J. Agrobiotech. **Vol 4,** 2013, p. 1–15.
© Universiti Sultan Zainal Abidin
ISSN 1985-5133 (Press)
ISSN 2180-1983 (Online)

Treatment of Rubber Processing Wastewater by Effective Microorganisms Using Anaerobic Sequencing Batch Reactor

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ABSTRACT

The rubber industry, one of the major industrial polluters in Malaysia, is discharging wastewater which contains much organic and inorganic matter from various stages of process operations. Therefore, this study investigated the effectiveness of effective microorganisms (EM) in an Anaerobic Sequencing Batch Reactor (ASBR) system to treat rubber processing wastewater. Four different ratios of EM/wastewater volume were used; 1:100, 1:500, 1:1000 and 1:2000. Chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), turbidity and total suspended solids (TSS) were analyzed in the wastewater. The treatment of EM/wastewater ratio of 1:1000 successfully reduced up to 60% of COD, 62% of BOD_5, 62% of turbidity, and 84% of TSS. This system managed to reduce the pollutants concentrations to the final COD concentration of 557 mg/L, BOD_5 concentration of 226 mg/L, turbidity of 255 NTU and TSS concentration of 75 mg/L. It was found that the ratio of 1:1000 performed best to treat the sample. Overall, this study suggested that EM technology in an anaerobic environment has the capability of elevating the quality of the treated rubber wastewater.

Keywords: Rubber wastewater, Anaerobic Sequencing Batch Reactor (ASBR), anaerobic treatment, effective microorganisms

ABSTRAK

Industri getah, salah satu industri pencemar utama di Malaysia, didapati menyingkirkan air buangan yang mengandungi banyak bahan organik dan tak organik berpunca daripada pelbagai peringkat operasi pemprosesan. Oleh itu, kajian ini dijalankan untuk mengkaji keberkesanan mikroorganisma berkesan (EM) dalam sistem Reaktor Kelompok Penjujukan Anaerobik (ASBR) untuk merawat air buangan pemprosesan getah. Empat nisbah isipadu EM/air buangan yang berlainan telah digunakan iaitu 1:100, 1:500, 1:1000 dan 1:2000. Analisis air buangan yang dijalankan termasuklah permintaan oksigen kimia (COD), permintaan oksigen biokimia (BOD_5), kekeruhan dan jumlah pepejal terampai (TSS). Rawatan dengan menggunakan nisbah 1:1000 telah berjaya menyingkirkan sehingga 60% COD, 62% BOD_5, 62% kekeruhan dan 84% TSS. Sistem tersebut berupaya mengurangkan kepekatan bahan pencemar sehingga menghasilkan kepekatan akhir COD yang bersamaan 557 mg/L, BOD_5 bersamaan 226 mg/L, kekeruhan bersamaan 255 NTU dan kepekatan TSS bersamaan 75 mg/L. Didapati nisbah 1:1000 memberikan perawatan sampel yang terbaik. Secara keseluruhannya, kajian ini menyarankan bahawa teknologi EM dalam sistem anaerob adalah berkeupayaan untuk meningkatkan kualiti air buangan industri getah yang telah dirawat.

Kata kunci: Air buangan getah, Reaktor Kelompok Penjujukan Anaerobik (ASBR), rawatan anaerob, mikroorganisma berkesan

INTRODUCTION

Malaysia is the third biggest producer of natural rubber in the world. In April 2012, the production of natural rubber was 60,888 tonnes, a reduction of 7.0% or 4,569 tonnes as compared to the production a year ago. The smallholding sectors contributed 95.1% of total production while the estate sectors contributed the remaining 4.9% (Department of Statistics, 2012).

