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Factors Affecting BOD₅ and TSS Removal from Wastewater Using UASB Reactor

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ABSTRACT

The purpose of this study is to investigate the efficiency of the UASB reactors (Upflow Anaerobic Sludge Blanket) at the laboratory scale in processing the mixture of domestic wastewater (greywater and black water). Two parameters of influent concentration and the upflow velocity were changed for the evaluation. Low, medium and high influent concentrations were used and the parameters examined were Biological Oxygen Demand (BOD₅) and Total Suspended Solid (TSS). Results showed 76% as the maximum BOD₅ removal efficiency and the maximum TSS removal efficiency was 72%. The BOD₅ and TSS concentrations available to be removed by the microorganisms increased with the increasing wastewater concentration. Generally, slower upflow velocity allowed more time for the biomass to achieve substrate decomposition in the wastewater, therefore higher removal efficiency was observed with slower upflow velocity. Nevertheless, further processing of the treated wastewater is recommended as the treatment using the UASB reactor did not meet the quality standards specified by the Ministerial Environmental Decree of Indonesia.

Key words: Mixture domestic wastewater, UASB, influent concentration, upflow velocity

INTRODUCTION

The wastewater from business and or settlement activities (real estate), restaurants, offices, commercial properties, apartments and dormitories has been defined by Ministerial Environmental Decree of Indonesia (Decree of Ministry of Environment, 2003) as domestic wastewater. Domestic wastewater can further be categories as: greywater, from bathing and washing and kitchen waste from resources other than a privy and black water or fecal water from toilets and privies. Department of Settlement and Regional Infrastructure of Indonesia (Department of Settlement and Regional Infrastructure of Indonesia, 2003) have stated that several pollutants form predominant components of the wastewater and contaminations of rivers, lakes and other fresh water resources from pollutants, such as; nutrients is a general cause for health issues and contaminations of freshwater resources also produces the need for purification treatment of drinking water.

However, the adverse effects of pollutants on human health can be avoided, if an effective wastewater treatment technique is adapted. There are three methods for the processing of the wastewater, namely: biological processes, physical processes and chemical processes. Among these three techniques, biological wastewater treatment method is considered as the most economic and efficient process for eliminating the organic pollutants from the waste waters. There are two further subdivisions of the biological treatment process of wastewater, which are termed as aerobic and anaerobic processes.

Compared to the aerobic process, the anaerobic digestion is widely employed as the technique for breaking-down of biomass into smaller molecules and a production source for the methane-rich biogases (Lettinga and Pol, 1991). As the microorganism consume certain nutrients in the wastewater to grow, the anaerobic digestion of wastewater by microorganisms is utilized in Upflow Anaerobic Sludge Blanket (UASB) reactors where wastewater is flown towards the top of the reactor through blanket/layer of sludge.

The study is aimed to investigate the processing ability of the UASB reactors for the domestic wastewater at the laboratory scale. For this purpose, samples of domestic wastewater were taken from Gabahan Village area, Central District of Semarang and Bukit Semarang Baru Residence, Ngaliyan District, Semarang, Indonesia. The reason for selecting two different districts was the zonal and municipal nature of each district, where Bukit Semarang Baru Housing represents a planned housing area and the Ngaliyan district corresponds to slum areas. The two parameters that are most dominant in the domestic wastewater were selected for the purpose of this study, which are the 5-day Biological Oxygen Demand (BOD₅) and the Total Suspended Solids (TSS). Tchobanoglous *et al.* (2003) have identified BOD₅ as the most widely used parameter of organic pollution applied to wastewater. The BOD₅ is usually exerted by dissolved and colloidal organic matter and imposes a load on the biological units of the treatment plant, whereas, the TSS is an indicator of suspended sediments in the wastewater body.

MATERIALS AND METHODS

This study had focused on all three types of the influent concentrations which are low, medium and high concentrations. As highlighted in Table 1, the variations in the sources of the domestic wastewater produced different concentrations of the domestic greywater and as the Bukit Semarang Baru housing wastewater concentration was lower than the Gabahan Village wastewater concentration, the wastewater characteristics of Gabahan Village were selected as the high concentration variant and the former was set as the lower wastewater concentration, while the middle point between both concentrations was selected as the middle concentration variant.

