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Variations of Organic Loading Rate on Tofu Wastewater Degradation using Upflow Anaerobic Sludge Blanket Reactor by Modified Stover-Kincannon Model

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ABSTRACT

This research aims to examine the varians of organic loading rate (OLR) on degradation of tofu wastewater using the hybrid upflow anaerobic sludge blanket (hybrid UASB) reactor using the modified kinetic model of Stover Kincannon. This reactor was operated at OLRs variation of 1.5-12 kg COD m^{-3} d^{-1} and HRT of 12 - 24 hours for 328 days. Higher COD removal efficiency of 86.41% and biogas production of 7700 mL were achieved at OLR 4.8 kg COD m^{-3} d^{-1} and HRT 24 hours on 140 days. Modified Stover-Kincannon model was observed and matched data sets were obtained. The kinetic values of model obtained at HRT variations, the parameters K_B and μ_{max} were 3.7, 12.97, 2.42 mgL^{-1} d^{-1} and 0.59, 9.41, 0.014 mgL^{-1} d^{-1}, respectively. This model was a plot of the inverse of the removal rate, versus inverse of the total loading rate resulted in a straight line. It showed that the Stover-Kincannon Model is the rate of substrate removal was affected by the organic load rate (OLR) that flowed into the hybrid UASB reactor.

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1. INTRODUCTION

Many cases of industrial and domestic wastewater contain high COD, which should be treated in a wastewater treatment system before being discharged into water bodies. The wastewater treatment plant (WWTP) system is one of the most important factors influencing the improvement of environmental conditions. The excess sludge from the WWTP was referred to as sewage sludge, which was the main waste accounts for an average of 3% of the volume of treated wastewater [1, 2]. Tofu industry wastewater is one of the liquid wastes that has a high organic load content, one of which has a high concentration of chemical oxygen demand (COD) [3, 4], this amount exceeds the maximum level set by the Indonesian government, which is 100 mgL^{-1} for COD and 200 mgL^{-1} for total suspended solid (TSS) [5]. Indonesia has a tofu industry with more than 84,000 units and an annual production capacity of more than 2.56 million tons. Industrial wastewater from tofu involves a TSS concentration of more than 1000 mgL^{-1} and a chemical oxygen demand (COD) of 5000–8000 mgL^{-1}. Waste water production can be up to 40–43 times larger for every kg of soybeans used to make tofu [4, 6].

An alternative method for lowering COD and creating biogas is anaerobic decomposition. Due to the comparatively high processing costs, many tofu industries in Indonesia continue to dispose of untreated liquid effluent. Tofu industry costs must be reduced by enhanced waste treatment [3, 7-11]. The anaerobic process has an economic advantage in which the sludge produced is low so it does not need to pay for the handling of sludge caused by anaerobic reactors which is an immediate economic benefit [8, 12-15]. Anaerobic biomass fermentation accompanied by methane production needs a long time, so organic waste requires a proper anaerobic digester [16, 17]. Processing of the anaerobic system is divided into a suspension system, attached and a combination of them. Anaerobic processing of the suspension system has been widely

