ENHANCEMENT OF BIOLOGICAL TREATMENT BY USING MOVING BED BIOFILM REACTOR (MBBR) FOR RUBBER GLOVE WASTEWATER

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Abstract – Operational parameters and effluent properties are the most important factors affecting the successful rate of biological treatment in wastewater treatment process. The main objective of this study was to access the feasibility of using moving bed biofilm reactor (MBBR) to enhance biological treatment of effluent from rubber glove manufacturing process. The effect of three operational parameters i.e hydraulic retention time (HRT), organic loading rate (OLR) and percent filling towards removal of chemical oxygen demand (COD) was studied. The rubber glove wastewater contains high organic loads and suspended solids that exceed the permissible limits set by the authority. Control test shows that the presence of biomedia increased COD removal. In addition, the higher the percent filling of biomedia in the wastewater, the higher the COD removal as the HRT prolong. The optimum HRT for MBBR is 8 hour with 62.4% of COD removal. The result also shows no trend of increasing organic loading rate with COD removal rate. However, COD removal increased with HRT regardless of the organic loading rate. In conclusion, MBBR shows promising alternative to enhance COD removal in comparison with conventional biological process in rubber glove wastewater treatment.

Key words : Biofilm, COD, Moving Bed Biofilm Reactor, rubber glove wastewater

I. INTRODUCTION

The rapid growth of rubber industries has produced large quantities of effluents from the process since the production of rubber gloves need large amount of water for the operation. In Malaysia, food and beverage producers, chemical based industries, textiles, paper, palm oil and rubber processing contribute the biggest problem for industrial water pollution [1]. In rubber glove manufacturing, there are two main sources of effluent which are latex compounding waste and leaching tank discharge [2]. Latex compounding waste contains uncoagulated latex and chemical sludge. It is usually discharged in batches during the cleaning of latex compounding and storage tanks [2]. Leaching tank discharge contains pollutants leached out from rubber gloves during washing. The effluents these two operational processes contain high concentrations of organic matters and suspended solids. Thus, the wastewater must be properly treated before discharge to the nearby water bodies to prevent the release of harmful waste into the environment.

Many methods have been studied for effective treatment of rubber processing waste including physic-chemical, oxidation process and biological treatments [3]. Unfortunately, most of these methods are costly and did not fully remove the contaminants. Hence the use of biological methods for wastewater treatment is of greater importance nowadays. For example, in treating anionic surfactants, MBBR is recommended because of its performance to remove Sodium Dodecylbenzene Sulfonate (SDS). SDS is an anionic detergent and MBBR was able to remove it up to 99.2 % with 200 mg/L concentration for a day, which was more efficient than other processes [4]. Juang et al. (2008) studied simultaneous combination of MBBR and chemical coagulation for textile wastewater treatment. In his study, activated carbon was used as aeration tank media and ferric chloride as coagulant, 95% COD and 97% color removal was achieved (Juang and Tsai, 2006). On the other hand, Aloui et al (2009) reported COD removal efficiency of 78% in fish processing saline wastewater treatment containing 2.5% salt and 2400 mg/L COD with HRT of 24 hours. Martinez et al. (2007) used two-stage biologic system (aerobic and anaerobic digestion) to treat olive plant wastewater. With organic load of 0.3 kg COD/l.d, 1.25 lb/l.d biogas was produced and yielded 93% COD reduction. They also observed 54% of phenol degradation during aerobic process and the biogas produced during anaerobic digestion contains 68- 75 percent methane [5]. So far, there is no evidence for COD removal enhancement using MBBR. Therefore, the aim of the current study was to determine the effectiveness of using MBBR for COD removal to treat the rubber glove wastewater.