During the processing of rubber, water is used for washing, cleaning and dilution. The amount of effluent generated from an average-sized rubber factory producing about 20 metric tons of rubber was estimated at 410,000 litres per day. On the basis of this calculation from Peninsular Malaysia alone, about 80 million litres of effluent is discharged per day, normally to nearby streams or rivers, mostly without any treatment which will cause environmental pollution (Rungruang and Babel, 2008). The plant involved in this study is a major producer of both natural rubber and synthetic latex in Peninsular Malaysia. The production volume on the average is 84,000 metric tonnes a year (Anon, 2005).

Rubber processing wastewater contains a high level of dissolved organic solid. The ratio of COD and BOD_5 has indicated that the effluent would be amenable to biological treatment (Mitra Mohammadi *et al.*, 2010). The treatment processes for rubber factory effluent that are currently being evaluated by the Rubber Research Institute of Malaysia (RRIM) includes anaerobic/stabilization ponding system, oxidation ditch, anaerobic filter, land disposal and rotating bio-disc (Isa *et al.,* 1988).

Anaerobic wastewater treatment is accomplished through microbiological degradation of organic substances in the absence of dissolved molecular oxygen. It requires long retention times and elevated temperatures and is considered economically viable on only wastes of high organic strength. It is normally used for stabilization of waste bio-solids from aerobic treatment process or as a treatment step preceding aerobic treatment, in which large, complex molecules were broken down to more readily biodegradable substances. It is now used routinely at ambient temperatures on industrial wastewaters with organic strengths as low as 2,000 to 5,000 mg/L COD (Woodard and Curran, 2006). Sequencing Batch Reactor (SBR) is a recent development to treat high solids waste streams. It consists of five operating periods: fill, react, settle, draw and idle. Biological reactions commence during the fill period while the contents are mixed. The food to microorganism ratio (F/M) is high right after the feed cycle is completed providing a high driving force for metabolic activity and high overall rates of waste conversion to biogas. Up to the end of the react cycle the substrate concentration is minimum, providing low F/M ratio for biomass flocculation (Dague *et al.*, 1992). The idle period is the time between the end of supernatant withdrawal and the next feeding of the reactor.

Application of anaerobic sequencing batch technology to wastewater with high solid content can offer improvement in performance and stability compared to conventional anaerobic digestion. The ASBR can successfully retain and treat high solid content wastewater without any problems related to clogging of solids (Zupancic *et al.*, 2007). Although the ASBR process is a relatively new concept, research in this field has been used, with some success, for the treatment of swine waste (Massé *et al.,* 2003), winery and distillery wastewater (Moletta, 2005) and domestic wastewater (Jiabin and Xiuping, 2011).

Higa (1991) started the EM system which describes the theories, technology and applications of beneficial microorganisms, such as phototrophic bacteria, yeast, lactic acid bacteria and actinomycetes. This technology is natural and is utilized in a wide range of applications including purifying water and sewage, improving recycled water, solving sanitary problems and improving the environment as well as used in agriculture, animal husbandry, fisheries and food production (Higa, 1991). EM consists of three principal organisms, namely phototrophic bacteria, lactic acid bacteria and yeasts. These three types are indispensable for EM and even if other species were not included, these would develop coexisting forms with other beneficial organisms in the environment. This happens, as EM is not made under sterile conditions, but using simple technology in many difficult environments (Higa, 2001).

The objective of this study was to determine the effectiveness of activated EM in improving the quality of wastewater from the rubber industry and to monitor the capability of biological treatment alone to treat the rubber wastewater in relation to the application of activated EM in an aquatic anaerobic environment that will remove and consume organic waste material.