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proven using UASB reactor. The UASB reactor is able to work for high load rates, high biomass concentrations and is very good for separating solids and liquids. The UASB reactor was developed by combining the attached system as a medium for the growth of microorganisms. This system is carried out on one reactor that is the hybrid UASB reactor [18, 19]. The hybrid UASB reactor is an attractive technology for the treatment of industrial wastewater from sago, tofu, refineries, starch and dairy industries. The hybrid UASB reactor was able to effectively remove up to 95% COD and produces biogas [8, 20]. The effect of OLR on degradation of wastewater in the hybrid UASB reactor using PVC as attached media showed 85.57% COD removal, day 171 at OLR 5.2 kg COD m^{-3} d^{-1} [21]. In the processing of refinery wastewater, the removal of organic load is obtained about 87.35% [22]. OLR was a parameter that, under operational circumstances, may have an impact on the state of the process and needed to be regulated [1, 20, 21]. The hybrid UASB reator at OLR 8.9 kg COD m^{-3} d^{-1} is able to remove up to 93% COD to treat dairy industrial wastewater [23]. The COD removal efficiency was found to be more than 95% at a 24-hour constant hydraulic retention time (HRT). The hybrid UASB reactor was reasonable, environmentally friendly and sustainable to handle refinery washing [24]. The hybrid reactor had a role as an additional processing stage is more significant in low HRT and rising flow velocity so that it could maintain biomass and contribute to improved granulation [25]. HRT is a significant main operating parameter because it contributes to the performance of the bioreactor as well [26-28]. Based on the biochemistry and microbiology of anaerobic processes, kinetic studies provide a rational basis for process analysis, control and design. Upflow system kinetics studies on COD removal are needed to determine the kinetics of bacterial growth. Kinetic model is an analytical approach to describe specific parameters for monitoring system performance. Kinetic models are currently being developed to help design and optimize processes for upflow and hybrid anaerobic reactors [1, 17, 21, 29, 30]. The kinetic model is also considered feasible and suitable for approaches on removal performance, prediction of effluent concentrations and optimization of biological processes [31]. Nevertheless, there are still very few studies related to the study of kinetic parameters for the process in the hybrid UASB reactor and there is no tofu industry that uses a treatment system for wastewater from tofu manufacture. This study aims to investigate the rate of change of the substrate using a modified Stover-Kincannon kinetic model due to the effect of OLR on the hybrid UASB reactor for handling tofu liquid waste. So that in the future the hybrid UASB reactor can become a reference as a good performance in the tofu industrial process wastewater treatment. Although, it requires a burdensome cost for the tofu factory industry and it is a task for the local government so that the tofu industrial wastewater treatment must still be carried out as a healthy environmental consideration.

2. MATERIALS AND METHODS

2. 1 Hybrid UASB Reactor Figure 1 is a lab-scale hybrid UASB reactor, which was designed like previous studies [3, 8, 32]. The hybrid UASB reactor consists of 3 parts, namely suspended sludge blanket, attached media and gas liquid solid separator (GLSS). The hybrid UASB reactor system is a combination of a suspended system and an anaerobic fixed film (Figure 1) [33], which is a hybrid wastewater treatment process with a fixed film attached system (supporting medium) providing a surface as an embedded medium in the biofilm to support the growth of anaerobic microorganisms. Wastewater as feed flows upward through the sludge layer and dissolved pollutants are absorbed by the biofilm, so decomposition occured. The hybrid UASB reactor was made of acrylic with a height ratio for suspended media and attached media of 1:1, each medium height of 80 cm. Suspended media is 3 inches in diameter and embedded media is 4 inches in diameter. The capacity of the reactor is 8.6 liters and the use of bioballs as attached media. Tofu wastewater was fed by a pristaltic pump to the hybrid UASB reactor as an upflow system to GLSS. Then it flowed continuously as a process that come out through the outlet as effluent to the clarifier and biogas to the biogas outlet. Biogas was collected into the reservoir via the gas flow. Bioball media was a media system to support the growth of microorganisms as a media attached to a UASB hybrid reactor. GLSS in the reactor to separate flue gas, liquid and solid when feed movement occured.

2. 2. Tofu Wastewater as Influent Tofu wastewater was processed from the tofu industry in the