II. METHODOLOGY

A. Bacterial culture preparation

Seeding process was carried out to grow bacteria in the biomedia. The biomedia was first cultured with glucose ($C_6H_{12}0_6$). The theoretical COD was calculated using ratio of molecular weight oxygen to glucose.

$$\mathbf{C_{12}H_{22}0_{11} + 60_2 \rightarrow 6CO_2 + 11H_2O}$$

Molecular weight of glucose (sugar) = 12(12) + 22(1) + 11(16)
= **342**

Molecular weight of oxygen = 6(32)
= **192**

ThOD = 5000 mg/L x (192/342)
= **2807 mg O_2/L**

Grams of the glucose (sugar) = $2807 \frac{\text{mg } O_2}{\text{L}} \times \frac{1 \text{ g}}{1000 \text{ mg}} \times 1\text{L (distilled water)}$
= **2.8 g in 1L of distilled water**

B. Acclimatization of bacteria culture

Acclimatization process was carried out as a process of microbial adaption to the wastewater from rubber glove processing factory. Bacteria acclimation was carried out by growing the bacteria in minimal organic salt medium amended with 10% of the rubber glove processing effluent. Table 1 shows the composition of the minimal organic salt medium.

Table 1: Composition of the minimal organic salt medium.

COMPOSITON	QUANTITY (mg/L)
KH_2PO_4	0.675
Na_2HPO_4	5.455
NH_4NO_3	0.25
$MgSO_4$	0.2
$Ca(NO_3)_2)$	0.1

C. The biomedia carriers

The biomedia carriers used for MBBR is Levapor with volume to reactor ratio (V/V) of 10%. The cuboid shape MBBR carrier was made of polyurethane foam impregnated with activated carbon to allow adsorption of toxic and inhibitory substances on it which provides remarkable process stability towards toxic short loadings. The PU foam carrier has very high inner porosity makes the biological process resilient to flow and pollutant loading variations. The characteristic of biomedia carrier is given in Table 2.

Figure 1 : Levapor biomedia carriers

Table 2: Characteristics of biomedia

Colour	Black
Dimension (mm)	20 x 20 x 7
Surface (m^2/m^3)	1. 34 mio
Configuration	cuboid
Material	PU foam
Bulk weight (kg/m^3)	30
Water binding capacity (kg/m^3)	100
Biofilm generation	120 min

D. Raw wastewater collection

The wastewater was collected from a rubber glove factory located in Taiping, Perak, Malaysia. The sample was collected between February to May 2019 at 15 days interval. The sample had been stored in the refrigerator in order to minimize the changes in the characteristics of wastewater sample.

E. Characteristic Raw Wastewater

The parameter tested for wastewater sample were pH, COD, TSS, TDS, Nitrite, Ammonium Nitrogen and turbidity. The characterization was carried out using Standard method (APHA). pH values were determined with pH meter (Toledo Swiss, model FE20). COD was determined according to close reflux method calorimetric method. Ammonical nitrogen and nitrate were measured by using, Salicylate Method and NitraVer, respectively using UV-Vis spectrophotometer (DR2800, HACH). Turbidity was analyzed using turbidity meter DR2100Q, whilst total suspended solid (TSS) and total dissolved solid (TDS) were determined through standard Gravimetric Method. Inductively Coupled Plasma (ICP 20074310) was used to determine trace elements concentration in rubber glove wastewater,

F. Experimental setup

A laboratory scale reactor with diameter x height of 12 cm and 60 cm, respectively was used as MBBR as shown in Figure 2. The volume of reactor were calculated and marked at the reactor to ease the reading of water level. The organism used is a mixed culture in the form of activated sludge obtained from the rubber glove wastewater treatment plant. Before start of the experiment, 2 L of sludge and 700 mL of biomedia was added into the reactor followed by actual wastewater until the total volume of reactor reached 7 L. The MBBR was operated under batch mode with hydraulic retention time (HRT) of 7 hours and 10% percent filling biomedia carriers. Aeration was provided by aquarium pump to mobilize the biomedia carriers contained in the reactor and provide dissolved oxygen to keep the system in aerobic conditions.

