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# THE EFFECT OF UPFLOW VELOCITY AND INFLUENT CONCENTRATION TO COD REMOVAL ON UASB REACTOR TREATING DOMESTIC WASTEWATER

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**ABSTRACT**

This study aims to estimate the laboratory scale of domestic wastewater (grey and black water) processing ability of UASB (Upflow Anaerobic Sludge Blanket) reactors by varying the upflow velocity and influent concentration. Three kinds of influent concentrations; low, medium and high was determined. The parameter examined was the Chemical Oxygen Demand (COD). The concentration of the COD that can be removed by the UASB reactor increased with the increased wastewater concentration. The maximum removal efficiency values obtained for the COD was 69%. Overall, the reactor with slower upflow velocity allowed more time for the microorganisms to decompose the wastewater substrate, increasing the observed removal efficiency. However, the UASB reactor treatment results did not meet the waste water quality standards released by Ministry of Environmental of Indonesia and thus requiring further processing before discharging to the environment.

**Keywords:** domestic wastewater, UASB, COD concentration, upflow velocity variation.

## INTRODUCTION

Domestic wastewater can be divided into two categories: wastewater from toilets, termed as fecal water or black water and wastewater from washing and bathing and non-outhouse kitchen waste, defined as the grey water. Improper treatment or poor disposal of this wastewater can cause pollution of rivers from pollutants like nutrients and may create health problems and enhance the operational costs for drinking water treatment systems [1].

Proper wastewater treatment can mitigate these adverse effects and can be performed in three ways: physical, chemical and biological processes. Biological wastewater treatment is the most efficient and economical way of removing organic pollutants. It is divided into two main categories as aerobic and anaerobic processes. Anaerobic digestion is a generally utilized source of renewable-energy due to its production of biogas that is rich in methane and breaking down of biomass into smaller molecules [2]. In case of Upflow Anaerobic Sludge Blanket (UASB) reactor, the wastewater flows upwards through a layer/blanket sludge and is anaerobically degraded by microorganisms.

In this study, domestic wastewater samples were collected from Gabahan Village area, Central District of Semarang and Bukit Semarang Baru Residence, Ngaliyan District, Semarang. Ngaliyan district was selected to represent the individual housing area and Bukit Semarang Baru Housing as real estate residential area. The chemical oxygen demand (COD), which is one of the dominant parameters in the domestic wastewater, is used as the parameter to measure the toxic organic matter in wastewater; the higher the COD value, the worse the water quality [3].

## METHODOLOGY

Low, medium and high influent concentrations are used for the purpose of this study. The different concentrations are produced through the varying characteristics of the domestic grey water originating from the dissimilar districts of Gabahan Village and Bukit Semarang Baru as shown in Table-1. The wastewater concentration in Gabahan Village is higher than that in the Bukit Semarang Baru Housing; therefore, the characteristics of the wastewater in Gabahan Village serves as the high concentration variant and the characteristics of the wastewater in Bukit Semarang Baru Housing serves as the low concentration variant, whereas the medium concentration variant is estimated by using the midpoint between the low and the high concentrations.

The UASB reactor has a volume of 1 L with a diameter of 8 cm and height of 30 cm. This research utilized a total of 9 reactors, and each reactor was operated at a different concentration and upflow velocity. Artificially prepared wastewater was used for treatment made from treated wastewater using artificial wastewater was made from distilled water, glucose, and kaolin. Trial and error approach is adapted to obtain the desired concentration variation. The upflow velocity is regulated through a valve and a gravity transmission system. Upflow velocities of 2.5 L/hour, 1.67 L/hour, and 1.25 L/hour

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were used which were converted into m/s then. The details of all reactors are shown in Table-2.

**Table-1.** Domestic wastewater characteristic of Gabahan village and BSB housing, Semarang.

| No. | Parameter | Unit | Gabahan village | BSB housing |
|---|---|---|---|---|
| 1 | COD | mg/l | 1673 | 865 |
| 4 | pH | - | 7.13 | 7.68 |
| 5 | Temperature | °C | 27.11 | 27.05 |
| 6 | DO | mg/l | 0.54 | 4.61 |

The reactors' operation was divided in 2 stages: the acclimatization stage and the running stage. Acclimatization stage was further subdivided as acclimatization stage with 50% of targeted concentration, and acclimatization stage with 100% of targeted concentration. The acclimatization stage was initialized with the 50% of targeted concentration into the reactor to prevent shock loading, as the COD removal efficiency became stable, the concentration was increased to 100%.