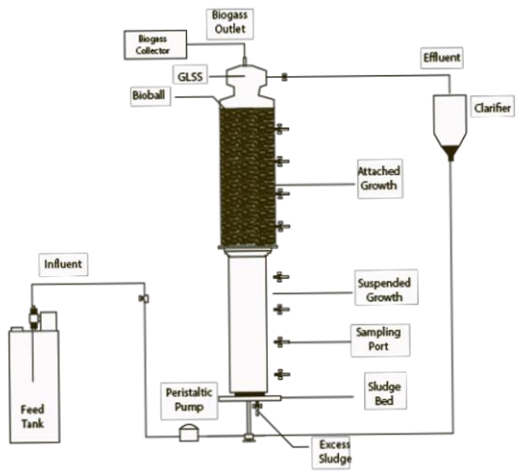

Figure 1. Schematic diagram of the Hybrid UASB reactor

city of Medan, Indonesia. Industrial wastewater tofu contained chemical oxygen demand 60000 mgL^{-1} and pH 3-4. To prevent pH fluctuations, $NaHCO_3$ was added and K_2HPO_4 to tofu wastewater. Tofu industrial wastewater is fed as inlet by a pristaltic pump, the system moves upward through the suspended and attached medium. The system media is attached as a filter used in this study were 167 bioballs, diameter of about 4 cm, specific area 230 m^2/m^3, cavity porosity of 0.92. Process water as outlet at the top reactor connected to clarifier as a waste tank. The reactor is equipped with a gas liquid-solid separator (GLSS) to separate the rising effluent due to the movement of the feed.

2. 3. Analytical Procedure Daily checks are made of the variables that influence the process, such as pH and temperature, biogas, COD, the flow rate (Q), HRT, Treated and untreated samples were analyzed for pH, COD, Total Suspended Solids (TSS), volatile suspended solid (VSS), volatile fatty acid (VFA) and alkalinity according to the Standard Method of Water and Wastewater Inspection. The closed reflux titrimetric approach was used to monitor COD. VFA and alkalinity were also assessed using titrimetry. All samples were filtered before analysis utilizing a 0.45 mm filter to remove suspended matters. Homogeneous samples were filtered with filter media that had been weighed. The residue retained on the filter media was dried in a temperature range of 103 °C to 105°C to constant weight. The increase in weight indicates (TSS). Furthermore, the filter media from the TSS test were tested for (VSS) analysis at a temperature of 550 ^{0}C. Observation of VSS to determine the number of microbes because the seeding is considered complete if the concentration of VSS > 3000 mg L^{-1}; this indicates an increase in microbial biomass. The whole determination was operated in accordance to APHA Standard Methods [34].

2. 4. Reactor Operation The acclimatization process at HRT 12, 18, 24 hours, the flow rate (Q) was in the range of 5.9-11.97 mL per minute and the flow rate increased (Vup) 0.08-0.17 m h^{-1}. The acclimatization process was carried out so that microorganisms adapt to the tofu industrial wastewater to be processed. The seeding treatment was carried out simultaneously with the acclimatization process after 7 days, with variations in concentration from the lowest to a concentration of 100% of tofu industrial wastewater (25, 50, 75, 100%). $NaHCO_3$ was added as a buffer to maintain pH 6.5-7. The wastewater from the tofu industry is channeled by a peristaltic pump to the hybrid UASB reactor with an upflow system.

2. 5. Modified Stover-Kincannon Model The Stover-Kincannon model was the most suitable model in determining kinetic evaluation. The parameters obtained in this model were very important for estimating the efficiency and performance of a bioreactor system. Therefore, it can be applied to large-scale industrial bioreactors. Model of Stover-Kincannon is used for determining the rate of change of substrate concentration which is stated in Equation (1) [17, 35-40].

$$\frac{dS}{dt} = \frac{Q(S_o - S_e)}{V} = \frac{\mu\left(\frac{QS_o}{V}\right)_{max}}{K_B + \left(\frac{QS_o}{V}\right)} \quad (1)$$

$$V\left(\frac{dS}{dt}\right) = QS_o - QS_e \quad (2)$$

Equation (3) is achieved by substituting Equation (1) into Equation (2):

$$V\left[\frac{\mu max\ (\frac{Q\,So}{V})}{K_B + (\frac{Q\,So}{V})}\right] = QSo - QSe \quad (3)$$

The concentration of effluent substrate is measured by Equation (4).

$$S_e = S_o - \frac{\mu max\ So}{K_B + (\frac{Q\,So}{V})} \quad (4)$$

where, So and Se are the influent and efluent substrate concentration (mg L^{-1}) respectively. μmax, K_B, V and Q are the maximum rate of substrate utilization (mg L^{-1} d^{-1}), the saturation constant (mg $L^{-1}d^{-1}$), the reactor volume (L) and the flow rate (L d^{-1}), respectively [17, 35-40].

$$\left[\frac{dS}{dt}\right]^{-1} = \frac{V}{Q(S_0 - S_e)} = \frac{K_B}{\mu_{max}}\frac{V}{Q\,S_0} + \frac{1}{\mu_{max}} \quad (5)$$

Input and output substrate concentrations, respectively, are So and Se (measured in mg L^{-1}). Maximum substrate consumption rate (mg L^{-1} d^{-1}), saturation constant (mg L^{-1} d^{-1}), reactor volume (L), and flow rate (L d^{-1}), are represented by max, K_B, V, and Q, respectively.

