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Original Research Paper

Application of UASB Reactor to Reduce the Concentration of BOD, COD and Phosphate in the Domestic Waste

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ABSTRACT

Pilot scale studies were conducted to investigate the contribution of the flow rate and the influence of the concentration on the function of upflow anaerobic sludge blanket (UASB) reactor in wastewater treatment of domestic greywater. In this study, the flowrates used were 2.5 L/hr, 1.67 L/hr, and 1.25 L/hr. On varying the concentration, the optimum processing conditions were obtained in the reactor with a high concentration for the efficiency reduction of biochemical oxygen demand (BOD) and chemical oxygen demand (COD) as 1440 mg/L for the COD and 667.8 mg/L for the BOD, with an average reduction of 84.15% for BOD and 76.32% for COD. Optimum efficiency of phosphate reduction was obtained in the reactor with the concentration being 0.3843 mg/L with an average value of 72.58%. In general, the optimum conditions were obtained at the lowest flow rate of 1.25 L/hr for all the parameters and the efficiency decreased with the average values of 83.32% for BOD, 73.31% for COD and 71.24% for the phosphate. The optimum values for the organic loading rate (OLR) of greywater was 8.71 kgCOD/m^3.day with the optimum condition for the UASB reactor observed at the highest flow rate of 2.5 L/hr, the highest concentration 1440 mg/L COD at the hydraulic retention time of 4 hours, with an upflow velocity of 0.051 m/hour and temperature of 35°C.

INTRODUCTION

According to the Decree of Ministry of Environment (2003), domestic waste can be divided into two categories: wastewater from latrines or toilets is termed as faecal water or black water and domestic wastewater from washing and bathing water and non-outhouse kitchen waste is called grey water. Black water and grey water have different properties and thus require different treatment methods. Greywater forms approximately 75% of the domestic wastewater's volume (Eriksson et al. 2002). Generally, greywater contains high biochemical oxygen demand (BOD), chemical oxygen demand (COD) and phosphate (PO_4). Reduction of high phosphate concentrations is needed to avoid excessive algal growth in the receiving water bodies. Excessive algal growth can result in low dissolved oxygen that can cause anaerobic conditions in water bodies, which may lead to noxious odours.

According to Tchobanoglous et al. (2003), the higher the value of BOD, the more will be the organic matter. COD is also one of the key parameters used to detect the level of water pollution. The existing water quality gets worse with higher value of COD (Alaerts & Santika 1984). However, the conventional practice in developing countries is to only perform blackwater treatment where the blackwater usually enters septic tanks, while the greywater is discharged through drainage channels to a nearby water body without treatment. Therefore, an appropriate greywater treatment method is needed to reduce the contents and ensure that the greywater does not pollute the environment.

One of the greywater treatment procedures is through the use of a reactor namely upflow anaerobic sludge blanket (UASB). A UASB reactor has the ability to treat wastewater with high organic load rate and is tolerant to shock loads. In a UASB reactor, the wastewater flows upwards through a sludge blanket where the organic matter biodegradation processes occur. Various concentrations, flow rates, and hydraulic retention time were employed for the determination of BOD, COD and phosphate reduction. Moreover, optimum values of BOD, COD and phosphate with respect to various concentrations, flow rates and retention time can be known. In addition, after proper greywater treatment, environmental pollution can be mitigated as the greywater entering the water body will meet the applicable water quality standards.

Therefore, the purpose of this study is to investigate the reduction of BOD, COD and phosphate under the influence of different concentrations and flow rates on the function of a UASB reactor in wastewater treatment of domestic greywater. This study also analyses the effect of concentration and flow rate variation on BOD, COD and phosphate reduction and to obtain optimum conditions of concentration and flow rate in greywater treatment by UASB reactor.

