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Treatment of Tofu Industry Wastewater using Bioreactor Anaerobic-Aerobic and Bioball as Media with Variation of Hidraulic Retention Time

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Abstract

Tofu which is made by grinding soy bean, generates huge amount of wastewater and thus considered as one of the most polluted food-industrial effluent owing to its high values of organic contents. The small industries of tofu preparation process release the wastewater directly into the water body without being treated first. Prior to discharge this wastewater into the waterbody, the wastewater must be treated to reduce the possibility of negative impact and the contamination of the waterbody. For these small industries, the best alternative of wastewater treatment is one which has the following criteria: easy in operation, low cost operation, low volumes of sludge produced, and can be used in high concentration wastewater. In this research, bioreactor anaerobic-aerobic with media bioball is used. The highest removal efficiency of COD took place in anaerobic zones. Bioreactors were operated with the variations of retention time at 24 hours, 18 hours, and 12 hours. The COD removal efficiency for Hydraulic Retention Time (HRT) of 24 hours, 18 hours and 12 hours were found 90.3% (organic loading rate is 15.1 kg COD/m^3.day), 84.4% and 76.3% respectively. The experiment showed that the longer of the hydraulic retention time (HRT), the higher the removal efficiency could be achieved. These occurred because a longer HRT will extend the contact time between wastewater and microorganisms attached. Therefore, microorganisms have a longer time to degrade organic matter in wastewater. Although the removal efficiency in these three-HRT was found high, the effluent of the reactor was still above the effluent standard based on regulation of Ministry of Environmental Permen LH No. 5/2014. Kinetics using Eckenfelder Equation results R2 equal to 0.9991, n equal to 0.293 and K equivalent to 7.3577 mg/L.

Keywords: *tofu wastewater, anaerobe, aerobe, bioball, wastewater, treatment, attached growth*

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INTRODUCTION

Water pollution is the contamination of water bodies (e.g. river) by certain types of compounds which causes changes in water characteristics. When the pollutants are directly discharged into the water bodies without adequate treatment to remove the harmful compounds, the waste will not only potentially degrade the quality of the water but also damage the entire water ecosystems. Therefore, the wastewater should be properly treated before finally being disposed to the river. One of the results from industrial process which frequently causes water pollution is the wastewater generated from tofu industry. Tofu consumption level in Indonesia reached 7.4 kg/person/year. Data obtained from BPPT (Agency for the Assessment and Application of Technology) showed that 2,610 kg waste generated, for every 80 kg tofu produced. Which means that a large amount of wastewater is discharged from tofu industries in each year in Indonesia (Dianursantia *et al.*, 2014). The main ingredient for producing tofu is soybean, an agricultural product which has a high level of protein substance. The wastewater generated from tofu industry is considered as a major problem threatening the entire biosphere. This industry is typically managed in small-scale or home industry process with traditional processing method and poor waste management. As a result, mostly tofu industries directly dispose their waste into the water bodies especially river without any proper waste management. This practice largely causes water pollution and damages the ecosystem in its surroundings. Chai *et al.* (1999) studied bean curd wastewater treated by membrane separation with a COD removal efficiency of 85.5%.