3. RESULTS AND DISCUSSIONS

3. 1. Hybrid UASB Reactor Performance The removal of the substrate depends on the load rate in the bioreactor system design that will produce biogas where the volume of the load rate is related to the mass of methanogens immobilized [8]. In this study amount of OLR fed into the reactor was based on the values of HRT (24, 18 and 12h). The OLR of the hybrid UASB reactor were varied from 1.5 to 12 kg COD m^{-3} d^{-1} for 328 days.

Substrate removal and biogas production at different OLRs during the process are shown in Figure 2. The highest efficiency of removal COD was 86.41% at OLR 4.8 kg COD m^{-3} d^{-1} and produced the highest biogas.

The process was carried out for 328 days with the influent pH range kept stable between 6.5 - 7.5 by the addition of $NaHCO_3$. Anaerobic bioreactor process in the hydrolysis phase and microorganism acidogenesis is able to work optimally in the pH range 5.5-7, and microorganisms in the methanogenesis phase are able to

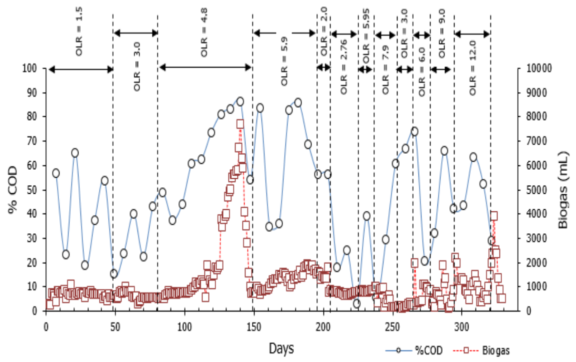

Figure 2. Relationship between % COD and biogas on OLRs

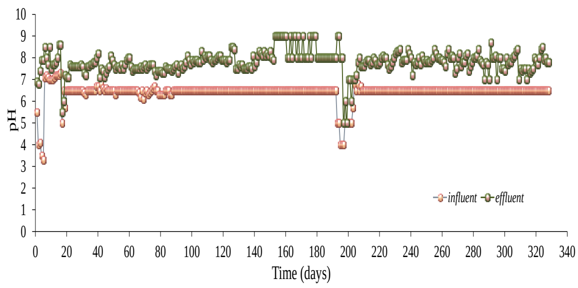

Figure 3. Values of influent pH and values of effluent pH on time

work optimally in the range of pH 6.5 - 8.0 [41] and the methanogen process can work optimally in the range of pH 6.5 -8.2 [42]. Figure 2. and Figure 3. indicated that COD removal and biogas production are highest at pH 7.6 at OLR 4.8 kg COD m^{-3} d^{-1}. This shows the OLR 4.8 kg COD m^{-3} d^{-1} and HRT 24 h have the optimum contact time in degrading organic compounds in the Hybrid UASB reactor and the process pH shows more active metanogenic microorganisms. Increased production of biogas and efficiency of COD are influenced by the OLR in the appropriate range. Increased organic loads provide modified granular structures and loss of stability. Hence the increased OLR causes a decrease in volatile solid and biogas production [19, 43, 44]. Excessive OLR levels can cause system instability. Therefore, the level of organic loading that grows must be in the right range so as to increase the rate of biogas production [42-44].