**Table-2.** UASB reactor details.

| No. | Reactor | Concentration | HRT | Vup | |
|---|---|---|---|---|---|
| | | | hour | m/hour | m/s |
| 1 | R4 | Low | 4 | 0.05 | $1.39x10^{-5}$ |
| 2 | R6 | Low | 6 | 0.033 | $9.17x10^{-6}$ |
| 3 | R8 | Low | 8 | 0.025 | $6.94x10^{-6}$ |
| 4 | S4 | Medium | 4 | 0.05 | $1.39x10^{-5}$ |
| 5 | S6 | Medium | 6 | 0033 | $9.17x10^{-6}$ |
| 6 | S8 | Medium | 8 | 0.025 | $6.94x10^{-6}$ |
| 7 | T4 | High | 4 | 0.05 | $1.39x10^{-5}$ |
| 8 | T6 | High | 6 | 0.033 | $9.17x10^{-6}$ |
| 9 | T8 | High | 8 | 0.025 | $6.94x10^{-6}$ |

## RESULTS AND DISCUSSIONS

In this research, the upflow velocity was regulated by using a valve to maintain a preset upflow velocity. Wastewater was directly flowed into the effluent tank using gravity system, where a relatively higher flowrate occurs. To overcome this, equalization basin was added between the influent tank and the reactor, so that the wastewater from the influent tank entered the equalization basin which was equipped with mixer to produce homogeneousness in the artificial wastewater, before being flowed into the reactor. The introduction of the equalization basin did not produce any significant effects on the flowrate fluctuations procured from the reactor. Fluctuations were observed in the upflow velocity, but not as much as the previous fluctuations.

### Acclimatization stage with 50% of targeted concentration

In this stage, the influent COD concentration used was about 50% of the concentration of the domestic wastewater characteristics test. The reactors were set as R4, R6, and R8 using a low concentration; reactors S4, S5 and S6 using a medium concentration; while the reactors T7, T8, and T9 using a high concentration. The concentration variations are shown in Table-3. The effluent COD removal in the 50% acclimatization stage is shown in Figure-1.

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**Table-3.** Concentration of Artificial Wastewater in Acclimatization Stage.

| No. | Variation of concentration | COD Concentration (mg/l) | |
|---|---|---|---|
| | | **50 %** | **100 %** |
| 1 | Low | 478 | 878 |
| 2 | Medium | 602 | 1345 |
| 3 | High | 870 | 1623 |

In Figure-1 (a), the highest COD allowance efficiency occurred at reactor R8 with an efficiency of 70% on day 7. In Figure-1 (b), the highest removal efficiency occurred at reactor S6 with an efficiency of 48% on day 2. In Figure-1(c), the highest COD allowance efficiency occurred at reactor T8 with an efficiency of 54% on day 4.

The occurrence of highest allowance at reactors R8 (low concentration) and T8 (high concentration) was due to the comparatively lower upflow velocity than reactors R4, R6, T4, and T6. The lower upflow velocity produced longer hydraulic retention time (HRT), allowing the bacteria to grow and degrade the wastewater, resulting in higher allowance efficiency. This is consistent with the research conducted by Nugrahini *et al.* [4] that the longer retention time allows longer contact of the anaerobic sludge and the wastewater, in which the COD degradation will also be better.

According to Lew *et al.* [5], the COD allowance increases with increasing retention time. On day 3, the COD removal efficiency decreased at every reactor. This was caused by the flowrate fluctuation and the decrease in pH. In anaerobic reactor, the methane-producing microorganisms can work at pH values of 6.5-7.5 [6].