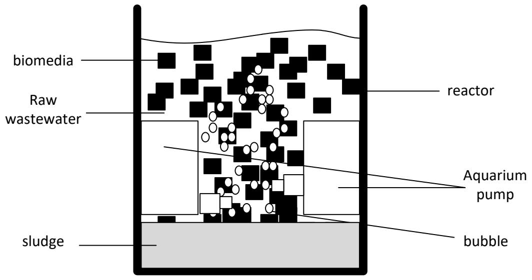

Figure 2: Schematic diagram of MBBR used in the study

The study was also carried out with variation of HRTs of 24 hours, 20 hours, 16 hours, 12 hours and 8 hours. Percent filling of biomedia was varied from 10% to 14% and 20% to investigate the effect of biomedia volume on MBBR performance. Different organic loading range between 535 mg/l to 745 mg/l was used to examine the organic loading rate on COD removal for MBBR process. The MBBR performance was measured by organic removal in COD by using the following equation :

$$\text{COD removal, (\%)} = \frac{COD_{initial} - COD_{final}}{COD_{initial}} \times 100\%$$

G. Determination of reaction rate constant, k

The biological reaction rate constant was determined using COD and MLVSS concentrations measured hourly from the batch reactor. Initially, the weight of clean glass filter paper was measured using balance and recorded (A g). 50 mL of mixture sample was withdraw from the reactor and filtered by using the weighed glass filter paper. The glass filter paper with suspended solids was then put into the oven at 105°C for an hour. The weight of dry glass filter paper was measured again (B g) until constant weight was obtained. The mixed liquor suspended solids (MLSS) was calculated by :

$$\text{MLSS} = \frac{B - A}{50\ mL} \times 1000$$

In order to calculate the mixed liquor volatile suspended solids (MLVSS), the filter paper (B g) was dry again in a furnace at 550°C for 20 minutes. The balance was put into the desiccators for an hour and weighted (C g).

$$\text{MLVSS} = \frac{B - C}{50\ mL} \times 1000$$

Experimental data of S (COD reading) vs Xt (MLVSS x time) was plotted. A linear relationship obtained from the plotted graph verified the validity of pseudo first order reaction. The reaction rate constant, k is calculated from equation

$$\ln S = \ln S_o - kXt$$

Thus, the gradient of the line on the plotted graph is k.

III. RESULTS AND DISCUSSION

A. CHARACTERISTIC OF RAW WASTEWATER

Table 3 shows the characteristic of raw wastewater then the mean value was calculated based on six batch results obtain in between February and May 2019.

Table 3 Characteristic of raw wastewater

Parameters	Average	Range	Standard B
pH	5.46	4.4 – 6.9	5.5 – 9.0
COD (mg/l)	1303	1018 – 1636	200
AN (mg/l)	16.69	0.13 – 31.0	20
TSS (mg/l)	238	110 - 365	100
TDS (mg/l)	2628	1154 - 6020	-
Nitrate (mg/l)	520	470 - 700	-
Turbidity (NTU)	189	189 - 247	-

As can be seen from Table 3, TSS and COD readings exceeded the permissible limit set by standard B Environmental Quality Act 1974. The pH value obtained was in the acidic range probably due to high amount of nitric acid used in the manufacturing process. The observation could also be evidenced from the high nitrate measured in the effluent. Generally, the COD and TSS value obtained from this study is comparatively higher than typical range from other rubber glove manufacturers. The main source of the pollutants is the coagulation serum, field latex coagulation, and skim latex coagulation [7]. As these compounds are readily biodegradable, high oxygen consumption is expected when the discharge of the wastewater to the surface water.

Table 4 shows the concentration of trace metal contains in rubber glove effluent and compared with Standard B for discharge of sewage and industrial effluent of Malaysia. The characteristic study for trace metals was within the range set in standard B. As these metals were danger to human and environment, so it is necessary to control carefully the amount present in the water discharge.

Table 4: Trace metals concentration in rubber glove effluents

Trace Metals (mg/l)	Average	Standard B
Silver	0.1173	1.0
Aluminium	1.7421	15
Barium	0.1473	2.0
Calcium	292.3	-
Cadmium	0.1064	0.02
Cobalt	0.0972	-
Chromium	0.3381	1.0
Copper	0.1460	1.0
Manganese	0.0894	1.0
Lead	0.1648	0.5
Zinc	1.0406	2.0

B. Control test

The control test was conducted in order to determine the effectiveness of MBBR (with biomedia carriers) in comparison with conventional activated sludge process (no biomedia carriers). Total COD (filtered) and soluble COD (decanted) were also measured. Figure 3 shows the COD removal (%) for both processes as a function of reaction time.