MATERIALS AND METHODS

Sludge blanket and artificial wastewater were used in this study. Sludge blanket consists of a mixture of water and mud obtained from the sedimentation basin of a pharmaceutical manufacturer called P T. Kimia FarmaTbk. Sludge conditioning was conducted before introducing it into the reactor. Each of UASB reactor was filled with 3.5 L of mud and mixed with water (± 5 L). The additional water was added during the making of sludge blanket due to mud viscosity. The influent artificial wastewater materials used were tapioca and phosphate standard solution (50 ppm) which represents PO_4 contaminant, while tapioca acts as a pollutant for BOD and COD.

Influent tank, storage tank and UASB reactor were used in this experiment. The influent tank was made from a drum with a diameter of 58 cm and 85 cm height and working volume of 200 L. The storage tank had a volume of 150 L with the height of wastewater level at 57 cm. This storage tank was also equipped with a ball valve that served to regulate the flow rate entering the UASB reactor. The UASB reactor used in this study was a tubular shape reactor with a diameter of 25 cm and 35 cm height with the mud volume as 35% of the waste volume. The turbulent flow in the reactor must be established to ensure that the turbulent flow is in accordance with the value of Reynold's number, so that the maximum work can be obtained.

This research was performed in three stages: seeding stage, acclimatization stage and implementation stage. Seeding stage was conducted to grow anaerobic microorganisms. In this study, seeding was conducted in batch system using sludge found at the bottom of the PT. Kimia Farma sedimentation tank and water and anaerobic bacterial cultures were obtained from the septic tank. Microorganisms require certain nutrients such as carbon (C), nitrogen (N) and phosphorus (P) for growth. In addition to carbon, trace amounts of glucose, urea nitrogen and phosphate (SP-36) were given after every three days. The C:N:P nutrient ratio of approximately 350:7:1 was maintained. The seeding stage formed a biofilm covering the top layer of the reactor, which caused a strong odour and also showed sizable and stable COD reduction. It can be continued to the acclimatization stage.

Acclimatization stage is a process in which the microorganisms adjust to a gradual change, allowing it to maintain performance across a range of environmental conditions. This study used the UASB reactor for acclimatization. Adaptation was achieved through the use of artificial wastewater with the smallest COD value, and the end of acclimatization stage was marked when the efficiency reduction of COD concentrations was quite high and stable.

Table 1: Stages of acclimatization process.

Variation of COD Concentration	Stages	COD in waste water during acclimatization
520 mg/L	Stage I = 25% × 520mg/L	130mg/L
	Stage II = 50% × 520mg/L	260mg/L
	Stage III = 75% × 520mg/L	390mg/L
	Stage IV = 100% × 520mg/L	520mg/L
986.67 mg/L	Stage I = 25% × 520mg/L	246.67mg/L
	Stage II = 50% × 520mg/L	493.33mg/L
	Stage III = 75% × 520mg/L	740mg/L
	Stage IV = 100% × 520mg/L	986.67mg/L
1440 mg/L	Stage I = 25% × 520mg/L	360mg/L
	Stage II = 50% × 520mg/L	720mg/L
	Stage III = 75% × 520mg/L	1080mg/L
	Stage IV = 100% × 520mg/L	1440mg/L

The implementation stage of research was conducted on the laboratory scale with 10 L of the total anaerobic reactor volume capacity. The UASB reactor ran at 4 hrs, 6 hrs and 8 hrs HRT for one cycle. Sludge volume was about 35% of the total volume in the UASB reactor after which the running phase was conducted and a sample was taken. The sample was taken after the reactor condition had stabilized. The steady state was determined by measuring the COD contents in each reactor and watched until the reduction of COD concentration had stabilized.

RESULT AND DISCUSSION

Seeding stage: Seeding stage was performed in accordance with a seven day physical monitoring at the beginning of the process. UASB reactor formed a biofilm causing a strong odour. It showed that the initial process of microorganism growth and biofilm formation in the media needed a certain amount of time, this process is known as the maturation process (Herlambang 2002). Seeding stopped after the COD reduction was stable and had reached high efficiency. Generally, organic compounds in the wastewater can be decomposed by microorganisms. The decomposition process can be quicker and more effective in breaking the pollutants present in the wastewater with the growth of microorganisms.