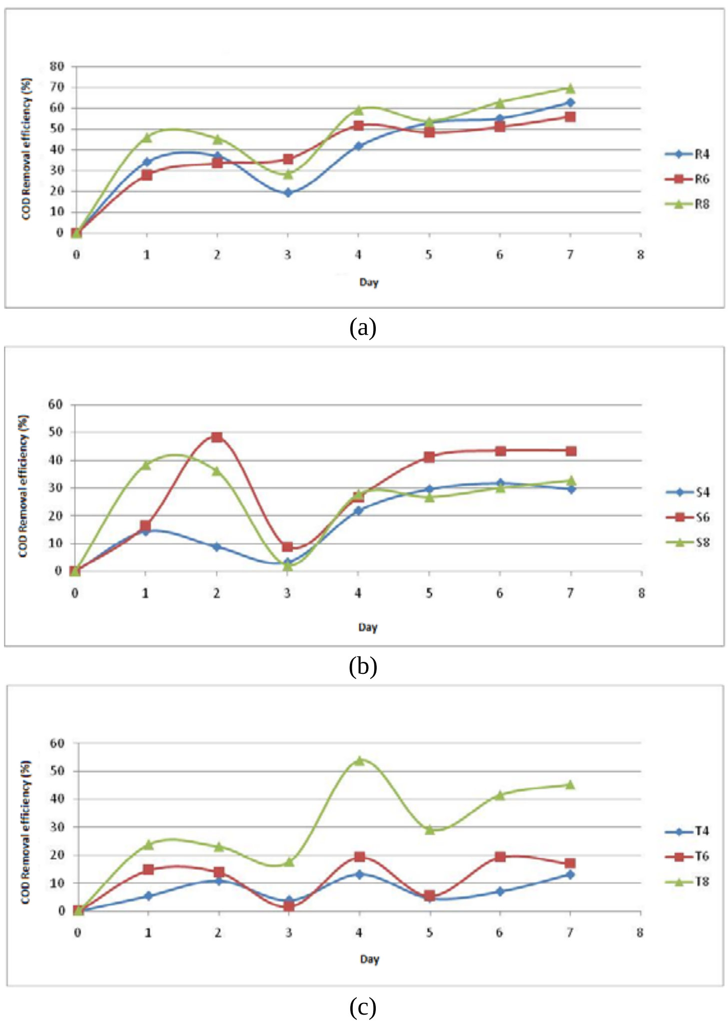



**Figure-1.** COD removal efficiency at acclimatization stage 50 % at (a) Low concentration (b) Medium concentration (c) High concentration.

During this stage, the stable pH ranged from 6.93-7.16. This shows that each reactor reached the normal pH value of 7.0. According to Tchobanoglous *et al.* [7], the wastewater can be properly treated at pH values in the range of 6.5-7.5. Generally, the COD removal efficiency at the early stages of 50% acclimatization stage was still low. However, the COD removal efficiency increased with increasing operation time. The stability of the acclimatization stage usually occurred on day 4, where the COD concentration value allowance had been similar. The stability of the microorganisms in the reactor was achieved after a short period of 4 days, while the anaerobic reactor requires longer time (about 3 months) to obtain the stability in which the UASB reactor performance will be shown in running stage. According to Al-Shayah *et al.* [8], reactor stability in COD allowance can be obtained with the passage of time.

The COD removal efficiency of low concentration was higher than the medium and high concentrations, for COD removal efficiency over the 4 days period in the 50% acclimatization stage. This is consistent with the results of the research conducted by Syafila *et al.* [9] where increasing the COD concentration caused decrease in the COD removal efficiency.

Increasing of COD concentration might trigger volatile acids and acidogenesis condition. This condition affected the ability of the methanogenic bacteria to perfectly conduct the methanogenesis; as a result the product of acidogenesis process was converted into methane and led to the reduction of COD allowance. However, this research did not measure the total amount of the methane gas.

**Acclimatization stage with 100% of targeted concentration**

In this stage, the influent COD concentration used was about 100% of the concentration of the domestic wastewater tested. Table-3 shows the concentration variations. Figure-2 shows the effluent COD removal in the 50% acclimatization stage.

The highest COD removal efficiency occurred in reactor R8 with an efficiency of 65% on day 3, as Figure-2 (a) shows. In Figure-2 (b), the highest removal efficiency occurred in reactor S8 with an efficiency of 89% on day 4. In Figure-2(c), the highest COD removal efficiency occurred in reactor T8 with an efficiency of 79% on day 4. The highest removal efficiency at varying concentrations occurred at reactor with the lowest upflow velocity and 8 hours HRT, that shows that the lower the upflow velocity, the higher the COD concentration. This is consistent with the results of the research conducted by Nugrahini *et al.* [4], which explained that the longer retention time (HRT) allows for longer contact between the anaerobic sludge and the wastewater, causing better waste degradation. According to Lew *et al.* [5], COD removal increases with the increasing retention time.

