions

The wastewater influent is fed into the UASB reactor with an upflow direction with a hydraulic retention time (HRT) of 7.4 h. This HRT is slightly lower than the recommended HRT of 8 to 12 h (Lier et al., 2010). However according to Daud et al. (2018) the HRT of 2 to 10 h is normally practice and acceptable worldwide. As for the upflow velocity, the UASB reactor has adopted the upflow velocity of 1.95 m/h, higher than the recommended of 0.5 to 1.5 m/h as reported by Tawfik et al. (2010). This UASB reactor operated at an ambient temperature of tropical climate and near to neutral pH 7.1 for the influent wastewater according to the condition described in the literature by Halalsheh et al. (2005).

3.2 Performance evaluation of the domestic wastewater

The performance efficiency of UASB in treating domestic wastewater was observed based on the COD removal efficiency. The Chemical Oxygen Demand (COD) removal was achieved at 59.5 % with 550 mg/L COD concentration in the influent within one month of operation. The removal efficiency is reported in between 21.5 to 89.6 % throughout the performance monitoring as illustrated in Figure 2. However the variation in performance removal may be resulted from fluctuation in the daily flow rate of influent to the UASB reactor where the UASB required a constant feeding of influent to the system for the optimum operation performance. This supported by Rizvi et al. (2018) where the removal efficiency of the COD varied between 50 and 81 % may be due to the inability to handle the incoming concentration. The rainy season or a sudden increase of sewage flow in the sewage pipeline may affecting the fluctuation of the crude sewage concentration (Laila et al., 2019). Additionally, a few mechanical issues occurred during the start-up period also one of other contribution factor. Nevertheless, the reactor still able to maintain the performance throughout the monitoring period.

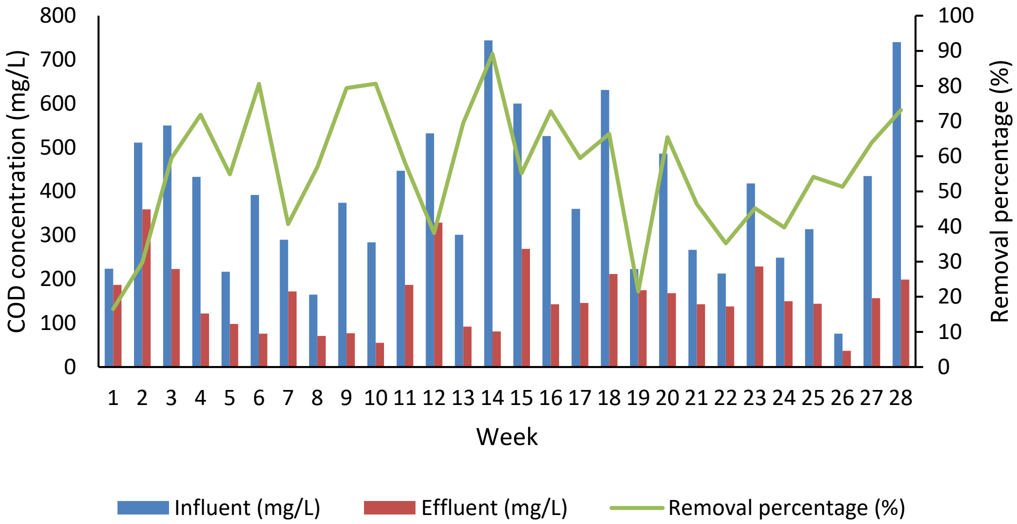


Figure 2: COD removal in the UASB reactor

The removal percentage for Total Suspended Solid (TSS) was measured as to understand on UASB removal efficiency in terms of solid removal and in order to monitor the desludging requirement. Generally, the UASB reactor able to meet the removal rate at average of 60 % throughout the monitoring period. This result supported by the research done by Syutsubo et al. (2011) at 68 % during the steady state of UASB operation and it indicate that the suspended solids in the sewage was able to be degraded in the UASB reactor. Nevertheless last 3 weeks data show removal started to drop to average -259 %. Given then result, on-site SV30 monitoring was performed to determine the settling rate of the sludge in 30 min. The SV30 reading was exceed the 50 % sludge settling rate where operationally the sludge level in this UASB reactor should be maintained and do not exceed 35 %. This indicates the reactor need to desludge to ensure better performance of the UASB reactor.