Considering the economic background of the industrial entrepreneurs of tofu, it is commonly found that tofu industries are managed by micro-scale home industries with limited technical and financial support. Therefore, it is important to provide an alternative technology for treating waste of the tofu industries which offers very practical yet economical solution. Moreover, the method should be simply implemented but relatively requires low processing cost. One of the technologies to treat organic waste economically and efficiently is the biological wastewater treatment, which utilize bacteria and other microorganism to break down the organic substance in the wastewater.
Referring to the results of previous studies conducted, waste treatment with anaerobic decomposing system still has high concentration of Biochemical Oxygen Demand (BOD5) ranged from 400 to 1400 mg/L. In other words, it does not comply with the effluent standard according to the Regulation of Ministry of Environmental which states that the range should be from 2000-4000 mg/L for suspended solids and 50-150 mg/L for BOD (PERMEN LH No. 5/2014). Therefore, for further treatment, more advanced process needs to be carried out to reduce BOD5 to reach below 75 mg/L. Wastewater resulted from Tempe-tofu industries typically contains waste with high organic compound. The wastewater has some distinctive characteristics, like color, odor, turbidity, BOD, Chemical Oxygen Demand (COD), and pH. The COD value of the wastewater of tofu industry generally ranges from 7500 to 14000 mg/L (Nurhasan, 1987) and has pH 4 to 5. One of the simple and practical alternatives for managing the wastewater is using biological treatment, specially wastewater treatment with submerged fixed bed biofilm reactor systems in which the microorganism attached to the media to enables direct contact with effluent in anaerobic and aerobic processing. The submerged fixed bed bioreactor with combination of "anaerobe-aerobe" is considered as the most appropriate system to decompose waste containing a high of organic compound. The significant contributions of anaerobic process in the sequential system to the overall performance accent the affirmation of reducing energy consumption and excess sludge production (Kassab, *et al*, 2010; Kothari, *et al*. 2010) Moreover biogas produced is a clean and environmentally friendly fuel, although it contains only about 55–65% of CH_4 (Appels *et al*., 2011).

The combination of anaerobic-aerobic biological process is very effective to reduce the organic pollutants in the wastewater, COD removal efficiency was obtained 93.54 % at Hydraulic Retention Time *(*HRT) 24 hours with carbon active as media (Astuti *et al*., 2007). This study is conducted to investigate the wastewater treatment of tofu industry using anaerobic and aerobic bioreactor with bioball media and to observe the efficiency and effectiveness of bioball media with a variation of HRT at 24, 18 and 12 hours. The main advantage of bioball compared to other bio media is not only unclog ability, but also the aeration it provides. The large gaps allow the entry of oxygen/ air-rich water to mix with the dispersed water surface, so that there is a very good interaction between air and water and the exchange of gas.

MATERIALS AND METHODS

Reactor Set Up

The bioreactor model implemented in this study, as can be seen in Figure 1 is a baffle-channel reactor consisting of 4 columns (2 anaerobic columns, 1 aerobic column, and 1 sedimentation column) and it used bioball media in both anaerobic and aerobic columns.

Removal efficiency was calculated by the percentage of reduction in concentration for each pollutant as follows:

$$= \left(1 - \frac{C_{eff}}{C_{inf}}\right) \times 100\% \quad (1)$$

where Cinf and Ceff is the influent and effluent concentrations in mg/L. The stages of conducting this research include seeding, acclimatization and operational with retention time variation.

Seeding

Seeding in this study is needed in order to obtain indigenous microorganisms which act as tofu wastewater decomposers by flowing seed sludge and tofu wastewater into a bioreactor. The seed sludge is obtained from the sump well near a tofu industry area at KOPTI Semanan in West Jakarta.