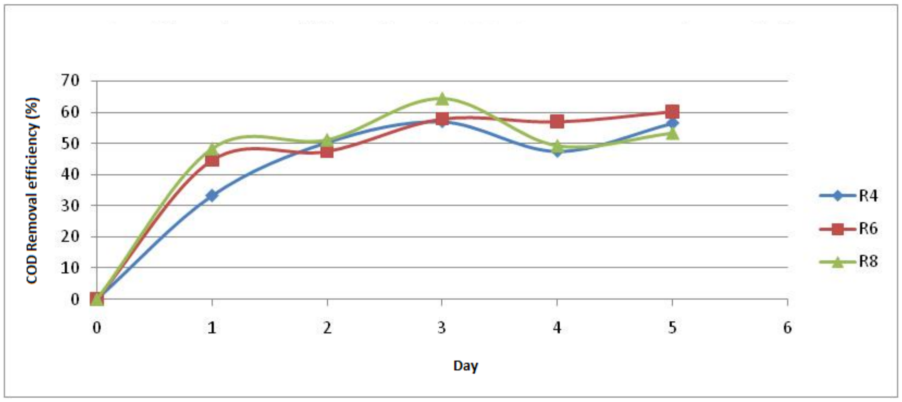
On day 1, pH value decreased in all the reactors. This is because the influent COD concentration increased from 50% to 100%. The pH value decrease in every reactor indicated that the acids formation by bacteria (acidogenesis and acetogenesis) occurred. Acidogenic and acetogenic activity increased with the increasing influent COD concentration, increased volatile fatty acid contents in the reactor and the decreased pH of water. A significantly decreased pH value can obstruct the microorganisms' ability to produce methane. However, the total methane gas has not been measured in this research.

According to Tchobanoglous *et al.* [7] optimal production of methane by microorganisms can occur at pH 6.5-7.5 [6] and required the least pH of 6.2 [10]. In this case, the pH range from 6.25-7.5, indicated that the methanogenesis process occurred and anaerobic digestion was held at the reactors, indicated by increased COD removal on day 1 until day 5 during acclimatization. However, at reactor S8, the pH on day 1 reached 5.63, causing decreased COD removal to be only 107 mg/l.

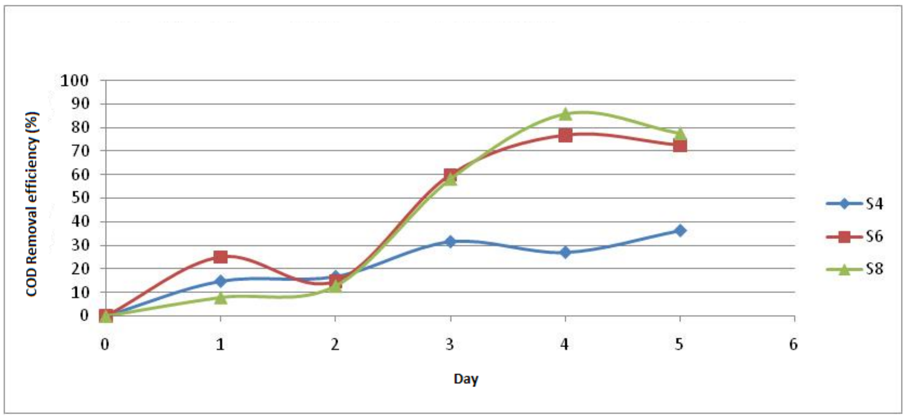
COD allowance at reactors R4, R6, R8, and S4 increased without any significant changes, thus in Figure-2, the line is not too sharp. Conversely, significant increase on day 4 was observed at reactors S6, S8, T4, T6, and T8. Generally, this is because the flowrate in reactors S6, S8, T4, T6, and T8 fluctuates. The flowrate fluctuations were not only caused by the inlet blockage at the reactor by biomass, but also because the influent flowed by gravity system under low pressure and flowrate, thus wastewater was not flowed to the reactor as targeted.