MATERIALS AND METHODS

Influent Characteristics

Rubber wastewater from a rubber processing plant in Johor, Malaysia, was collected and treated in a laboratory experiment without any preliminary treatment. Wastewater generated was contributed by five different processing plants inside the site which are Emultex, Alkyd 1, Alkyd 2, Plasticizer and Natural Rubber. Each of the plants has different characteristics and the effluents have been homogenized in a homogenizing tank. Composite samples of the wastewater were collected and analyzed for COD, BOD_5, turbidity and TSS. The apparatus used to measure the COD concentration was HACH 2000 COD Reactor and Spectrophotometer. BOD_5 was determined by incubating a sealed sample for five days and the loss of oxygen was measured by using the Dissolved Oxygen Meter while the turbidity was determined by using a HACH Turbidimeter. For the TSS measurement, the water sample was filtered through a pre-weighed filter. The residue retained on the filter was dried in an oven at 103 to 105 ^{o}C until the weight of the filter no longer changes. The increase in weight of the filter represented the total suspended solids

Wastewater from rubber processing has a wide range of characteristics depending on the product. The average pollutant concentrations in wastewater are shown in Table 1.

Table 1. Influent characteristics of the rubber processing wastewater

Parameters	Concentrations
COD	1377 mg/L
BOD_5	587 mg/L
Turbidity	657 NTU
TSS	465 mg/L

Activation of Effective Microorganisms

Effective microorganisms are available in a dormant state and require activation before the application. Activation involves the addition of 7 liters of chlorine free water and 1.5 kg of brown sugar to 3 liters of dormant EM one week prior to application. Adding a sugar source and culturing the microorganisms ensures that the microbes are active.

These ingredients were mixed together in either a 15 liter or 20 liter container and stored in an area with minimal temperature fluctuations. The survival of microorganisms is highly influenced by the temperature fluctuations of their environment. Activating EM is a mostly anaerobic process, thus the presence of excessive oxygen is not desirable. The pH in the solution was determined to ascertain the completion of the process. It was indicated that the pH of the EM should be approximately 4.5 (Szymanski and Patterson, 2003).

Anaerobic Sequencing Batch Reactor Setup and Operation

This system was designed to biologically treat the effluent from the rubber industry. The biological treatment was accomplished using a 30-liter cylindrical reactor made of fibreglass material with an internal diameter of 0.25 m and a height of 0.6 m. The reactor was equipped with a cover plate at both ends to prevent the existence of the oxygen as it was an anaerobic system, rubber stopper silicon tube and a mixer. Another accessory used was a water suction pump. In this study, the reactor was operated at room temperature and no temperature control was carried out. The diagram of the bench scale ASBR system used is depicted in Figure 1. The reactor was operated on a 24 hour cycle as shown in Table 2.

A volume of 20 liters of the wastewater was placed in the ASBR tank in 15 minutes by using a water suction pump. Then, the activated EM in liquid form with a pH of 3.28 was added at a ratio of 1:100. During the react period, both wastewater and activated EM had been mixed using a mixer. A digital timer connected to the reactor was used to automatically control the mixing process which was stopped after 18 hours and followed by a 5 hour settling period. A volume of 2 liters effluent was withdrawn at the end of the settling period. Finally, the system was given 30 minutes of idle time while awaiting the new influent to be treated. This completed an ASBR cycle. An equal amount of wastewater was added to start the next cycle.

A hydraulic retention time (HRT) of 10 days was applied. This refers to the average length of time the whole wastewater remains in a tank. It was calculated by dividing the volume of the wastewater in the tank by the flow rate through the tank (Spellman, 1999). The 10 day HRT was chosen according to Timur and Ozturk (1999), who stated that a 10 day HRT successfully removed approximately 80% of COD in municipal landfill leachate by using lab-scale ASBR. The experiment was repeated for four different ratios which are 1:100, 1:500, 1:1000 and 1:2000 to determine the best ratio that gives the greatest improvement to the wastewater quality.