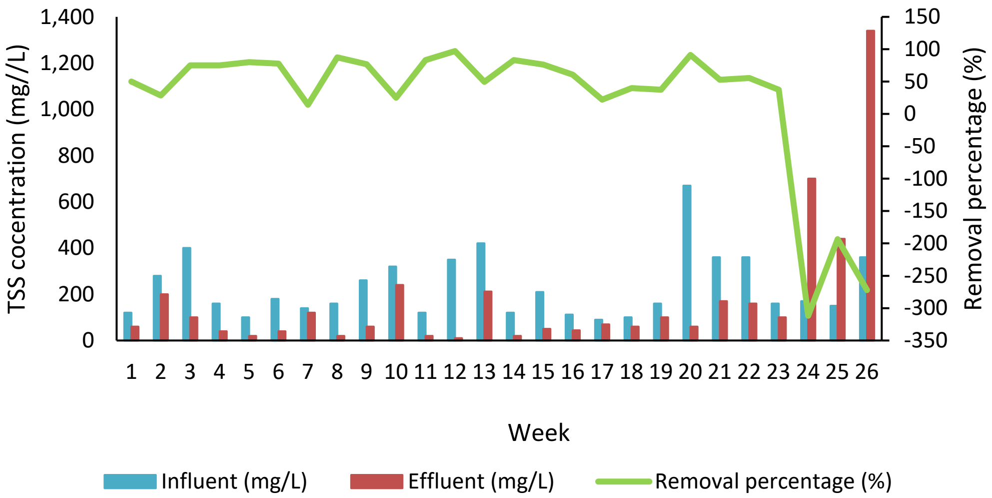


Figure 3: TSS removal in the UASB reactor

The monitoring of ammoniacal nitrogen (NH_3N) was done as to evaluate if the UASB will adversely increase the ammonia concentration in the UASB discharge that indirectly will impact the ammonia loading into the downstream wastewater treatment. Throughout the study, it was found for some data the NH_3N of effluent is higher than then influent as illustrated in Figure 4 and it is expected will not be removed due to UASB is not designed for nutrient removal. This was supported with study from Hasan et al. (2019) that the ammonia concentration in the effluent is higher than the influent, the increment is due to the organic nitrogen being hydrolyzed in the UASB reactor. However the effluent concentration is still within the compliance allowable limit of 50 mg/L. It can be concluded that UASB did not significantly contribute to the ammonia concentration in the UASB discharge.