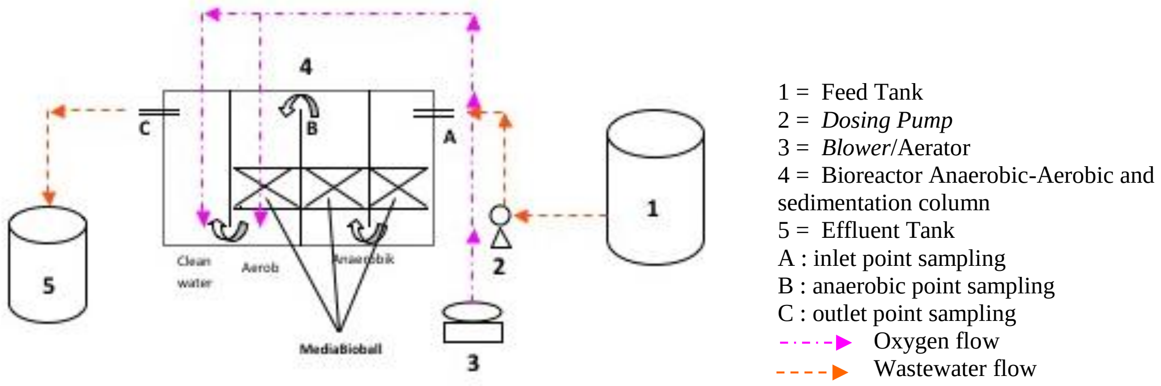

Figure 1. Bioreactor Anaerob-Aerob Media Bioball

Table 1. Parameters and Analysis Method

No	**Parameters**	**Unit**	**Method Analysis**
1.	BOD	mg/l	Winkler
2.	COD	mg/l	*Open Refluks*
3.	VSS	mg/l	Gravimetric
4.	TSS	mgl	Gravimetric
5.	DO	mg/l	Winkler
6.	pH	-	Latmus Paper
7.	Alkalinity	mg/l	Volumetric
8.	TDS	mg/l	Gravimetric

An HRT-24 hour was maintained. During the seeding process, glucose is added to provide carbon sources which enable the microorganisms to grow faster.

Acclimatization

Acclimatization is a process which helps microorganisms to adapt to the changes in the new environment. The acclimation process is carried out in the reactor by gradually replacing wastewater with newly produced wastewater within 24 hours. During the acclimatization process, the biofilm layer will be thicker. This process finished when the wastewater has been completely replaced by the original tofu wastewater and the COD concentration achieve stable removal efficiency more than 80% (≥80%) along with± 5% fluctuation, this condition is termed as steady state.

Kinetics Study

Eckenfelder (1970) as cited from Reynolds (1982) developed a specific velocity equation of substrate discharging for first order reactions presented as follows:

$$\left[\frac{\delta S}{x.\delta t}\right] = K.S \qquad (2)$$

where:

$\frac{1.\delta S}{x.\delta t}$ = specific average of substrate utilization
δS = rate of substrate utilization,
δt = (mass / (period x volume)
K = constant, volume / (microbe mass x period)
S = substrate concentration, mass/volume

The integration of equation 2 results as follows:

$$\frac{S_t}{S_0} = e^{-kxt} \qquad (3)$$

Here:
S_t = substrate concentration after t, mass/volume
S_0 = substrate concentration at t=0, mass/volume
x = average of mass cell concentration, mass volume

The average concentration of x cell mass is equivalent to the surface area of the media (A_s)

$$x \approx A_s \qquad (4)$$

Since biofilm thickness is equal then:

$$x = S$$
$$x = k'.A_s$$

In which: k' = constants

For contact period of t, Howland W.E (1957) formulates:

$$t = C\left(\frac{D}{{Q_l}^n}\right) \qquad (5)$$

Where:
t = contact duration
D = depth of filter
Q_l = hydraulic load / surface hydraulic (m^3 / m^2.day)
C, n = experimental constant

The substitution of equations 2, 3 and 4 can be simplified as follows:

$$ln\frac{S_t}{S_0} = \frac{-k.D}{Q_l^n}$$

$$ln\left[ln\frac{S_0}{S_t}\right] = ln\,k.D - n.lnQ_l \qquad (6)$$

The value of n can be known from the graphic comparison between:

$ln\left[ln\frac{S_0}{S_t}\right]$ and lnQ_l

RESULTS AND DISCUSSION

Wastewater observed in this study is obtained from the waste of tofu industries from Micro Industry Village, KOPTI Swakerta, Semanan District, West Jakarta. The initial characteristics of the waste can be seen in Table 2 presented as follows.

Table 2. Wastewater Characteristics Tofu

Parameters	Concentration(mg/L)	Effluent standards
BOD	2150 – 2530	150
COD	5800 – 7000	300
TSS	850 – 350	4000
TDS	6060	-
pH	4	6-9

Seeding

This process aims to multiply or increase the microorganisms which have significant role for in degrading or decomposing wastewater. This process forms a layer of biofilm attached to a bioball media.