3. 2. Performance of The Kinetic Model of Stover-Kincannon Substrate utilization rate is shown as a function of organic loading rate on the Stover-Kincannon model. Figure 4. shows a linear regression curve between the rate of organic load and the rate of substrate removal at HRT 24 h. Kinetic constants (K_B = μ_{max} x b) are saturation constants and μmax is the maximum rate of substrate utilization and μmax is the maximum rate of substrate utilization (μ_{max} = 1/a). Figures 4, 5 and 6 indicate plot of COD loading V/QSo versus COD removal rate V/(Q (So-Se)) of hybrid reactor UASB. From Figure 4. slope and intercept of a best line (R^2 = 0.9704), constant of kinetic for COD removal in the hybrid reactor of UASB were determined as μ_{max} = 0.59 mg L^{-1} d^{-1} and K_B = 3.7 mg L^{-1} d^{-1}, respectively.

Therefore organic loading rate (OLR) in reactor hybrid UASB takes the following form:

$$\frac{Q(So - Se)}{V} = \left[\frac{0.59\,(\frac{Q\,So}{V})}{3.7 + (\frac{Q\,So}{V})}\right] \tag{6}$$

And effluent substrate of reactor hybrid UASB could be predicted by rearranging Equation (6):

$$S_e = S_o - \left[\frac{0.59\ So}{3.7 + (\frac{Q\,So}{V})}\right] \tag{7}$$

Figure 5 shows a linear regression curve between the rate of organic load and the rate of substrate removal in HRT 18 h. From Figure 5, the slope and intercept of a best line (R^2 = 0.9425), constant of kinetic for COD removal in hybrid UASB reactor were determined as μmax = 9.41 mg L^{-1} d^{-1} and K_B = 12.97 mg L^{-1} d^{-1}, respectively. Therefore organic loading rate (OLR) in hybrid UASB reactor takes the following form:

$$\frac{Q(So - Se)}{V} = \left[\frac{9.41\,(\frac{Q\,So}{V})}{12.97 + (\frac{Q\,So}{V})}\right] \tag{8}$$

And effluent substrate of reactor hybrid UASB could be predicted by rearranging Equation (9):

$$S_e = S_o - \left[\frac{9.41\ So}{12.97 + (\frac{Q\,So}{V})}\right] \tag{9}$$

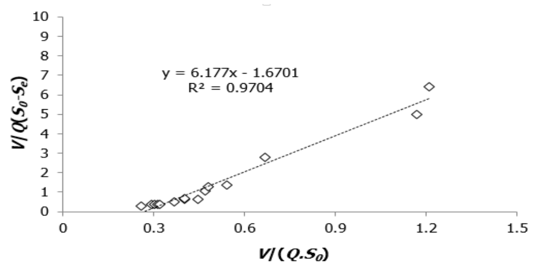

Figure 4. Plots of substrate removal for COD removal at HRT 24 h

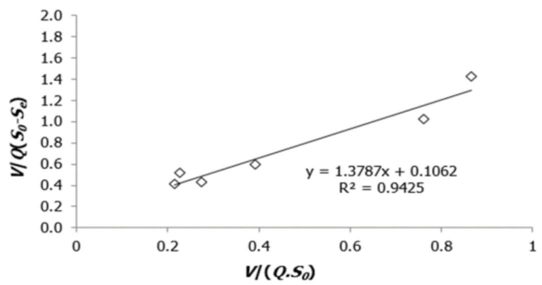

Figure 5. Plots of substrate removal for COD removal at HRT 18 h

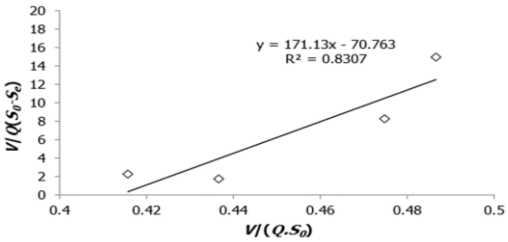

Figure 6. Plots of substrate removal for COD removal at HRT 12 h

Figure 6 shows a linear regression curve between the rate of organic load and the rate of substrate removal in HRT 12 h. From Figure 6 the slope and intercept of a best line (R^2 = 0.8307), constant of kinetic for COD removal in the hybrid UASB reactor were determined as μmax = 0.014 mg L^{-1} d^{-1} and K_B = 2.42 mg L^{-1} d^{-1}, respectively. Therefore, organic loading rate (OLR) in the hybrid UASB reactor takes the following form:

$$\frac{Q(So-Se)}{V} = \left[\frac{0.014\left(\frac{Q\,So}{V}\right)}{2.42+\left(\frac{Q\,So}{V}\right)}\right] \quad (10)$$