On day 5^{th}, the COD removal efficiency decreased by approximately 14-60% with an average of 41.31%. From day 7 to day 38, no significant change in the COD removal performances was observed and the removal was around 50-69%. However, different results were observed on the 40^{th} day, as the COD removal efficiency reached 74-76%. This was due to the addition of anaerobic bacterial culture from the septic tank on the 38^{th} day. The presence of strong

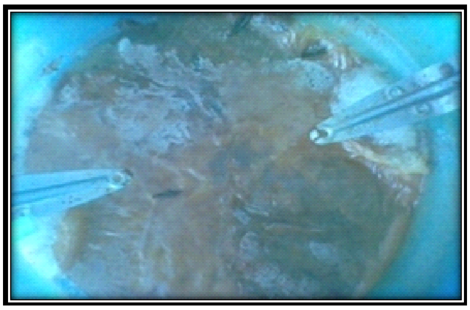

Fig. 1: Sludge blanket after 5 weeks monitoring.

odour and gas bubbles on the surface of the reactor showed that the seeding stage had reached an advanced stage of progression. The seeding stage proceeded for 42 days as the biofilm started to get thicker and the COD removal efficiency also increased and reached 76-78% on day 42.

Artificial wastewater: This research was conducted using three various flow rates and three pollutant concentration variations. In the acclimatization stage, artificial wastewater was prepared with twelve different concentrations. For each concentration, variations were made as approximately 25%, 50%, 75% and 100% of those in the original waste concentration. However, the running stage only used the concentration variation of 100%.

Acclimatization stage: The end point of acclimatization was reached when the COD removal efficiencies became quite stable. During the acclimatization stage, stable pH and dissolved oxygen (DO) approached the zero limit and the organic efficiency gradually increased. The DO in the initial acclimatization process ranged from 1 to 1.5 and in final stage ranged from 0 to 0.5. Bacteria adjusted to the gradual environmental changes such as pH and temperature, with pH at ± 7 and temperature from 26°C-35°C. According to Tchobanoglous et al. (2003), bacteria can live and multiply optimally at a temperature range of 25°C-35°C and pH in the range of 6.5-7.5, while the UASB efficiency ranges from 70%-73%. After the efficiency of the anaerobic treatment process had stabilized and showed significant decrease, the running stage continued. Acclimatization results are shown in Fig. 2.

The results showed that various concentrations and flow rates did not produce significant variations. However, at Q= 2.5 L/hr, performances became quite stabilized and the optimum COD removal efficiency occurred faster compared with Q=1.67 L/hr and Q=1.25 L/hr. The reason for this observation was that for the higher flow rate, the higher upflow velocity occurred. This implies that the contractions between the wastewater and sludge blanket increased. As an increasing flow rate allowed the microorganisms to get a better substrate supply than efficiency low flow rate, the bacterial activity increased more rapidly than the reactor with the lower flow rate. Thus, it can be concluded that the 4 hours duration was sufficient for the bacteria to decompose the organic compounds. This statement can further be connected with the fact that the hydraulic retention time (HRT) of more than 6 hours could decrease the concentration of substrate fermentation (Lettinga & Pol 1991). However, if the flow rate was too high, the sludge would have passed through and come out along with the effluent so that the sludge volume inside the reactor would have decreased and reduce the reactor performances, which can also be a cause for concern.

BOD concentration removal: In Fig. 3, it can be seen that the efficiency of BOD removal fairly stabilized. The BOD removal efficiency at 667.80 mg/L of concentration and 0.00035 L/s of flow rate exhibited an average value of 84.62%. Efficiency removal of biodegradable COD was generally in the excess of 85% or even reached 90%. The biodegradable COD is sometimes reflected in the parameter of BOD. This showed that the bacteria activity got better with greater substrate supply as the bacteria released enzymes that oxidized the organic compounds in the organic matter (Gerardi 2006).