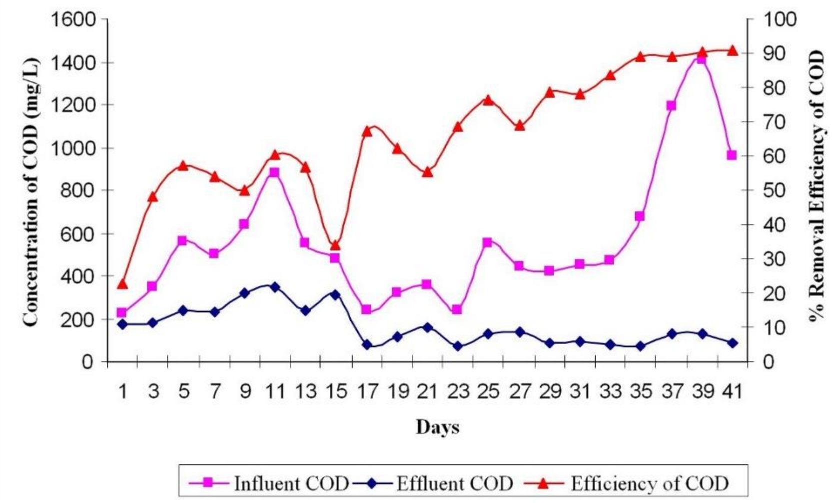

Figure 2. Graph of Days operations (X) and % Removal of COD Concentration (Y2) at Seeding Process

Figure 3. Graph of Days operations (X) and % Removal of COD Concentration (Y2) at Acclimatization Process

At this stage, glucose is used as carbon source with an HRT-24 hr. The retention time 24 hours is selected in order to have sufficient contact between wastewater with the bioball media, so that the microorganism can grow faster and well attached. The growth of microorganisms on the media can be observed both from its VSS concentration and COD removal efficiency. The increased removal efficiency indicates that the microorganisms have grown rapidly and degraded organic pollutant from the wastewater (Figure 2).

From the graph presented in Figure 2. it can be seen that in the first and second weeks, the removal of COD concentration is still low and not stable. This condition occurs as in the initial operation a layer of biofilm was not yet formed which means that microorganisms have not attached to the media. It is also observed that the VSS concentration analyzed is still high. When the biofilm layer is formed, it indicates that microorganisms have been widely attached to the media and it results to small VSS concentration in the outlet.

At the fourth week, the removal efficiency of COD slightly increased due to the additional glucose given. At the beginning of the 5th week, removal efficiency of COD increased and achieved stability at the end of the 5th week. The removal efficiency of COD has reached 90.8% and the research can be proceeded to next steps.

Acclimatization

Acclimatization is a process in which microorganisms adapt to the wastewater that will be treated. The process is conducted through steps by steps, so that it will not decrease the removal efficiency of COD. Acclimatization is conducted by gradually replacing the wastewater of the seeding with the original tofu wastewater. The replacement starts with an initial ratio of 10% of the original tofu waste up to 90%. The replacement is done gradually until it reaches 100% original tofu wastewater. The acclimatization process is finished when the removal efficiency of COD has been stable (fluctuations ± 5%) and the replaceable wastewater has 100% original tofu wastewater. The results can be demonstrated in Figure 3.

From Figure 3, we can see that the stability of the COD removal efficiency is slightly observed at 4th week. This condition occurs when the percentage ratio of tofu wastewater to wastewater in tank reached 75%:25%. However, the percentage is observed and found stable on the 34th day, when 100% of wastewater has been replaced with tofu wastewater and achieved a COD removal efficiency of 93.94%.

Decreased COD concentrations that often occur early with the addition of nutrients due to microorganisms need to adapt the new condition, but once the microorganism has adapted the removal efficiency will be stable.

Effect of Retention Time Variations on COD Removal Efficiency

After the acclimation process has been completed, the continuously operation can be conducted. Variation of HRT is observed within 24 hours, 18 hours, and 12 hours.

The results of the study show that the greater the HRT, the higher the level of organic removal efficiency. Based on the results of COD removal efficiency analyzed over various HRT, it was found that the highest removal efficiency was in HRT 24 hours with 90.3%. While at HRT 18 hours resulted a removal efficiency of 84.4%, and at an HRT 12 hour obtained a removal efficiency of 76.3%.

COD parameters at each HRT is shown in Figures 4 to 6. From Figure 4 illustrated above, it can be seen that in HRT 24 hours the achieved COD removal efficiency was relatively high with 90.3%. Moreover, on the next day, the percentage is slightly decreased to 89.1% but it then increased again to 90.9%. Therefore, it can be said that stability is achieved on the 4th day with a removal efficiency of 90.3%.