This study employed 9 reactors in total and each UASB reactor had a volume of 1 L with 30 cm height and 8 cm diameter. Different concentrations and upflow velocities were maintained for each operating reactor. Kaolin, glucose and distilled water were employed for the production of artificially manufactured wastewater. Kaolin was selected as the source of the TSS and glucose as the BOD source. The desired concentration variation was obtained through the employment of the trial and error approach. Gravitational transmission system and a valve were used for the regulation of the upflow velocity and the upflow velocities used were of 2.5, 1.67 and 1.25 L h⁻¹. The input data of the upflow velocity was then converted into m sec⁻¹ for the purpose of the calculation. Table 2 lists the details of all the reactors used in this study.

The operation of the reactors was divided into two stages: the acclimatization stage and the running stage. The acclimatization stage was further subdivided into two stages, namely: Acclimatization stage with 50% of planned concentration and acclimatization stage with 100% of

Table 1: Characteristic of domestic wastewater of Gabahan village and BSB housing, Semarang

Parameters	Gabahan village	BSB housing
BOD ₅ (mg L ⁻¹)	486.00	403.00
TSS (mg L ⁻¹)	1350.00	834.00
pH	7.13	7.68
Temperature (°C)	27.11	27.05
DO (mg L ⁻¹)	0.54	4.61

Table 2: UASB reactor details

Reactors	Concentrations	HRT (h)	Vup	
			m h ⁻¹	m sec ⁻¹
R4	Low	4	0.05	1.39×10 ⁻⁵
R6	Low	6	0.033	9.17×10 ⁻⁶
R8	Low	8	0.025	6.94×10 ⁻⁶
S4	Middle	4	0.05	1.39×10 ⁻⁵
S6	Middle	6	0.033	9.17×10 ⁻⁶
S8	Middle	8	0.025	6.94×10 ⁻⁶
T4	High	4	0.05	1.39×10 ⁻⁵
T6	High	6	0.033	9.17×10 ⁻⁶
T8	High	8	0.025	6.94×10 ⁻⁶

planned concentration. The initialization of the acclimatization stage at the induction of only 50% of the planned concentration into the reactor was performed to prevent shock loading and after the stabilization of the removal efficiency, the concentration was increased to be 100%.

RESULTS AND DISCUSSION

This study had employed a valve for the purpose of obtaining the regulation of upflow velocity, so that, it could be maintained at a fixed upflow velocity value, as planned. Gravity system was utilized for obtaining direct flow of the wastewater into the effluent tank. However, as the gravity system encourages a relatively higher flowrate, an equalization basin equipped with mixers was added between the influent tank and the reactor. Under this configuration, the wastewater from the influent tank entered the equalization basin, which produced homogeneity in the artificial wastewater and was then subsequently flown into the reactor. The need for maintaining homogeneousness through mixing in the equalization basin is mainly for accurate measurement of TSS as otherwise, the kaolin in the artificial wastewater could settle easily. It was also observed that the inclusion of the equalization basin in the reactor configuration did not impose any significant influences upon the flowrate fluctuations from the reactor.

Running stage: During the running or operational stage of the UASB reactor, the performance of the UASB reactor in the treatment of the artificially-manufactured wastewater was assessed against the BOD₅ and the TSS criteria. The running stage was conducted in a 20 days' time period. The readings for the effluent values were noted after every three days to obtain the allowance values for the TSS and BOD₅. Table 3 lists the concentrations of the two parameters investigated in this study.

BOD₅ removal: Figure 1-3 illustrates that the performances of UASB reactors in treating the BOD₅ showed considerable fluctuations. The removal efficiency of the BOD₅ decreased in almost all the reactors on the 6th day but was then increased and remained fairly stable until the last sampling. The cause of this observance can be attributed to the declining pH of water in almost all of the reactors. The decrease in the pH shows that acidogenesis and acetogenesis processes might have already occurred, therefore, the organic matter was converted into volatile fatty acids and the pH further inclined towards the acidic side. The accumulation of the volatile fatty acids in the reactor could have caused obstruction in the methanogenesis process and would then have affected the organic removal efficiency.