**Performance comparison of acclimatization stage 50% and 100%**

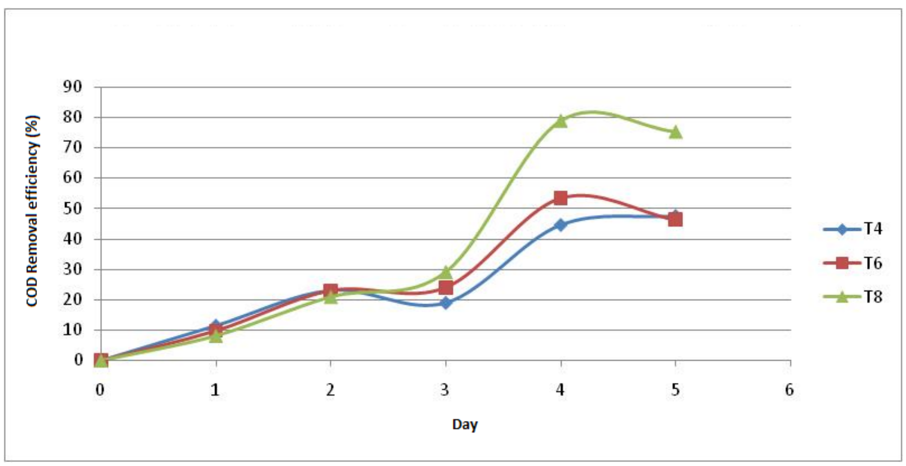
The initial concentration (influent) of 50% acclimatization stage at high concentration had similar value as the influent concentration of 100% acclimatization stage at low concentration; the values were 870 mg/l and 878 mg/l consecutively. Reactors R4, R6, and R8 at 100% acclimatization stage had the same upflow velocity, HRT, and concentration as the reactors T4, T6, T8 at 50% acclimatization stage. Both conditions produced different results, though the treated concentration are the same. Figure-3 provided the comparison performance of UASB reactor.




(a)




(b)




(c)

**Figure-2.** COD removal efficiency at Acclimatization stage (a) Low concentration (b) Medium concentration (c) High concentration.

Figure-3 shows comparison between the COD removal of 50% and 100% acclimatization at 4 hours, 6 hours and 8 hours HRT with almost equal influent COD concentrations. Figure-3 (a) shows that the COD allowance was higher at reactor R4 of 100% acclimatization. Figure-3 (b) implies higher COD

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allowance at reactor R8 of 100% acclimatization. Figure-3 (c) indicates that at reactor R4 of 100% acclimatization, the COD removal was higher. These results show that the COD allowance obtained from the reactors was higher at 100% than the 50% acclimatization stage. The reason behind this observation is that at 50% acclimatization stage, only some COD was degraded as the reactor microorganisms were still adapting; while the adaptation, growth and degradation of substrates as nutrients by microorganisms had occurred at 100% acclimatization stage, causing larger COD degradation.