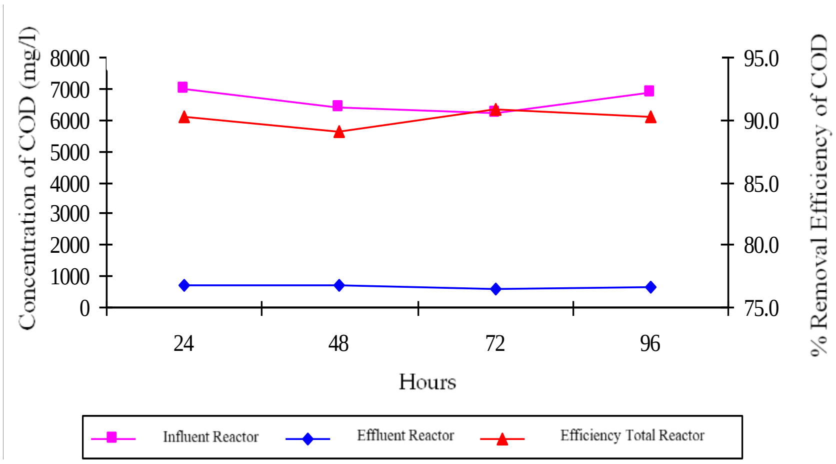

Figure 4. Graph of Hours operations (X) and % Removal of COD Concentration (Y2) in HRT 24 hours

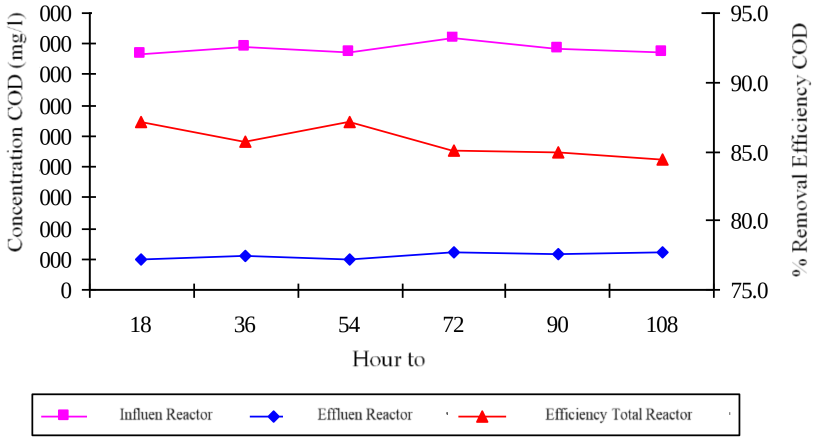

Figure 5. Graph of Hours operations (X) and % Removal of COD Concentration (Y2) in HRT 18 Hours

This process is conducted for 4 times of HRT 24 hours as the obtained percentage of COD removal efficiency rate has been stable, and fluctuations decreased less than 5%. The COD concentration in this anaerobe tank decreased, indicated by a pH value of 7, which means the transformation of acetic acid into methane gas in the methanogen process. Although the COD removal efficiency has increased, but the concentration of COD on the wastewater of the reactor is still excess than the effluent standard according to Regulation of Ministry of Environmental Permen LH No. 5/2014.

In HRT 24 hours, the alkalinity concentration at the inlet point is obtained at 774.06 mg $CaCO_3$/L with a pH 5 (acid conditions). Meanwhile, alkalinity concentration of the anaerobe tank becomes higher, that is equal to 2009.84 mg $CaCO_3$/L in which the alkalinity concentration indicates that the buffer system in anaerobe degradation process goes well and pH increased to 7 (neutral). According to Malina and Pohland (1992) anaerobe degradation process run well when the neutral pH value is about 6 to 7. If the pH is too low, there will be too much accumulation of acid and it can be an inhibitor for bacteria during methanogens process. At HRT 24 hours, the alkalinity concentration resulted 1982.68 mg $CaCO_3$/L with a pH value of 7. In this case, sufficient alkalinity is essential for pH control, because alkalinity acts as a buffer in the system, which results a neutral pH value in anaerobic condition.