In Fig. 3, BOD removal efficiency was stable at various flow rates as the load increments were not high. This means that the retention time did not affect the running process significantly due to the inoccurrence of organic shock loading, but also due to the adaptation of the microorganisms during the acclimatization stage (Kristaufan et al. 2010). Moreover, according to the research results, the optimum flow rate occurred at the smallest flow rate of 1.25 L/hr with 8 hours of retention time. The value further decreased with the longer retention time as the long retention time allowed the microorganisms to break the organic compounds in wastewater.

Reduction of COD concentration: The optimum processing conditions were obtained in the reactor with a large concentration parameter for the efficiency reduction of COD (1440 mg/L COD) and 0.00035 L/s of flow rate with an average of 75.16%, as displayed in Fig. 4. This is consistent with the research conducted by Sperling et al. (2001), where the COD removal efficiency by UASB reactor was observed to be in the range of 69-84%. Furthermore, the greater the occurrence of COD concentration, the more stable was the running process. This was because with the occurrence of greater COD concentration, the percentage of organic compounds also increased, which resulted in a better ability of the bacteria to break the organic compounds during the degradation process or diffusion process.

Both COD and BOD removal efficiencies stabilized at various flow rates. As the longer retention time allowed more

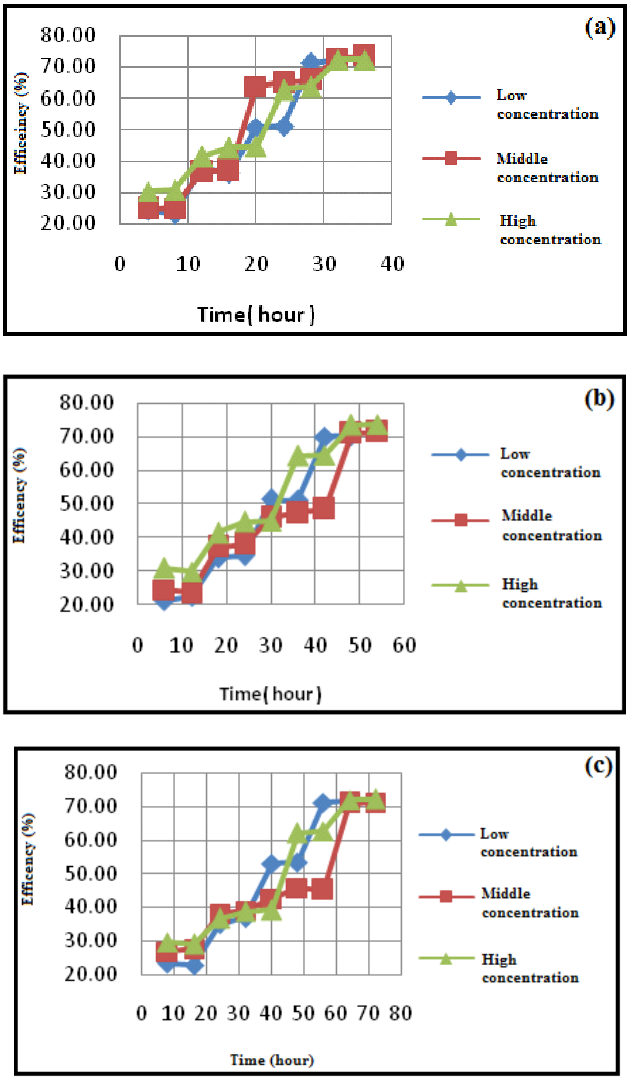

Fig. 2: COD removal efficiency during an acclimatization stage at (a) Q = 2.5 L/hour, (b) Q = 1.67 L/hour and (c) Q = 1.25 L/hour.

time for the bacteria to decompose the organic compounds in wastewater, the BOD value decreased with the extending retention time. The optimum condition occurred at the smallest flow rate of 1.25 L/hr with 8 hours of retention time.