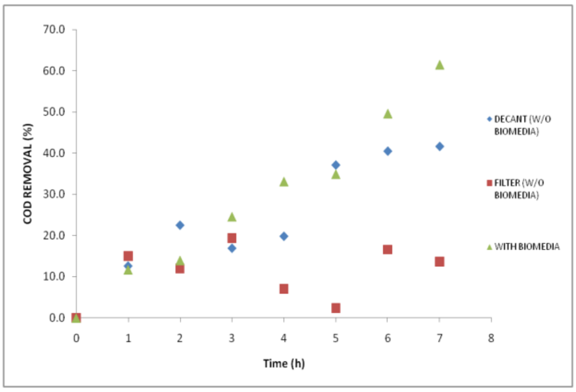

Figure 3: COD removal for MBBR and conventional activated sludge process

During the 1st hour of biological process, the COD removal was about the same for both processes, probably due to the similar reaction rate under insufficient HRT. However, conventional activated sludge process shows fluctuations for both total and soluble COD measured. This observation reflects the inconsistency of conventional process, probably due to other inhibitory short loadings in the process. On the other hand, MBBR process shows increasing COD removal as reaction rime prolong as shown in Figure 3. In addition, MBBR also exhibited constant COD removal, highest at HRT of 7 hours with 62% COD removal. It can be concluded that MBBR is more efficient in comparison with conventional activated sludge process. This observation was in agreement with the research work by Yogita and Mitali (1997) in which the they found that MBBR is an efficient and effective treatment for BOD and COD removal from sewage wastewater.[8]

C. Percent filling

Variations of percent filling of biomedia carriers were carried out through different in biomedia volume to reactor volume. The biomedia carriers provide more surfaces for bacteria growth and increase the biomass in the reactor. Figure 4 shows that the effect of percent filling i.e 10%, 14%, 20% as a function of reaction time.

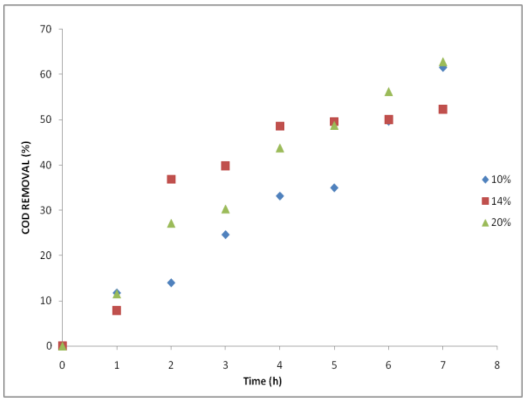

Figure 4: COD removal vs time at different percent filling

For 10% filling of biomedia, the COD removal increased with reaction time at slower rate compared to 14% and 20% filling. At 2nd hour, 14% filling of biomedia shows drastic increased in COD removal until it reached the 5th hour. Overall, it is observed that COD removal was on the same trend with the percent filling of biomedia. This is because biomedia carriers provide more surfaces for biofilm growth. Feng and colleagues found similar findings on the study of the removal of organic compounds and nitrogen using MBBR system [9].