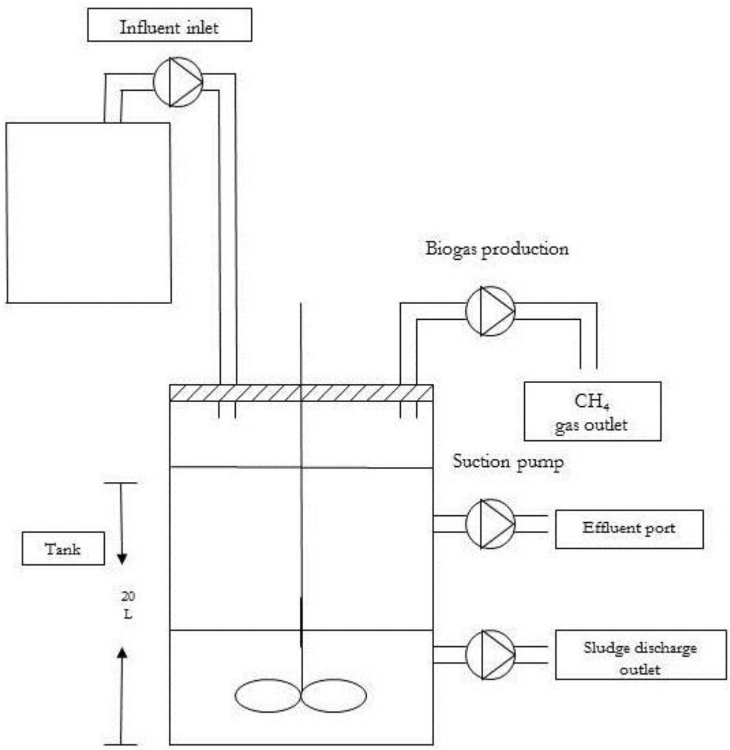

Fig. 1. Schematic diagram of the ASBR system used in this study.

Table 2. Operating period of 24 hours ASBR cycle

Type of Operation	Duration of Operation
Fill	15 minutes
React	18 hours
Settle	5 hours
Draw	15 minutes
Idle	30 minutes

RESULTS AND DISCUSSION

COD and BOD_5 Removal

The removal pattern of COD after treating the rubber wastewater by using biological treatment in the ASBR system for a seven day run is shown in Figure 2.

Figure 2 shows that all the ratios of EM/wastewater volume reduced the COD concentration in all runs of the current research and the differences were statistically significant with a 95% confidence level. However, it was found that the optimum ratio that gave the highest removal was 1:1000. The COD concentration was reduced up to more than 70% after the seventh run. Final COD was approximately 557 mg/L in comparison to the initial concentration of 1377 mg/L. This high effluent COD observed could be caused by the presence of some slowly biodegradable matter (Uyanik, 1997).

Gede (2001) reported that the fermentation process of organic compounds by activated EM has gradually decreased the COD concentration of the wastewater. This means that the biochemical reaction in activated EM treated-wastewater is increasing due to a higher concentration of oxygen in the wastewater. In this study, EM was applied at a concentration of 0.57 mL/L of wastewater and resulted in approximately 80% of COD, eleven days after treatment. The result of fermentation by microbes was the formation of simpler organic compounds such as amino acids, alcohol, sugars, organic acid and ester. It was also assumed that the fermentation process released active oxygen diluted in the wastewater that consequently activates the biochemical reaction (Higa, 1994).