Phosphate removal efficiency: Fig. 5 illustrates that the optimum processing conditions were obtained in the reactor with a large concentration parameter of 0.3843 mg/L for the efficiency reduction of phosphate and flow rate of 0.00035 L/s with an average value of 75%. Sundstrom & Klei (1979) have found that carbon, nitrogen and phosphorus contents are required for new cell syntheses, metabolism, and preliminary treatment of organic matter. Moreover, phosphate is needed for microbial growth and storage of phosphate intra-cellularly as polyphosphate (Cahyana & Haryanto 2006). However, the balance of food (organic matter) in wastewater must be maintained to preserve its digestive system. Setiawan et al. (2008) have recommended a nutrients ratio or C:N:P ratio of 350:7:1 for microbial growth.

Table 2: Characteristics of artificial wastewater.

Variation	COD (mg/L)	BOD (mg/L)	PO_4-P (mg/L)
Low Concentration	520	197.72	0.2795
Middle Concentration	986.67	375.16	0.3843
High Concentration	1440	547.53	0.4454

Table 3: Values of kinetic pollutant removal coefficients.

Parameter	Concentration (mg/L)	K
BOD	221.10	0.22
	461.10	0.23
	667.80	0.24
COD	520	0.17
	986.67	0.17
	1440	0.18
Phosphate	0.2795	0.12
	0.3843	0.17
	0.4454	0.16

Tchobanoglous & Burton (1991) have stated that the phosphate removal efficiency with secondary treatment is approximately in the range of 10-25%. This is inconsistent with this research, because the phosphate concentrations were lower than the C:N:P ratio. During anaerobic condition, precipitation might have occurred with the help of microbes. Phosphate precipitation and disposal could have occurred due to the microbial activity in the reactor. As stated by Bitton (2005), phosphate precipitation with the help of the microbes can also occur in the biofilm during the denitrification process. Water pH decreased during the initial stage of the reactor process due to the microbial activity, which caused the phosphate compounds to be dissolved. At the end of the operation, water pH increased which caused the precipitation and incorporation of phosphate compounds into the sludge and phosphate precipitation occurred in the denitrifying biofilm.

Generally, the phosphate removal efficiency influenced the flow rate variation. It can also be seen that lower the flow rate, the greater was the phosphate removal efficiency as retention time in the reactor increased with the lower flow rates. Furthermore, the phosphate effluent concentration decreased with longer detention time because long retention time allows the microorganisms to further break the organic matter and nutrients in the wastewater.

Relationship between BOD, COD and phosphate removal efficiency: The results exhibited that different observations were made for the three parameters of BOD, COD and phos-

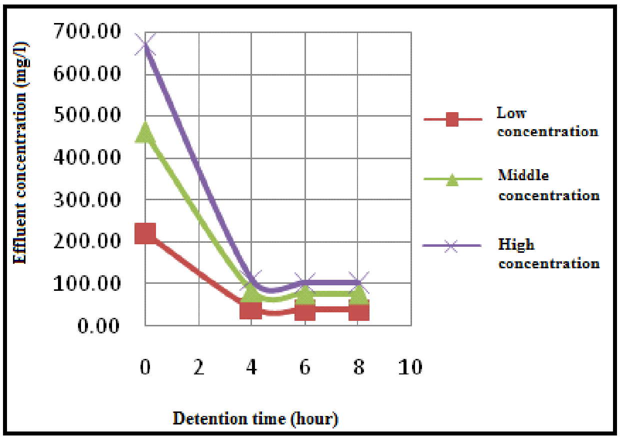

Fig. 3: BOD removal during running stage.

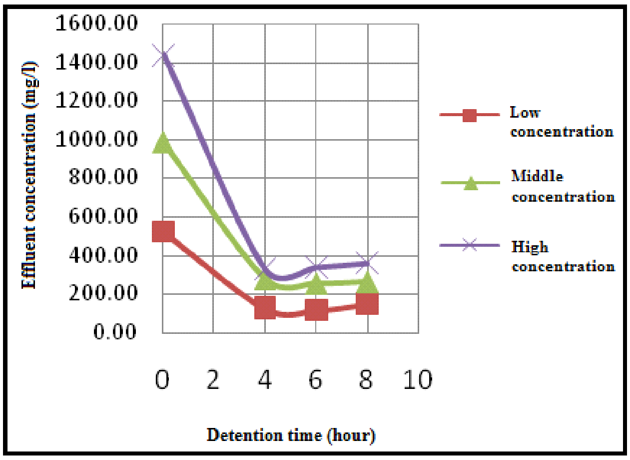

Fig. 4: COD removal during running stage.