D. Hydraulic retention time (HRT)

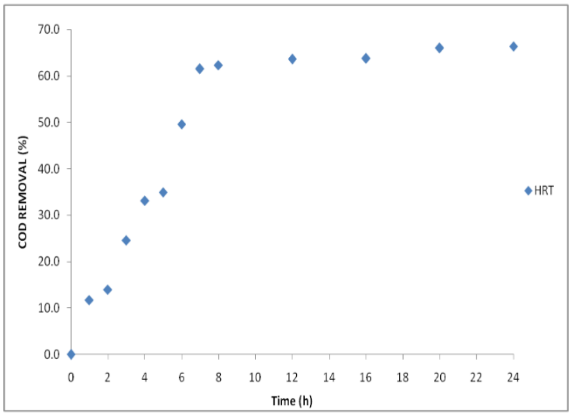

Figure 5: COD removal with different HRT

Figure 5 shows the COD removal in variation with HRT. As shown in Figure 5, COD removal increased with longer HRT. According to Qi Jiang et al (2018), enhanced system performance could be achieved when the MBBR-MBR system was operated at HRT of 18 h [10]. However, in our study, the COD removal reached plateau at saturation HRT of 8 hours. This could be that all biodegradable fraction of organic has been readily degraded by the biomass in the wastewater. Further increase of HRT would not result in further enhancement in COD removal.

E. Organic loading rate (OLR)

Figure 6 shows the COD removal (%) at different organic loading range from 535 mg/l to 746 mg/l.

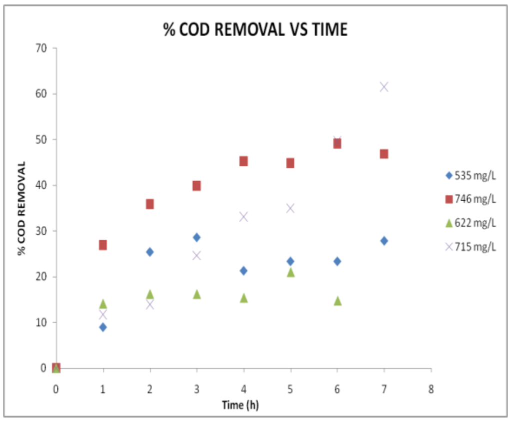

Figure 6: COD removal vs time with different OLR

Generally, COD removal increased with reaction time for regardless of the strength of organic loading. However, no correlation of organic loading with COD removal is observed in this study. Aygun et al. (2008) state that the MBBR process offers an efficient alternative to the conventional biological treatment processes for organic matter removal at high organic loading rates.[11]

F. Reaction rate constant, k

Figure 7 shows the plot of COD readings as a function of Xt. A linear plot was obtained, indicating that the biological process in MBBR is a pseudo-first order reaction.

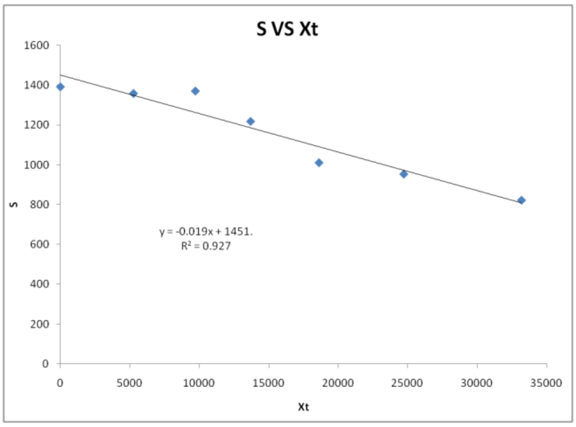

Figure 7: Determination of k value

From the plot, the regression coefficient of 0.927 showed that the experimental data obtained in this study has strong correlation between the COD readings and MLVSS. The biological kinetic coefficient obtained in this first-order linear plot is 0.019 s^{-1}. The biological kinetic coefficient is important as one could apply this data to predict the treatment efficiency of the biological process.

IV. CONCLUSION

In this study, the feasibility of applying MBBR to treat rubber glove wastewater was successfully carried out. In comparison, the MBBR was more efficient than conventional activated sludge process as the biomedia gave more surface contact for suspended solid to attached and encourages biomass growth. The laboratory scale MBBR was effective to remove 62% COD, with 10% filling of biomedia and HRT of 8 hours. The percent filling also gave significant effect to the efficiency of MBBR as the higher percent filling enhanced COD removal in rubber glove effluent. The reaction rate constant obtained for rubber glove wastewater using MBBR process is 0.019 $s^{-1.}$

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