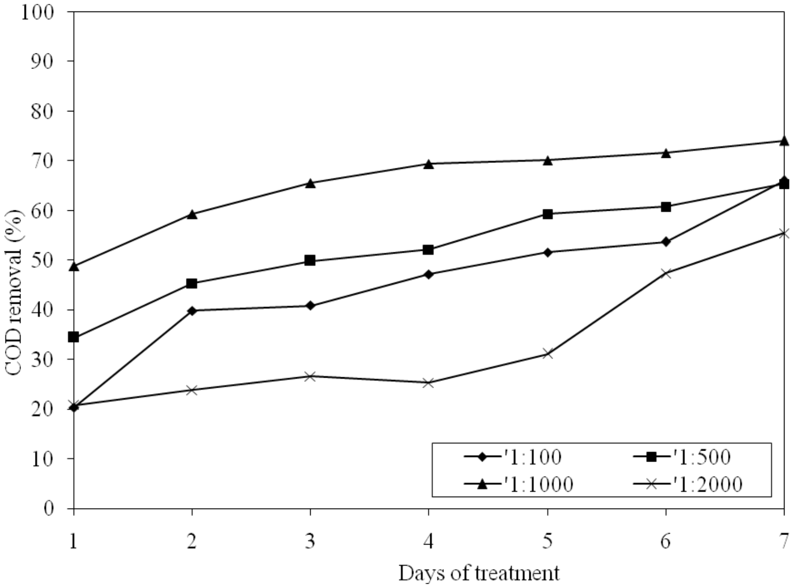

Fig. 2. Percentage of COD removal for four different ratios of EM/wastewater volume.

The same trend can be seen for the removal of BOD_5 for all ratios used. Figure 3 demonstrates the percentage of BOD_5 removal for all the ratios of EM/wastewater volume in the seven day run. This result indicates that the percentage removal increased during the seven day treatment and basically the ASBR system using EM technology can reduce a fraction of BOD_5 concentration present in rubber wastewater with statistically significant removals at a 95% confidence level. The BOD_5 concentration of the final effluent after the seventh day was 225 mg/L, which was treated using the ratio of EM/wastewater volume of 1:1000. This result gave a percentage reduction of about 70%.

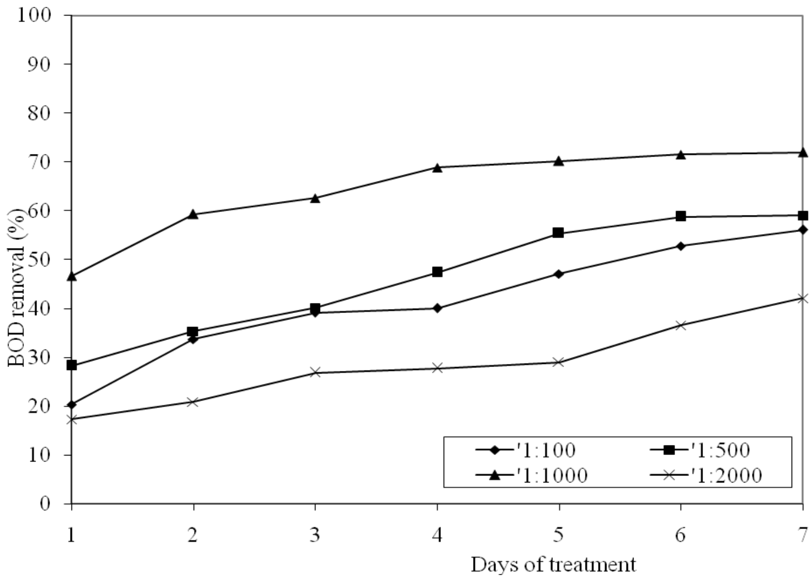

Fig. 3. Percentage of BOD_5 removal for four different ratios of EM/wastewater volume

The complexity of organic and inorganic compounds in the wastewater makes it more degradable by a mix culture of microorganisms rather than single culture of microorganisms. Chemoheterotrophic and photosynthetic bacteria have important roles for the wastewater management to degrade each organic compound (Betty and Winiarti, 1990). Basically, the BOD_5 removal is performed by the heterotrophic microorganisms. These types of microorganisms use carbon for the formation of new biomass (Szymanski and Patterson, 2003).

Turbidity and TSS Reduction

The turbidity reductions of the rubber wastewater using different ratios of EM/wastewater volume are illustrated in Figure 4. In general, all cycles gave a reduction in the value of turbidity, and show the effectiveness of the system. The main trend obtained from the experiment was a decrease in the turbidity of rubber wastewater after the addition of different EM volume. The final effluent has a turbidity of 190 NTU. An effective system is capable to reduce the turbidity of the wastewater. However, one possible explanation of the turbidity variations is that there are different dissolved solid concentrations in each influent leading to little change in the wastewater transparency (Lin and Lin, 1993).