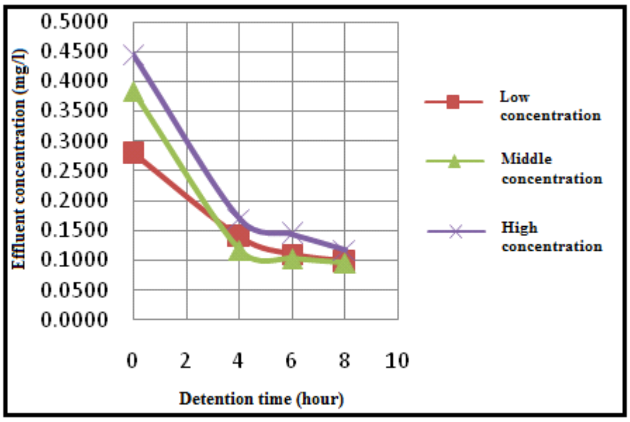

Fig. 5: Phosphate removal during running process.

phate removal efficiencies. The highest value was noted for the BOD removal efficiency compared to the COD and phosphate removal efficiencies. In this case with nutrients removal, phosphate was limited in supply for bacterial growth.

As stated earlier, the preliminary organic matter treatment requires carbon, nitrogen and phosphorus, the C:N:P nutrient ratio of approximately 350:7:1, this implies that phosphorus removal in the biological treatment has to be less than the carbon removal.

A tentative conclusion can be drawn that the average efficiencies of BOD, COD and phosphate in various concentrations with biological treatment using UASB, exhibited a high concentration optimum efficiency as 667.80 mg/L for BOD and 1440 mg/L of COD, whereas, in middle concentration was obtained as 0.3848 mg/L of Phosphate. The optimum conditions were obtained on the variation of flow rate 1.25 L/hr for all of the parameters.

Optimum reactor conditions: Considering that the research was conducted on the laboratory scale, with 10 litre of total reactor volume, the optimum conditions were obtained at the lowest flow rate of 1.25 L/hr. The highest COD concentration of 1440 mg/L occurred at the reactor with 4 hours of HRT, flow rate of 2.5 L/hr, upflow velocity of 0.051 m/hr, temperature of 35°C and organic loading rate of 4.35 kg COD/m^3/day.

Kinetic pollutant removal coefficients: In practice, the performance of wastewater treatment plants cannot be generalized as the treatment plant operation may vary. Kinetic pollutant removal coefficient values are required for UASB reactor design in wastewater treatment of domestic greywater so as to modify or improve the treatment process (Farzadkia et al. 2015). Pollutant removal coefficients are determined using a first order reaction rate as they have linear relationships with a single nutrient concentration. This is because the removal efficiency itself is influenced by time. In addition, the negative coefficient indicated the removal of pollutant concentration. The regression plot exhibits that the desired pollutant concentration can be planned by using the retention time and the influent concentration. Phosphate reduction constant was higher in the middle reactor because of the optimum phosphate removal efficiency in middle reactor, which was 0.3843 mg PO_4/L.

CONCLUSION

This laboratory scale research was performed to estimate the domestic greywater treatment performance of a UASB reactor through the employment of two controlling parameters, namely concentration variation and flow rates. Three different flow rates of 1.25 L/hr, 1.67 L/hr and 2.5 L/hr were used with varying concentrations. Based on the experimental setup, the following conclusions were drawn after conduction of the UASB treatment operation:

1. Optimum pollutant removal was obtained for flowrate of 1.25 L/hr for all the controlling parameters. On vary-

ing the concentration, the optimum processing conditions were obtained in the reactor with a middle concentration of 0.3843 mg/L PO_4 for phosphate removal efficiency and the reactor with the highest concentration for the efficiency reduction of BOD and COD at 1440 mg/L for COD and 667.80 mg/L for the BOD.

