Hazardous waste landfill leachate treatment using an activated sludge-membrane system

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Abstract This research was aimed to investigate the capability of a combined system of activated sludge and microfiltration processes with backflushing technique to reduce organic carbon and nitrogen compounds in hazardous landfill leachates. The experiments included acclimation, batch and continuous processes. The continuous process was conducted with a 24 hour HRT (Hydraulic Retention Time), and the SRT (Solid Retention Time) ranged from 16 to 36 days. The aeration basin volume was 5 L and the membrane filter used was a hollow fiber module made from polypropylene with pore size of 0.2 µm.

The batch process (without membrane separation) achieved its steady state condition over a period of 33 days. The removal of COD, BOD5 and ammonia-N were 52.5%, 94.3% and 75.5%, respectively. The kinetic parameters obtained are as followed: the maximum specific growth rate constant (µm): 0.96/day and the saturation substrate constant (Ks): 16,445.32 mg/L. The high value of Ks indicated that the leachate was not easily biodegraded. The continuous process revealed that the system with SRT of 32 days was more stable than that of 16 and 24 days. The reduction of COD, BOD5 and ammonia-N were 31.3%; 66% and 98%, respectively. The stable flux was achieved around 5 L/m2.hour.

Keywords Activated sludge; hazardous waste; leachate landfill; membrane separation

Introduction
The increase of national development activities in all areas, especially industrial activities, has increased the amount of wastes being produced including hazardous wastes. To solve the disposal of hazardous wastes problems, the hazardous waste landfills (secured landfills) concept was developed as a secure hazardous waste basin which could prevent or minimize hazardous waste loadings to the environment. Leachate is a contaminated liquid produced from contact between wastes and precipitation or other external waters. Hazardous waste landfills (secured landfills) are made so that leachate can be recirculated or treated before being safely disposed. Leachate compositions depend on the type of waste in the landfill and reactions occurring in it. The leachate from hazardous landfills are characterized with high contents of COD, NH3, metals and alkalinity (Lugowski et al., 1989).

A relatively economical alternative wastewater treatment process to reduce organic carbon and nitrogen compounds in hazardous landfill leachates, compared with physical-chemical technology, is biological treatment. The activated sludge process is one of the aerobic biological treatment methods and consists of aeration and a sedimentation tank.

The conventional activated sludge process (CASP) has several disadvantages. For instance, the production of sludge is high and large areas are required. In addition, its performance is strongly affected by several parameters, i.e. concentration of feed, sludge retention time (SRT), hydraulic retention time (HRT), biomass concentration in aeration tank (MLSS, Mixed Liquor Suspended Solids), organic loading, food to microorganism ratio (F/M ratio), sludge wastage rate, and sludge settling characteristics in sedimentation tank (Grady and Lim, 1980). An increase in biomass concentration will increase the degradation rate and reduce the area needed. Nevertheless, high MLSS in the aeration tank would cause settling problems, because the settling qualities are poor at high sludge
concentrations. In addition, a disadvantage of the secondary sedimentation tank is that its separation ability depends on the operating conditions in the aeration tank. Therefore, the performance enhancement of CASP by increasing MLSS can only be achieved through new methods which do not use sedimentation. An alternative method to replace the sedimentation is the membrane separation technology.

However, a widespread application of membrane technology has been hindered due to the relatively low flux and high energy needed for the membrane filtration. The high energy requirement with this membrane separation is due to high crossflow velocity and pressure to maintain flux stability (Dijk and Roncken, 1997).

In order to reduce flux decline, sufficient high crossflow velocity over the membrane surface has to be maintained. This is subject to high operation cost due to recirculation. An effort to minimize energy consumption has been made by several researchers. Yamamoto et al. (1989) incorporated a hollow fiber membrane directly into the suspended solids aeration tank. It enabled direct solid liquid separation without necessitating a recirculation pump. However, there are still uncertainties whether the process can be stable over a long time operation or not, as the hollow fiber membrane has an inherent drawback of severe clogging at the neck of the module.

Another technique is the rapid backflushing technique. It offers an alternative to maintain flux stability at a low crossflow velocity and pressure. Wenten (1995) has used this technique in microfiltration of fermentation broth. The backflush was used with a high frequency and extremely short duration time (backshock) and combined with the use of reverse asymmetric membrane structures. This backshock mode allows filtration with very stable fluxes at extremely low crossflow velocities and transmembrane pressure, which would significantly reduce energy requirements. This technology integrated with an activated sludge process, has not been studied in detail. Therefore, this research was conducted to investigate the capability of a combined system of activated sludge and microfiltration processes with backflushing technique to reduce organic carbon and nitrogen compounds in hazardous landfill leachates.