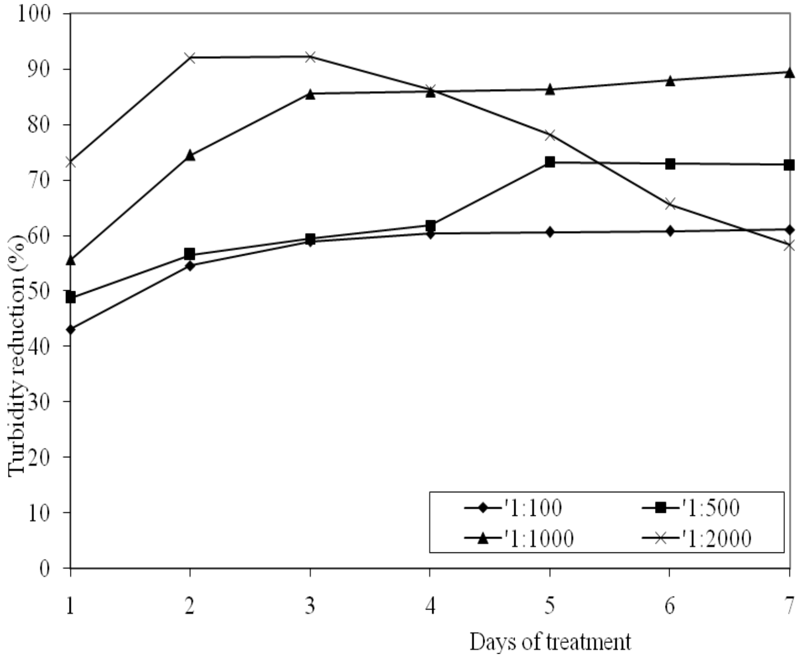

Fig. 4. Percentage of turbidity reduction for four different ratios of EM/wastewater volume

An interesting feature to note from Figure 4 is the decline of turbidity reduction percentage produced by the ratio 1:2000 after the third day of treatment. It was possibly due to the high dilution rate that caused the EM to not stand the high turbidity of the wastewater. The small colony of EM that exists could not reduce the turbidity of the wastewater.

The removal pattern of TSS is displayed in Figure 5. From the figure, it can be concluded that the mixtures of microorganisms in the system used in this research have played their role successfully, resulting in a significant reduction in TSS concentration of the effluent. Higa (1993) supports this statement that EM treatment can reduce the need for solid handling. Little or no solid handling will be necessary because EM works to stabilize organic material and to reduce or eliminate the harmful pathogenic organisms that are in typical wastewater sludge. Sritoomma (1998) stated that EM application was able to reduce pollution of pig wastewater in terms of BOD_5 to about 36.46%, and TSS to about 68.87%. When introduced into an environment of anaerobic biodegradation, the EM rapidly devours the methanogens and toxic pollutants which are formed as a result of the chemical breakdown process.

The ratio of EM/wastewater volume that gave the highest removal was 1:1000. Almost 98% of the initial TSS concentration can be removed and gave the final concentration as low as 75 mg/L. The creation of an antioxidant environment by EM assists in the enhancement of the solid-liquid separation, which is the foundation for cleaning water (Higa and Chinen, 1998). However, the removal of percentage was fluctuating. Possible explanation for the fluctuation is the instability of the EM survival due to the short period of treatment applied in this study. This study has shown that one of the important advantages of anaerobic processes over aerobic processes in wastewater treatment is a high percentage conversion of organic matter to gasses and liquid and a low percentage of conversion to biological cells. The EM introduced to anaerobic wastewater treatment facilities help to reduce the unpleasant by-products of anaerobic decomposition, leaving very little residual sludge (Cheremisinoff and Paul, 1994).