2. As the concentrations were varied, it was observed that the bacterial activity got better with a greater substrate supply as the bacteria released enzymes which oxidized the organic compounds in the organic matter. The balance of food (organic matter) in wastewater or the C:N:P ratio must be maintained to preserve its digestive system. Whereas, upon varying the flow rate, the longer the hydraulic retention time (HRT), the lower was the value as the long retention time allowed the microorganisms further time to break the organic compounds in the wastewater.
3. This research was conducted on a laboratory scale with 10 L of total reactor volume and the optimum condition was obtained at the highest flow rate of 2.5 L/hr. The highest COD concentration of 1440 mg/L occurred in the reactor with 4 hours of HRT, upflow velocity of 0.051 m/hour, temperature range of 30°-35°C and organic loading rate of 8.71 kg COD/m^3.day

REFERENCES

Alaerts, G. and Santika, S. 1984. Metoda Penelitian Air. Usaha Nasional: Surabaya (In Indonesian).

Bitton, Gabriel 2005. Wastewater Microbiology. John Wiley & Sons: New Jersey.

Cahyana, P.T. and Haryanto, B 2006. Pengaruh kadar amilosa terhadap permeabilitas film dari pati beras. Prosiding Seminar Nasional PATPI. Yogyakarta (In Indonesian).

Decree of Ministry of Environment 2003. Decree of Ministry of Environment, Number 112 Year 2003 concerning threshold limit of domestic waste, Jakarta (In Indonesian)

Eriksson, Eva, Karina Auffarth, Mogens Henze, and Anna Ledin 2002. Characteristics of grey wastewater. Urban Water, 4(1): 85-104.

Farzadkia, M., Ehrampush, M.H., Abouee Mehrizi, E., Sadeghi, S. Talebi, P. and Salehi, A. 2015. Investigating the efficiency and kinetic coefficients of nutrient removal in the subsurface artificial wetland of Yazd wastewater treatment plant. Environmental Health Engineering and Management Journal, 2(1): 23-30.

Gerardi, M.H. 2006. Wastewater Bacteria, 1st Edn. John Wiley and Sons: New York.

Herlambang, A. 2002. Teknologi Pengolahan Limbah Cair Industri Tahu. Pusat Pengkajian dan Penerapan Teknologi Lingkungan (BPPT) dan Badan Pengendalian Dampak Lingkungan Samarinda. Kalimantan Tengah (In Indonesian)

Kristaufan, J.P., Purwati, S. and Setaiwan, Y. 2010. Pengolahan air limbah industri Kertas Karton dengan up-flow anaerobic sludge blanket (UASB) dan Lumpur Aktif. Berita Selulosa, 45(1): 22-31 (In Indonesian)

Lettinga, G. and Pol, L.W.H. 1991. UASB process design for various types of wastewaters. Water Sci. Technol., 24: 87-107.

Setiawan, Yusup, Sri Purwanti, Rina S. Soetopo, and Kristaufana, J.P. 2008. Peningkatan efektivitas pengolahan air limbah proses pemutihan pulp dengan reaktor up-flow anaerobic sludge blanket (UASB) dan Lumpur aktif termobilisasi. Berita Selulosa, 43(2): 74-82 (In Indonesian)

Sperling, V., M, VH Freire, and CA de Lemos Chernicharo. 2001. Performance evaluation of a UASB-activated sludge system treating municipal wastewater. Water Science & Technology, 43(11): 323-328.

Sundstrom, Donald William and Herbert, E. Klei 1979. Wastewater Treatment: Prentice Hall.

Tchobanoglous, G., Burton, F.L., Stensel, H.D., Metcalf and Eddy 2003. Wastewater Engineering: Treatment and Reuse: McGraw-Hill.

Tchobanoglous, George and Franklin, L. Burton 1991. Wastewater engineering treatment, disposal and reuse. In: Wastewater Engineering Treatment, Disposal and Reuse. McGraw-Hill, Inc.