Materials and methods

The research methods included experiments with batch and continuous systems using an activated sludge-membrane system. Leachates used in this experiment were obtained from a hazardous landfill located 60 km south of Jakarta.

The batch process without membrane separation was conducted in a tank with working volume of 10 L. Leachate substrate was given only on the first day of operation. The continuous process was conducted in aeration tanks with working volume of 5 L and 24 hour HRT. The SRT was varied, namely 16, 24, and 36 days. The membrane used for the microfiltration process was hollow fiber made from polypropylene. Backflushing was applied with pressured air from the permeate side of the system. The experimental set-up of the activated sludge-membrane combination process is shown in Figure 1. The optimum conditions obtained from membrane characterization was operating TMP (Trans Membrane Pressure) of 0.3 bar and backflushing applied at 0.6 bar, 1 second long with an interval of 2 minutes (Fairus, 1999).

Results and discussion

Batch system operation

The batch system experiment was conducted in a tank with a working volume of 10 L. On the first day, the dissolved COD concentration was 2,036 mg/L, MLSS concentration was 2,240 mg/L and MLVSS was 935 mg/L. Observation of the batch-system was stopped as the system reached steady state conditions which were characterized with constant COD over sev-
eral days. The COD reduction during the batch process is shown in Figure 2. The COD reduced to 988 mg/L (51.5% reduction), while BOD$_5$ reduced to 20 mg/L (94.1% reduction) at the end of experiment. The reduction of ammonia-N at steady state condition was 77.6%.

The low ratio of MLVSS to MLSS (Figure 3) could be caused by the low value of the ratio BOD$_5$ to COD, which was 0.17. This indicated that there was only a small amount of substrate which could be used for maintenance and growth of microorganisms, which resulted in slow microbial growth. According to calculations using a regression technique, by plotting $1/\mu$ to $1/S$ ($\mu$ = specific growth rate and $S$ = residual concentration of limiting substrate), kinetic parameters for the batch system were obtained. The values of $\mu_m$ and $K_s$ were 0.96/day and 16,445.32 mg/L, respectively. The $K_s$ parameter shows substrate affinity to microorganisms. The high value of $K_s$ confirms that the substrate was difficult to be degraded by microorganisms.

**Continuous system operation**

The MLSS and MLVSS data for different SRTs are shown in Figure 4. MLSS concentration at SRT of 16 days increased in the middle of experiment but then decreased again. This indicated that the daily sludge disposal at SRT of 16 days was not balanced with sludge production. MLSS at SRT of 24 and 32 days tended to increase during the experiment. This showed that daily sludge disposal was balanced with sludge production rate.

Figure 5a shows that the permeate COD for SRT of 16 days increased on the 9th day and slowly decreased when COD loadings were lowered by adding fresh substrate with low COD. This indicated that the operation condition with SRT of 16 days and the given COD loading rate (0.34–0.42 kgCOD/m$^3$.day) could not be used in the system.

**Figure 1** Schematic diagram of the combination of activated sludge process and membrane separation

**Figure 2** The COD reduction during the batch process

**Figure 3** MLSS and MLVSS concentration during the batch process
The influent characteristics at SRT of 24 days was as follows: COD, BOD5, ammonia-N and nitrate were 1,800 mg/L, 267.5 mg/L, 114.8 mg/L and 0.32 mg/L, respectively. The increasing permeate COD value phenomenon was also observed in the process with SRT of 24 days (see Figure 5b). This shows that microorganisms could not adapt with the system for a longer period of time. This indicated that the system did not give enough contact-time for microorganisms and substrate to produce energy. Therefore sludge disposal was not balanced with cell growth.

The system conditions at SRT of 32 days were more stable than those at SRT of 16 and 24 days. The value of permeate COD to the last day of experiments did not increase (Figure 5c). It can be concluded that the SRT of 32 days has a more stable condition compared to those of 16 and 24 days, because until the 27th day there was no inhibition of microorganisms in the system. The COD reduction at the end of experiments was 31.3%).
Flux observation at continuous operation

Flux observation at continuous operation with transmembrane pressure (TMP) of 0.3 bar can be seen in Figure 6. The flux value at SRT of 16, 24 and 32 days was relatively constant at 5 L/m².hour. This was lower than the initial flux of 15 L/m².hour at the same operation pressure. This phenomenon occurred because the membrane had been used for some time before being used for this experiment. After a series of experiments had been done, the membrane was washed and had a new permeability value, which was lower than the previous value. This was caused by several factors such as solute adsorption in the membrane, interaction between solute particles with the membrane or with another solute.

The SRT of 32 days experiment was carried out in the first run, therefore a higher initial flux was observed than those of SRT of 16 and 24 days. After initial decrease of flux, the flux values at any SRT was able to be maintained relatively constant with back flushing applied at 0.6 bar, 1 second long with an interval of 2 minutes, for more than 30 days.