From Figure 5 presented above, it can be seen that with HRT 18 hours, the obtained COD removal efficiency is lower compared to the COD removal efficiency at HRT 24 hours. At HRT 18 hours, the obtained removal efficiency of COD is 87.2%. Moreover, after 6 times observation of HRT 18 hours, the results showed that COD removal efficiency is 84.4%.

By applying HRT 18 hours in inlet with pH 4 (acid condition), alkalinity concentration was measured low, equal to 787.644 mg $CaCO_3$/L, whereas in anaerobe tank, alkalinity concentration increased to 2050.58 mg $CaCO_3$/L, with pH 7, and lastly in the outlet, the alkalinity concentration degrades to 1018.5 mg $CaCO_3$/l and the pH was 6. The dissolved oxygen (DO) concentration in the anaerobe tank is and anaerobe tank was found 0 and 3.2 mg/L indicating that the treatment occurs under aerobe conditions.

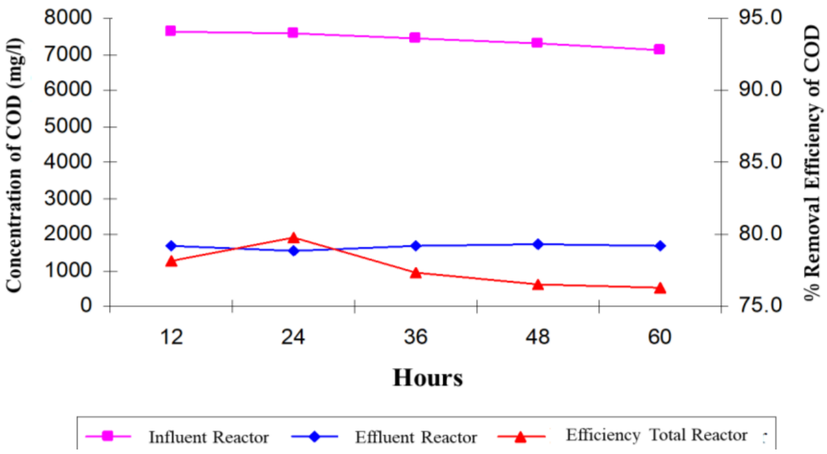

Figure 6. Graph of Hours operations (X) and % Removal of COD Concentration (Y2) in HRT 12 hours

While from Figure 6 above, it can be seen that with HRT 12 hours, the removal efficiency of COD decreased to 78.1% and HRT 60 hours provided a removal efficiency of 76.3%. At the end of the 'td' treatment, the alkalinity concentration was 977.76 mg $CaCO_3$/L with a pH 4 (acidic condition) determined in inlet point. On the other hand, in an anaerobe tank, the alkalinity concentration detected was very high of about 2240.7 mg $CaCO_3$/L with pH 8 in inlet point. The alkalinity concentration slightly decreases in 1982.68 mg $CaCO_3$/L in outlet point with pH 7. The dissolved oxygen (DO) in the anaerobe tank was measured 0 mg/L, which proves that the process was favorable under anaerobic condition. Whereas in the aerobic tank, the dissolved oxygen (DO) demand during the process was found 3.7 mg/L. This indicates that oxygen supply was sufficient to support the decomposition process of the organic material in the bioreactor.

The highest organic loading rate was monitored at HRT 12 hours with 29,2 kg COD/m^3.day efficiency with 76.3% removal efficiency of. According to Malina & Pohland (1992) organic loading rate for some food processing waste using anaerobe wastewater treatment are found in the range of 4 to 17.5 kg COD/m^3.day, with COD removal efficiency from 75% to 95%. Chan *et. al*. (2009) mentioned anaerobic–aerobic fixed film bioreactor using long corrugated PVC tubes as support media results an overall COD removal efficiency of 92% with an organic loading rate of 0.39 kg COD/m^3.day (Chan *et al.,* 2009).