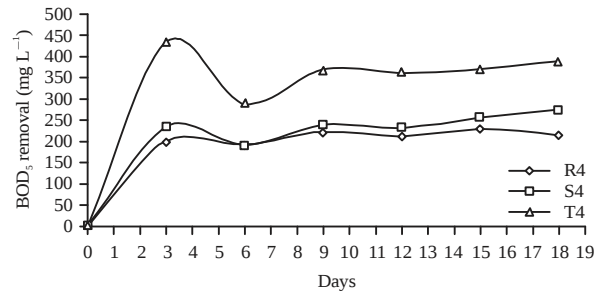


Fig. 1: Effect of concentration variation on BOD₅ removal in reactor R4, S4 and T4

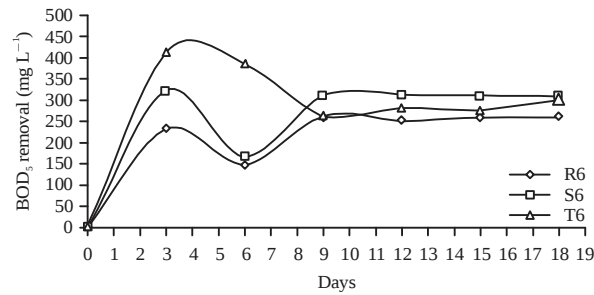


Fig. 2: Effect of concentration variation on BOD₅ removal in reactor R6, S6 and T6

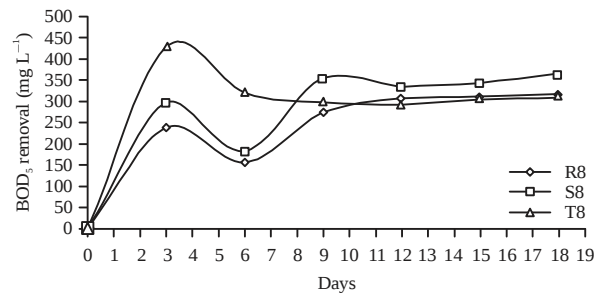


Fig. 3: Effect of concentration variation on BOD₅ removal in R8, S8 and T8

Table 3: Influent concentration on running stage

Variation of concentration	BOD ₅ concentration (mg L ⁻¹)	TSS concentration (mg L ⁻¹)
Low	415	850
Middle	617	1100
High	847	1350

During the running stage, the value of pH ranged from 4.68-7.22. More acidic condition occurred in the reactor with the higher concentration variant, whereas, the reactor with the middle concentration variant showed quite normal pH value. Liu *et al.* (2008) have specified that methanogens (microorganisms that produce methane) are suitable with the pH values in the range of 6.5-7.5, while the minimum pH value of 6.2 has been identified by Eckenfelder *et al.* (1988). However, the lower limit of pH value of 4 has been identified by Gerardi (2006), stating that an acidic pH can be tolerated by the microorganisms as long as the pH value is not lower than 4. Therefore, the basic value of pH encountered in this case implies that the conditions are suitable for the growth of the microorganisms.

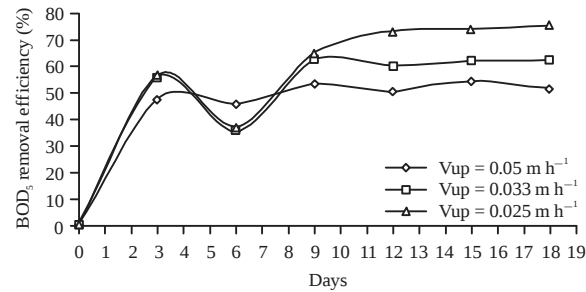


Fig. 4: Effect of upflow velocity on BOD₅ removal efficiency in low concentration of influent

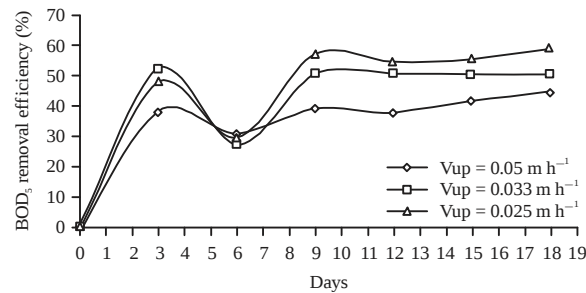


Fig. 5: Effect of upflow velocity on BOD₅ removal efficiency in middle concentration of influent

It can be stated that the amount of the BOD₅ removed by the microorganisms in the reactor increased with increase in the influent BOD₅ concentration. The substrate enters the cell of a microorganism through diffusion in which the molecules from higher solute concentration move to the lower solute concentration. Therefore, an increase in substrate concentration, would have readily allowed the entrance of substrate in the microorganisms cells, as BOD₅ allowance.