And effluent substrate of hybrid UASB reactor could be predicted by rearranging Equation (10).

$$S_e = S_o - \left[\frac{0.014\,So}{2.42+\left(\frac{Q\,So}{V}\right)}\right] \quad (11)$$

Calculations of the above kinetic parameters to predict kinetic parameters in the hybrid UASB reactor. The model of Stover-Kincannon can be said that the substrate removal rate is influenced by the organic load rate (OLR) that enters the hybrid UASB reactor. The compatibility of the Stover Kincannon model for each HRT is shown by the regression coefficient (R^2). Which is the best performance shown in Figure 4 (R^2 = 0.9704). This is much different when compared to the pulp and paper industrial wastewater treatment using hybrid UASB reactor, namely R^2 = 0.4994 [21]. Therefore, it can be said that the hybrid UASB reactor for treating tofu wastewater at HRT 24 h can be applied to industrial scale.

4. CONCLUSION

The OLR is one of the parameters that influences the wastewater treatment process in the bioreactor. Process control is related to loading rate. Therefore the loading rates must be pressed up in order to reduce the size of the reactor so that monitor and control are more critical.

Increased efficiency of COD removal and biogas production were influenced by the level of suitability of the organic load (OLR) in the reactor process. The optimum process was shown in OLR 4.8 kg COD $m^{-3}d^{-1}$ and HRT 24 hours in the hybrid UASB reactor where these conditions resulted in the highest COD removal efficiency and biogas production, namely 86.41% and 7700 mL. Modified Stover-Kincannon model was observed and matched data sets were obtained. The kinetic values of model obtained of HRT variations (12, 18, 24h), the parameters K_B and μ_{max} were 3.7, 12.97, 2.42 mgL^{-1} d^{-1} and 0.59, 9.41, 0.014 mgL^{-1} d^{-1}, respectively. This model was a plot of the inverse of the removal rate, versus inverse of the total loading rate resulted a straight line. This shows that model kinetic of Stover-Kincannon is the rate of substrate removal that is affected by the organic load rate (OLR) that enters the hybrid UASB reactor.

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Persian Abstract

چکیده

هدف این تحقیق بررسی متغیرهای نرخ بارگذاری آلی (OLR) در تصفیه فاضلاب توفو با استفاده از راکتور لجن بی‌هوازی هیبریدی با جریان بالا (Hybrid UASB) با استفاده از مدل سینتیک اصلاح‌شده Stover Kincannon است. این راکتور با تغییرات OLR 1.5-12 کیلوگرم $COD\ m^{-3}\ d^{-1}$ و HRT 12 تا ۲٤ ساعت به مدت ۳۲۸ روز کار می کرد. راندمان حذف COD بالاتر ٨٦.٤١٪ و تولید بیوگاز ۷۷۰۰ میلی لیتر در OLR 4.8 کیلوگرم $COD\ m^{-3}\ d^{-1}$ و HRT 24 ساعته در ۱٤۰ روز به دست آمد. مدل اصلاح شده استوور-کینکنن مشاهده شد و مجموعه داده های منطبق به دست آمد. مقادیر جنبشی مدل به دست آمده در تغییرات HRT، پارامترهای K_B و μmax به ترتیب ۳.۷، ۱۲.۹۷، ۲.٤۲ $mgL^{-1}\ d^{-1}$ و ۰.۵۹، ۹.٤۱، ۰.۰۱٤ $mgL^{-1}\ d^{-1}$ بود. این مدل نمودار معکوس نرخ حذف بود، در مقابل معکوس نرخ بارگذاری کل منجر به یک خط مستقیم شد. نشان داد که مدل استوور-کینکنن نرخ حذف بستر تحت تأثیر نرخ بار آلی (OLR)است که به راکتور هیبریدی UASB جریان می‌یابد.