Kinetics of COD Removal Concentration

The kinetics of COD utilization rate (substrate) aims to determine the level of substrate utilization in wastewater treatment in a submerged fixed bed bioreactor with bioball media. The calculations are based on the rate of substrate removal developed by Reynold (1982). Kinetics of removal on the submerged fixed bed bioreactor is determined by evaluating the value of rate constant n and k (equation 4).

As observed in Figure 7, linear equation is y = -0.293 x + 0.7981 with a correlation value (R^2) equals to 0.9985, which is very close to 1 and r is equal to 0.9992. From the linear equation we get the value of n equals to 0.29. Based on Eckenfelder's (1970), the value of n depends on the flow characteristics and usually the value of n ranges from 0.50 to 0.67. The smaller the value of n, the higher removal of So to St.

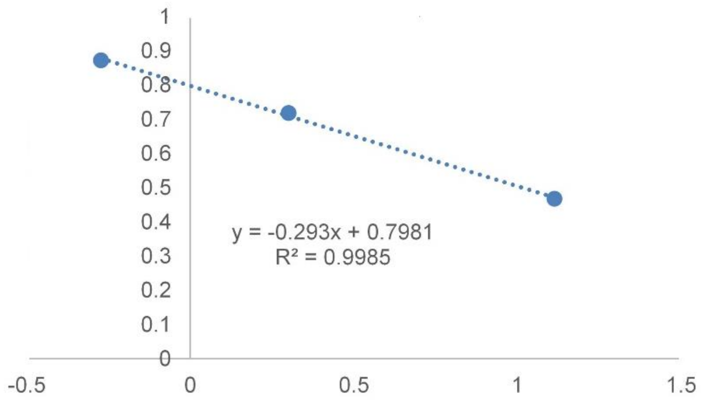

Figure 7. Graph of Calculation of n value for COD Concentration Removal

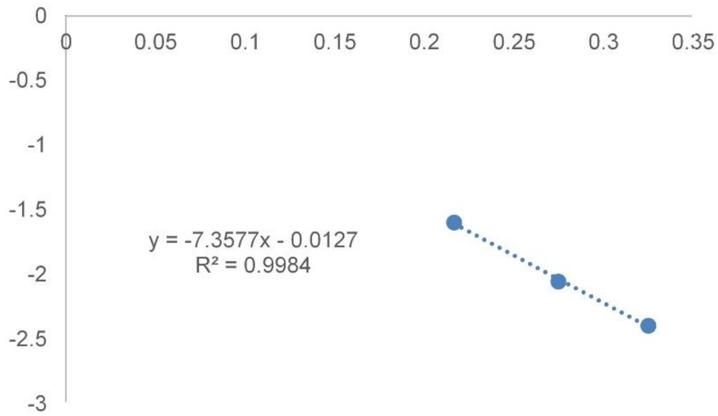

Figure 8. Graph of Calculation of K value for COD Concentration Removal

Based on Figure 8, the linear equation was found like y = -7.3577 x – 0.0127 with a R^2 value equals to 0.9984, which is almost equal to 1 and the value of 'r' is equals to 0.9984. From the linear equation, the value of 'k' was obtained equal to 7.36/day. Astuti, AD. et. al., (2007) used activated carbon as media which resulted the value of 'n' and k equal to 0.4721 and 12,42/day.

A greater value of k is desirable because higher value of k provides smaller S_t value which means higher percentage of substrate removal, higher % removal of COD concentration.

CONCLUSION

Based on the study of the HRT effect on the removal of organic matter from tofu industry wastewater using a bioreactor with a combination of anaerobe and aerobe with bioball media, the COD removal efficiency with HRT 24 hours, 18 hours and 12 hours is found 90.3%, 84.4% and 76.3% respectively. It can be inferred that bioreactor with bioball media was effective in tofu industry wastewater treatment and the highest COD removal efficiency is obtained at HRT 24 hours. Kinetics parameters in the process of substrate utilization in the reactor calculated the value of n and k equal to 0.29 and 7.36/day. Organic loading rate with HRT 24 hours is measured 15.1 kg COD/m^3.day, whereas the organic loading rate with HRT 12 hours is 29.2 kg COD/m^3.day.

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