The highest BOD₅ removal efficiency occurred at low concentration (Fig. 4) and middle concentration (Fig. 5), at the reactors R8 and S8, with an upflow efficiency of 0.025 m h⁻¹. The upflow velocity of 0.025 m h⁻¹ was the lowest upflow velocity in this research, in which the microorganisms were in contact with the substrate for the longer retention time (HRT) of 8 h occurred, as displayed by the increasing BOD₅. These observations are quite consistent with the observations by other researchers, that have suggested that the longer retention time results in an increase in the contact time of the microorganism, thus increasing the degradation of the organic matter in the effluent (Ali *et al.*, 2007; Nugrahini *et al.*, 2008).

In the reactor with high concentration (Fig. 6), the highest BOD₅ removal efficiency occurred in the reactor with an upflow velocity of 0.05 m h⁻¹ and HRT of 4 h. It can be observed that the extent of the mixing of microorganisms and the substrate in the reactor increased with the increasing value of upflow velocity. Research has shown that the reactor removal efficiency increases with the rising value of the upflow velocity as higher upflow velocity results in better contact between the biomass and the substrates (Yasar and Tabinda, 2010). The improvement in the wastewater treatment performance is affected by the flowrate and the influent equalization in the entire cross-section of the reactor and therefore, constitute as major factors that influence the performance of UASB reactor (Mahmoud *et al.*, 2003).

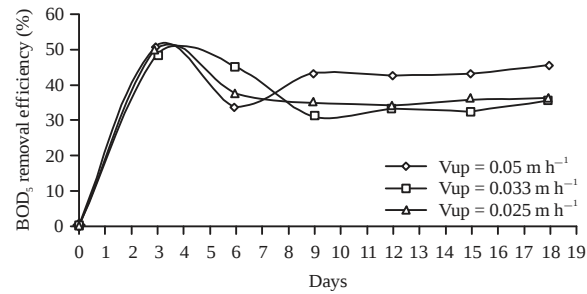


Fig. 6: Effect of upflow velocity on BOD₅ removal efficiency in high concentration of influent

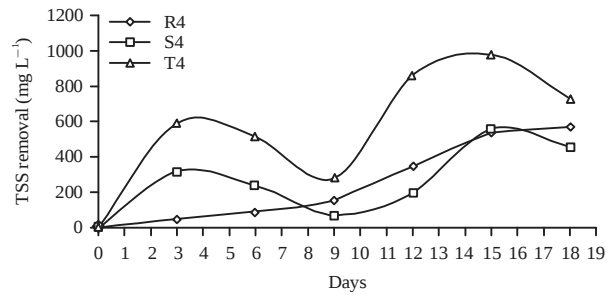


Fig. 7: Effect of concentration variation on TSS removal in reactor R4, S4 and T4

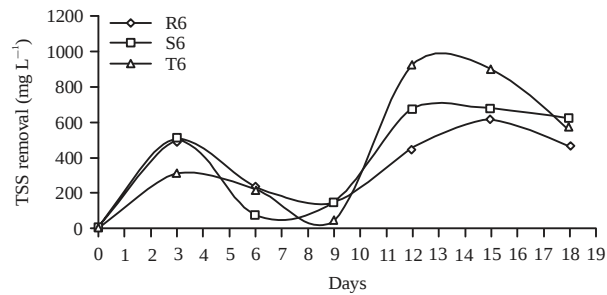


Fig. 8: Effect of concentration variation on TSS removal in reactor R6, S6 and T6