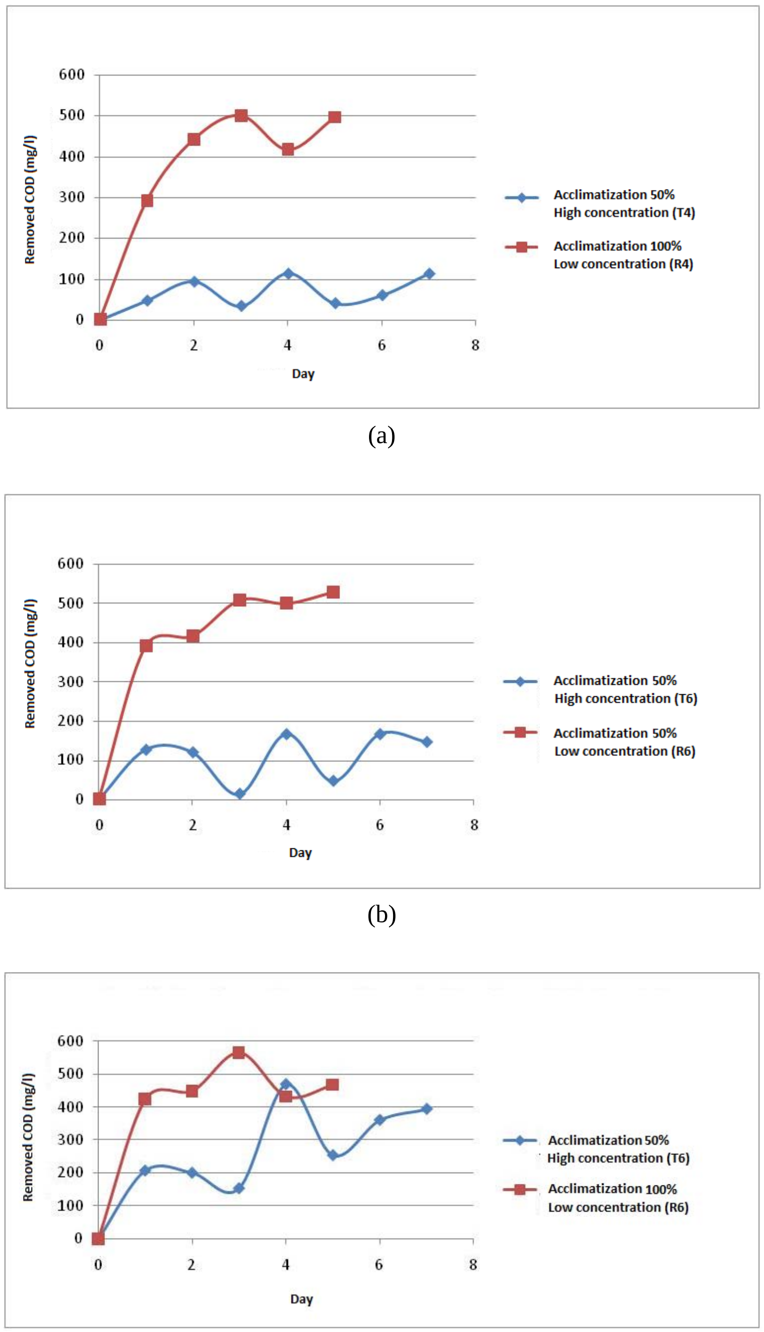


**Figure-3.** Performance comparison of Acclimatization stage in the UASB reactor (a) Reactor R4 and T4 (b) Reactor R6 and T6 (c) Reactor R8 and T8.

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**Running stage**

The next stage was the running stage, where UASB reactor performance in treating COD was assessed after 100% acclimatization. Running stage was conducted in 20 days. Effluent values were taken every three days to obtain the COD allowance value. The COD concentration is shown in Table-4.

**Table-4.** Influent concentration on running stage.

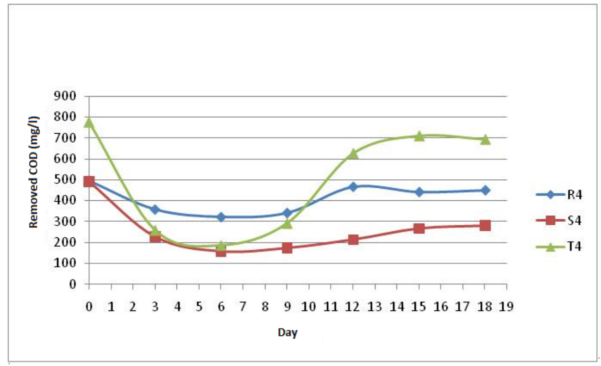
| No. | Variation of concentration | COD concentration (mg/l) |
|---|---|---|
| 1 | Low | 878 |
| 2 | Medium | 1345 |
| 3 | High | 1623 |

**COD removal**

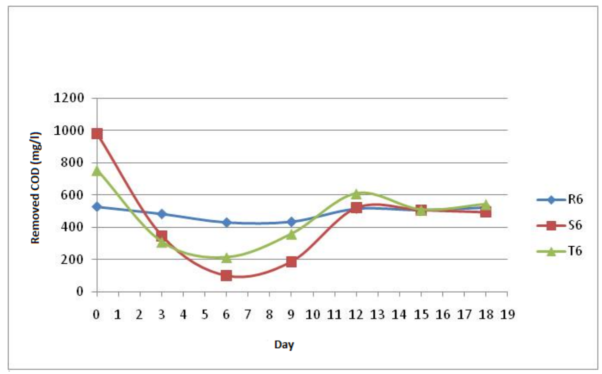
Because COD measurements were conducted in acclimatization stage, the allowance graph on day 0 using recent acclimatization data is a continuation of acclimatization stage. The effect of concentration variation on COD removal is shown in Figure-4.

As per Figure-4, COD removal efficiency decreased in almost all the reactors. On day 0 as the end point of 100% acclimatization, the COD removal efficiency was quite high; however, it sharply declined in the medium concentration and the high concentration reactors. The removal efficiency was least affected by the decline in pH values. If the first day pH value is compared with that at the last day of acclimatization, generally the decrease in the pH occurred in all reactors. This caused a reduction in the efficiency, though the treated COD concentrations in acclimatization were the same.