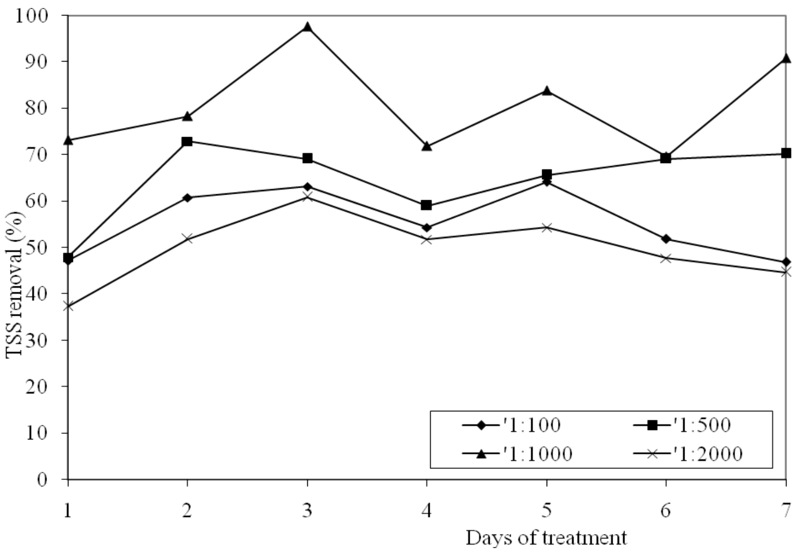

Fig. 5. Percentage of TSS reduction for four different ratios of EM/wastewater volume

Overall Performance of ASBR

Table 3 portrays the comparison of the effluent characteristics of the rubber processing wastewater before and after being treated biologically using the best ratio of EM/wastewater volume of 1:1000. Our results showed that pollutant concentrations were reduced by the treatment of EM using the ASBR system.

Table 3. Effluent characteristics of the rubber processing wastewater before and after being treated biologically

Parameters	Before treatment	After treatment	Percentage reduction
COD (mg/L)	1377	557	60%
BOD_5 (mg/L)	587	225	62%
Turbidity (NTU)	657	255	62%
TSS (mg/L)	465	75	84%

However, the results showed that the COD, BOD_5 and turbidity levels still did not meet the limit set by the Department of Environment (DOE) as displayed in Table 4. A possible explanation is the short treatment period applied which causes the reduction of EM survival. A longer treatment period of up to 20 days will increase the EM survival in order to degrade the pollutants effectively (Namsivayam *et al.*, 2011). Yet, the system has successfully reduced the TSS concentration to 75 mg/L which already meets the DOE limit of 100 mg/L for the standard B discharge.

Table 4. Parameter limits of Standard B effluent

Parameters	Concentrations
COD	100 mg/L
BOD	50 mg/L
Suspended solids	100 mg/L

Source: Government of Malaysia (2003)

CONCLUSION

One of the significant findings emerging from this study was that EM technology has the ability to reduce the pollutants existence in the rubber wastewater. Appreciable reduction of COD, BOD_5, turbidity and TSS were found. Anaerobic treatment is merely efficient for removing biodegradable organic matter. It was observed that the removal percentage increased as the period of treatment increased for all the ratios used. This was attributed to the creation of optimal conditions for EM survival and hence may result in further decreases of pollutant concentrations. The best ratio of EM/wastewater volume was found to be 1:1000. By using the best ratio, the removal percentage of the pollutants achieved after seven days treatment were 60% for COD, 62% for BOD_5, 62% for turbidity and 84% for TSS. From these results, it can be concluded that biological treatment alone might treat rubber wastewater but with a few modifications on the design parameters of the ASBR.

Based on the findings and conclusions of this study, further investigation is recommended to prolong the treatment period in order to increase the EM survival. It is also recommended to have further research to quantify the reduction of odour in rubber wastewater. Temperature and pH monitoring during the whole treatment process can also be carried out as the degradation may affect these two parameters.

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