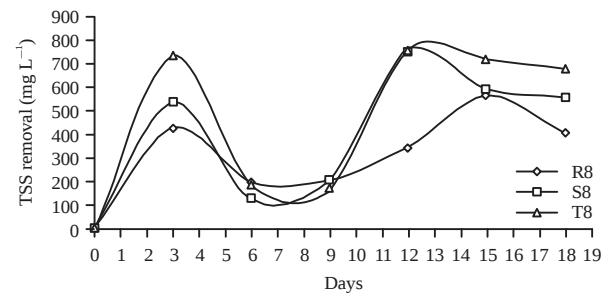


Fig. 9: Effect of concentration variation on TSS removal in reactor R8, S8 and T8

TSS removal: Fluctuations were observed in the TSS removal efficiency in almost all of the reactors, as illustrated in Fig. 7-9. It was noted that the removal efficiency decreased on the 6th and the 9th day, while a rise was observed for both day 12 and 15 in the TSS removal efficiency

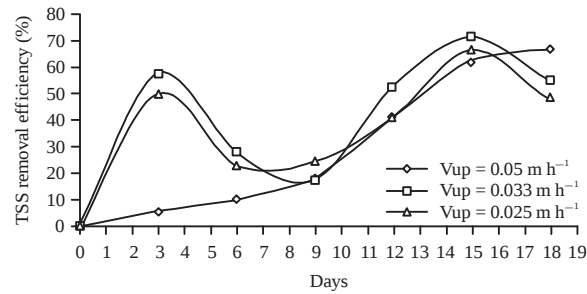


Fig. 10: Effect of upflow velocity on TSS removal in low concentration of influent

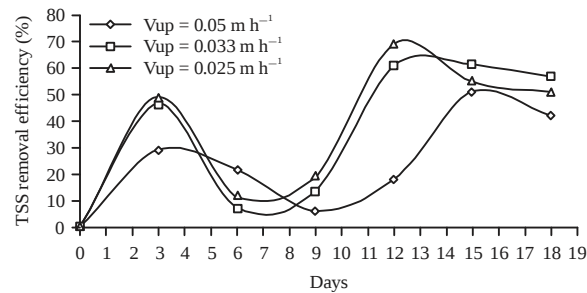


Fig. 11: Effect of upflow velocity on TSS removal in high concentration of influent

value, but it declined again on the 18th day. The fluctuations in the value of the TSS removal efficiency can be attributed to have occurred due to the accumulation of solids inside the reactor. Therefore, as more solids started accumulating in the reactor and were not carried over into the effluent, higher removal efficiency values were obtained and the effluent seemed to be much clearer. Furthermore during a certain time, the unstable accumulations were carried over into the effluent and, thus smaller removal efficiencies and higher turbidity levels were obtained. In a research conducted on UASB systems, Aiyuk *et al.* (2010) have also found that the sludge bed can act as filter for the suspended solids and thereby increasing their specific residence time. Therefore, the UASB reactor may achieve high TSS removal at relatively short Hydraulic Retention Times (HRTs). However, the accumulation of suspended solids in the sludge bed can provoke the displacement and dilution of the active cells (called biocatalysts).

The pH conditions in the reactor had less influence on the TSS removal levels. As the pH value increased, the value of the TSS removal efficiency remained relatively unchanged. Similar observations have been documented by Mukminin *et al.* (2012) and they have proposed that the TSS levels of the effluent are not influenced significantly by the pH values.

Generally, similar tendencies were observed for the removal efficiencies of the three concentration variants with the same upflow velocity (Fig. 10-12). The highest TSS removal efficiency in the reactor with low concentration occurred in reactor R6 with an upflow velocity of 0.333 m h^{-1} . While, the highest TSS removal efficiency for the middle concentration occurred in reactor R8 with an upflow velocity of 0.025 m h^{-1} . Moreover, for the high concentration variant, the highest TSS removal efficiency was observed in reactor T4 with an upflow velocity of 0.05 m h^{-1} . Therefore, each of the concentration variant, the maximum value of the TSS removal efficiency occurred in the reactor with different upflow velocity. Alphenaar *et al.* (1993) have stated that the upflow velocity can influence the treatment system in two ways.