At the same flowrate and HRT, different influent concentrations led to different results. Figure-4 shows that COD allowance was fairly stable for low concentration of reactor than the medium and high concentrations; it shows that the concentration variation affects the UASB reactor performance. These results are consistent with the findings by Aslan and Sekerdag [11] that concentration variations influence COD allowance levels. Davis [12] received lower effluent concentration than other researchers by using higher influent concentration. And Suriadi [13] stated that the greater the COD concentration that flows into reactor, the greater the COD allowance.




(a)

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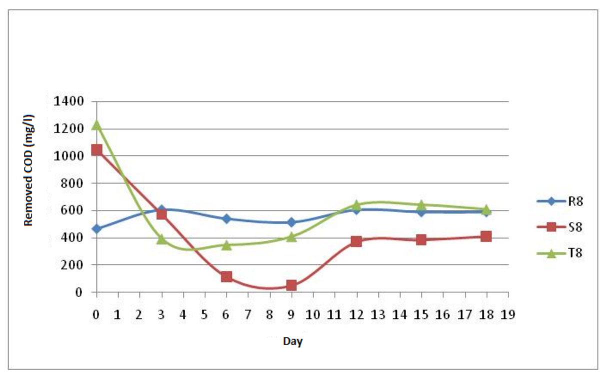
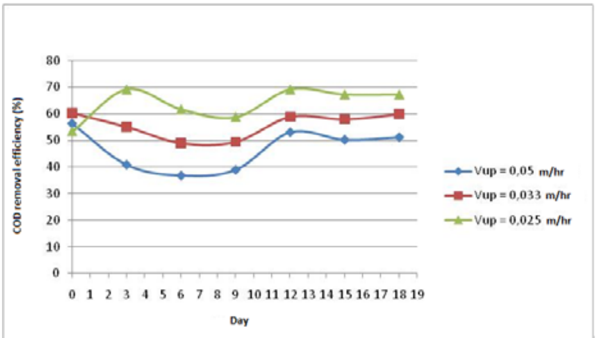


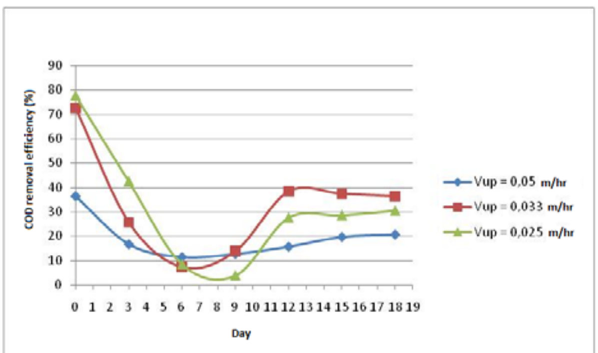

(c)

**Figure-4.** Effect of concentration variation on COD Removal (a) Reactors R4, S4, T4 (b) Reactors R6, S6, T6 (c) Reactors R8, S8, T8.

On the other hand, in the applied varying upflow velocities with low influent concentrations (Figure-5(a)), the greatest COD removal efficiency occurred at reactor R8 with an upflow efficiency of 0.025 m/hour which was the lowest upflow velocity in this research. The highest COD removal sequentially occurred at an upflow velocity of 0.025 m/hour, followed by 0.033 m/hour, and the lowest at 0.05 m/hour. As the upflow velocity declined, retention time in the reactor became longer, thus giving more time for microorganisms to cause COD degradation, producing better effluent. This is consistent with the research conducted by Ali *et al.* [14] and Nugrahini *et al.* [4] which showed that if the substrate and biomass interact for a longer period, the organic matter will be better degraded.




(a)

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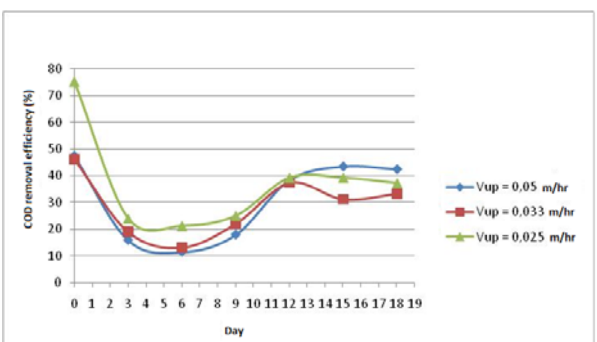


(c)

**Figure-5.** Effect of upflow velocity on COD removal at (a) Low concentration (b) Medium concentration (c) High concentration.