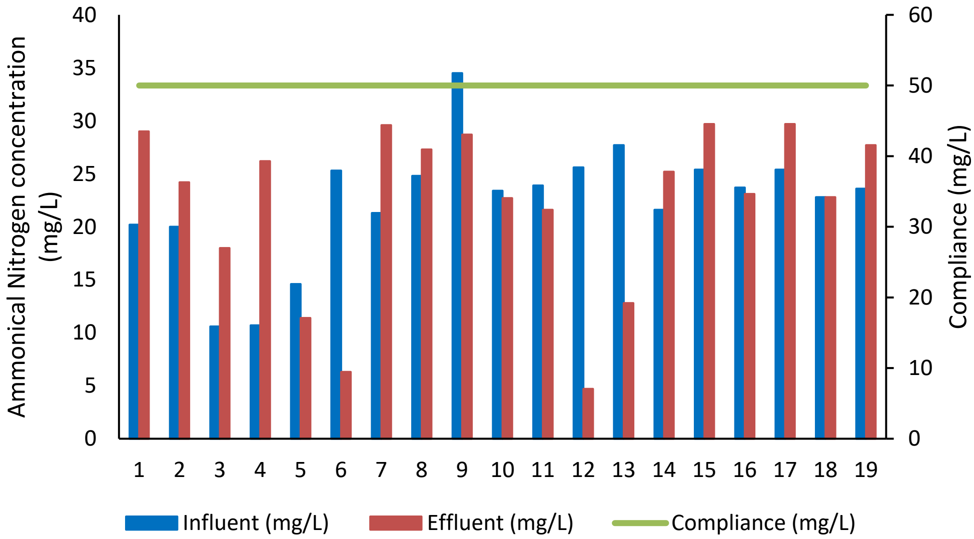


Figure 4: NH_3N removal in the UASB reactor

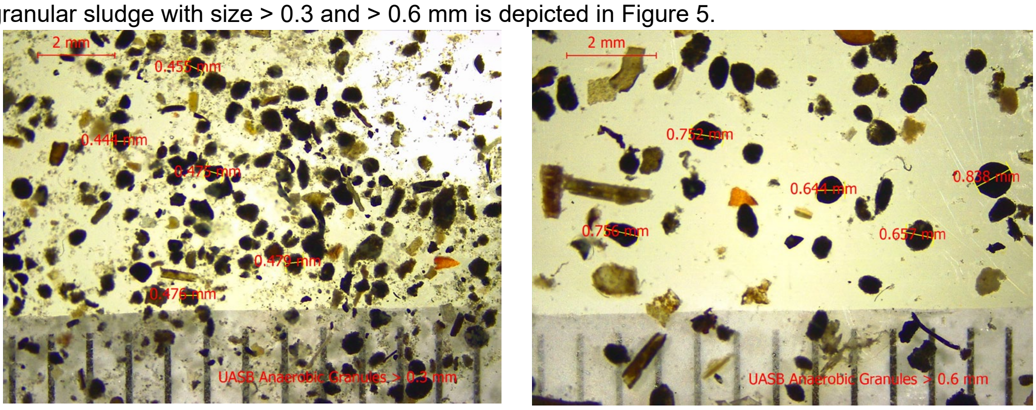
3.3 Assessment on anaerobic granular sludge

The physical properties of the sludge at the end of monitoring period were analyzed to confirm the occurrence of anaerobic granular sludge during operation. It is confirmed that the formation of small amount of granular sludge was occurred at the bottom, middle and top of UASB reactor. Table 2 presented results on the amount (in volume) of granules retained on sieve with size 0.3, 0.6 and 1.0 mm. Obviously, the highest amount of granules obtained from bottom part, followed by middle then top of reactor. However, there is no sludge/granules was retained on the sieve size 1.0 mm.

Table 2: Amount of anaerobic granules (in volume, mL) per 1,000 mL sludge sampled

	> 0.3 mm	> 0.6 mm	> 1.0 mm
Top	6	2	Not obtained
Middle	48	6	Not obtained
Bottom	100	30	Not obtained

In addition, other sludge properties such as sludge concentration and sludge settleability as shown in Table 3 proven that the developed granules are compact and stable (Syutsubo et. al., 2011). The image of anaerobic granular sludge with size > 0.3 and > 0.6 mm is depicted in Figure 5.



(a) (b)

Figure 5: Photo of anaerobic granules obtained from UASB reactor (a) size > 0.3 mm and (b) size > 0.6 mm

Table 3: Physical properties of sludge sampled from top, middle and bottom part of reactor and average settling velocity of anaerobic granules at different size

Parameter	Unit	Top	Middle	Bottom
MLSS	mg/L	8,500	8,000	24,000
MLVSS	mg/L	6,500	5,800	18,000
SVI_{30}	mL/g	95	90	55
SV (size > 0.3 mm)	m/h		30	
SV (size > 0.6 mm)	m/h		25	

4. Conclusions

The UASB reactor as a pre-treatment for domestic wastewater treatment showed adequate removal efficiency of COD and TSS. The results showed that the integration with UASB performance as a pre-treatment able to reduce organic and solid loading from incoming influent (COD ~ 50 % removal and TSS ~ 60 % removal). The formation of anaerobic granular sludge is also observed in the UASB reactor. The analysis proved that granules with size between 0.3 to 0.6 mm were obtained in the sludge bed of the UASB reactor, and the highest amount (volume) was obtained from bottom part. Based on physical properties analyses, these granules have an excellent settling ability and compact sludge settleability (SVI_{30} 55–95 mL/g, SV 25–30 m/h). In conclusion, this study is significantly indicated that UASB can be deployed for enhancement of domestic wastewater treatment, by using anaerobic granular sludge as seed sludge for subsequent activated sludge process, thus will improve overall sludge settleability performance of the plant. Also, very few studies reported about the benefits of anaerobic granular sludge for domestic wastewater treatment. Findings from this study will become a baseline for next step of research, to enhance the formation of more granules in the UASB for the enhancement of domestic wastewater treatment.

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