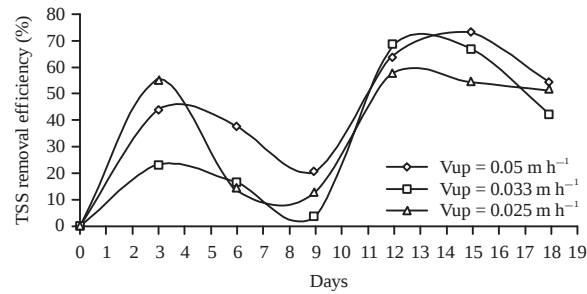


Fig. 12: Effect of upflow velocity on TSS removal in high concentration of influent

Table 4: Comparison between effluent and quality standard

Effluent		Quality standard (mg L ⁻¹)	
Concentrations	concentration (mg L ⁻¹)	Ministerial environmental decree of Indonesia	Regional regulation of Central Java province
Low			
BOD ₅	102	100	30
TSS	240	100	50
Middle			
BOD ₅	256	100	30
TSS	340	100	50
High			
BOD ₅	411	100	30
TSS	370	100	50

Firstly, the hydraulic shearing force can be enhanced by an increase in upflow velocity, which can then trigger the detachment of the captured solids, resulting in a decline in the performance of the system. Secondly, an increase in the upflow velocity accelerates the collisions between the suspended particles and the sludge. Consequently, it can be stated that the efficiency of the system can be increased by the increase in the upflow velocity. On the other hand, the decrease in the upflow velocity has two adverse effects on the UASB performance, provided the contact time between the microorganisms and substrate is sufficient and results in better organic matter degradation (Ali *et al.*, 2007).

However, the reduction in upflow velocity results in improper or lesser mixing, which may cause little or no contact between the substrate and the biomass. These observations are consistent with the results obtained in this study, which showed that performance of the UASB reactor was influenced by the upflow velocity. At this stage it should also be noted that past researches (Lew *et al.*, 2004; Halalsheh *et al.*, 2005; Moussavi *et al.*, 2010) have shown that high values of the upflow velocity can disturb the sludge bed and the solids can therefore be carried from the reactor into the effluent.

Comparison between quality standard and effluent concentration: The results from the domestic wastewater treatment processes using UASB reactor that have been conducted in this study have been compiled in Table 4. It can be stated that the quality of the effluent did not met the standards for the domestic waste water as have been specified by the Ministerial Environmental Decree of Indonesia (Decree of Ministry of Environment, 2003) and threshold limit defined by Regional Regulation of Central Java Province (2004). Therefore, it is recommended that the domestic wastewater investigated in this study has to be processed further before it can be discharged to the environment.

CONCLUSION

The study investigated the removal efficiency of the UASB reactor in the treatment of the domestic waste water at the laboratory scale. It was observed that the maximum BOD₅ removal efficiency value was noted as 76% and the maximum TSS removal efficiency was 72%. The BOD₅ and TSS allowance values increased with the increasing influent concentrations. The influent concentration employed for 847 mg L⁻¹ BOD₅ and TSS of 1350 mg L⁻¹. Generally, the reactor with 6.94×10⁻⁵ m sec⁻¹ or 0.025 m h⁻¹ upflow velocity performed relatively better than the reactors that involved other variants of the upflow velocities. This observance of comparatively higher value of the removal efficiency can be attributed to the assumption that slower upflow velocity will allow more time for the microorganisms to decompose the substrate in the wastewater.

There are few observations that can be used for the identification of the fluctuations in the removal efficiency. As the pH value tended to decrease and became more acidic, decline was observed in the BOD₅ removal efficiency. The reason for the decrease in removal efficiency can be that as more organic matter was decomposed into volatile acids, the pH value dropped to be more acidic which could have obstructed the methanogenesis process. The moderate value of the BOD₅ was observed as the pH value tended to be normal. However, small allowance efficiencies and high TSS values resulted in a cloudy effluent as due to the unstable upflow velocity, the ability to trap solids in the reactor was affected and small removal efficiency was obtained as if these solids were carried into the effluent. However, the treatment of the wastewater using the UASB reactor did not meet the quality standard stated by Ministerial Environmental Decree of Indonesia and Regional Regulation of Central Java Province.

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