SRTs of 24 and 32 days were conducted using the same membrane, membrane I. MLSS concentration tends to increase during the experiment at SRT of 32 days. The increasing MLSS concentration at SRT of 32 days caused its flux to be lower than that of SRT of 24 days. The experiment with SRT of 16 days was conducted with membrane II, which had smaller permeability than membrane I, therefore it gave a lower stable flux.

OUR (Oxygen Uptake Rate)

It is not practical to identify and evaluate bacterial species which influence BOD reduction because there are various kinds of microorganisms in the mixed culture. Therefore, other parameters are needed to identify biological activity, i.e. OUR (Oxygen Uptake Rate) (Boyajin and Glueckstein, 1987).

The lower OUR shows lower biological activity, because of its lower oxygen uptake rate. From Table 1, it can be seen that the batch system has a small OUR (0.149 mg/L.minute), whereas for the continuous system, the longer SRT gave the bigger OUR value.

The process with SRT of 32 days had the highest OUR value of 0.232 mg O₂/L.minute. The process with SRT of 16 days had the smallest OUR value of 0.095 mg O₂/L.minute, and the OUR value at 24 days SRT was 0.12 mg O₂/L.minute. This phenomenon supports the conclusion that the lower SRT gives the smaller biological activity. The OUR values of batch and continuous processes in this study were relatively low compared to a similar

![Figure 6](https://iwaponline.com/wst/article-pdf/48/8/111/423877/111.pdf)

**Figure 6** Flux observation at continuous operation

<table>
<thead>
<tr>
<th>System</th>
<th>Oxygen uptake rate (mg/L minute)</th>
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<tbody>
<tr>
<td>Batch</td>
<td>0.149</td>
</tr>
<tr>
<td>SRT 16 days</td>
<td>0.095</td>
</tr>
<tr>
<td>SRT 24 days</td>
<td>0.120</td>
</tr>
<tr>
<td>SRT 32 days</td>
<td>0.232</td>
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</table>
system treating cassava starch with a high BOD₅ to COD ratio. In the latter experiment, the OUR value for SRT variations of 16, 24, and 32 days were 3.12; 2.60; and 2.03 mg O₂/L·minute, respectively (Budiyono, 1997). The lower OUR value in this experiment might be caused by a low BOD₅/COD ratio in the leachate wastewater. Therefore, degradable substrate for microorganisms was very limited.

For the batch system, substrate (BOD₅) was only fed at the beginning of experiment which was reduced by 94.3% on day 33. MLVSS tends to increase, therefore the amount of substrate left could not fulfill energy needs. For the continuous system, a longer SRT caused MLSS to increase. At SRT of 32 days, daily sludge disposal rate could be balanced with cell growth or active viable cell proportion in the system. MLVSS at SRT of 32 days was relatively constant, as were MLVSS values at SRT of 16 and 24 days, but microorganism activity was assumed to be higher which can be seen from the higher value of OUR.

Conclusions
Hazardous landfills (secured landfills) have been developed to solve hazardous waste disposal problems. Yet, especially when the operation of the secured landfill is ongoing, the contact between external waters (precipitation) with stabilized waste in the secured landfill forms leachates. Leachates are characterized dominantly with COD and NH₃, besides metals and alkalinity.

Biological processes in activated sludge could degrade leachate which consists of recalcitrant organic compounds, with BOD₅/COD ratio about 0.1–0.17. Therefore, this process could become an alternative for leachate treatment. This process could also become the first treatment stage for minimizing physical–chemical treatment loadings, in order to get maximum effluent results.

In the batch process, initial values of COD and BOD₅ were 2,036 mg/L and 350 mg/L, respectively; these values could be reduced to 988 mg/L (51.1%) and 20 mg/L (94.3%). The initial values of MLSS and MLVSS were 2,240 mg/L and 935 mg/L, respectively. Ammonia-N concentration decreased from 107.8 mg/L to 56.8 mg/L at steady state conditions after 33 days.

In the continuous process, SRT of 32 days gave the most stable conditions compared with other variations of SRT. The reduction of COD, BOD₅ and ammonia-N in SRT of 32 days were 31.3%; 66% and 98%, respectively, with faster periods compared to those of the batch system. Longer SRT caused the longer biomass contact with substrate and therefore produced more energy in substrate metabolism. This was emphasized with the OUR value found from the experiment. The longer SRT gave bigger OUR values, which were 0.095; 0.12 and 0.232 mg/L·minute for SRT variations of 16, 24 and 32 days, respectively. The stable flux was achieved around 5 L/m²·hour at various SRTs with permeate consisting of no solids.

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References