Meanwhile, at medium influent concentrations (Figure-5(b)), the greater removal efficiency occurred at reactor S6 with 0.033 m/hour as upflow velocity, then at reactor S8 with 0.025 m/hour, and the lowest efficiency occurred at reactor S4 with 0.05 m/hour. COD removal efficiency was lower at the first and the second day of experiment than the removal efficiency on the last day of the experiment when the reactors R6 and R8 reached 100% acclimatization. Conversely, the removal efficiency reduction was not large at reactor R4; probably as the removal efficiency on the last day of 100% acclimatization was also not very high. Inlet blockage at the reactor could have been responsible for reduction of removal efficiency. As the influent flowing systems is a gravity flow system, water pressure might not be large enough to flow it into the reactor, so the upflow velocity became smaller than targeted and good contact between the biomass and substrate in the reactor did not occur. Ali [14] states that the velocity reduction can reduce the mixing between biomass and substrate.

UASB reactor performance in COD reduction at variation of high influent concentration is shown in Figure-5. A substantial reduction of COD removal efficiency from the removal efficiency at 100% acclimatization occurred during the first sampling. At the second sampling, removal efficiency decreased without any significant change, and then the COD removal efficiency increased until the last sampling. The same thing happened in the medium concentration reactor, reduction of removal efficiency could have occurred due to the inlet blockage by biomass. Due to the influent flowing systems being a gravity flow system, the upflow velocity became smaller than targeted because of low water pressure and improper contact could have occurred in the reactor between the biomass and substrate. The highest removal efficiency occurred at reactor T4 with an upflow velocity of 0.05 m/hour, causing reactor T4 HRT to be shorter than reactors T6 and T8 as the influent spread evenly throughout the reactor cross-section due to the high upflow velocity. Those are the most important operational parameters that affect the UASB reactor performance [15]. Yasar and Tabinda [16] stated that the high upflow velocity causes good contact between biomass and substrate and increases reactor removal efficiency.

**Comparison between effluent and quality standard**

In Table-5, the results of the domestic wastewater treatment using UASB reactor have been compiled. It shows that the quality standard was not met the standard for domestic waste water released by Ministry of Environmental of Indonesia [17] and threshold limit defined by The Government of Central Java Province [18], thus further processing is required before discharging to the environment.

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**Table-5.** Comparison between effluent and quality standard.

| No. | Concentration | Influent concentration (mg/l) | Quality standard (mg/l) | | Remarks |
|---|---|---|---|---|---|
| | | | Ministry of Environmental of Indonesia | The Government of Central Java Province | |
| 1 | Low | 102 | 100 | 30 | Unacceptable |
| | | 270 | - | 50 | Unacceptable |
| | | 240 | 100 | 50 | Unacceptable |
| 2 | Medium | 256 | 100 | 30 | Unacceptable |
| | | 779 | - | 50 | Unacceptable |
| | | 340 | 100 | 50 | Unacceptable |
| 3 | High | 411 | 100 | 30 | Unacceptable |
| | | 923 | - | 50 | Unacceptable |
| | | 370 | 100 | 50 | Unacceptable |

## CONCLUSIONS

In the process of domestic wastewater treatment using UASB reactor, the maximum COD removal efficiency value obtained was 69%. The following points were drawn from the variation of the upflow velocity and the influent concentration:

a) The COD allowance value increased with the higher influent concentration. The influent concentration used was COD of 1623 mg/l.
b) Overall, the reactor with upflow velocity of 0.025 m/h ($6.94 \times 10^{-5}$ m/s) was found to be relatively better than the reactors with the other upflow velocity variations. This means that the slower upflow velocity allows more time for the microorganisms to decompose the substrate in the wastewater, resulting in higher value of the removal efficiency obtained.
c) Fluctuations of removal efficiency can be identified from a few things. Reduction of the COD removal efficiency marked by a decrease in the pH value tending towards acid. This is because the organic matter was decomposed into volatile acids, thus pH value dropped, this could have obstructed the methanogenesis causing decreased the removal efficiency. If the COD removal efficiency is good, pH value tends towards normal.
d) The results of UASB reactor treatment did not meet the quality standards released by Ministry of Environmental of Indonesia and The Government of Central Java Province and require further processing.

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