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Performance of a Powdered Activated Carbon (PAC) Augmented Activated Sludge Process Treating Semi-Aerobic Leachate

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ABSTRACT: Semi-aerobic leachate is characterized by organic matter (COD, BOD) which is relatively low in concentration and difficult to biodegrade. In conventional treatment systems, the low biodegradability is attributed to partial stabilization of leachate at the landfill. Biological treatment of leachate in Malaysia is not well established and any important data for the treatment process is not available. The behavior of microbes is unknown for semi aerobic leachate. This research was conducted to establish some of the important data in the biological treatment of semi-aerobic leachate with and without the influence of powdered activated carbon (PAC). For the present study, semi aerobic leachate was collected from Pulau Burung Landfill Site (PBLS), Nibong Tebal, Penang, Malaysia. The experiment involved operating two 16 L laboratory-scale activated sludge reactors in parallel at room temperature and adjusted to pH of 6.5±0.5. One of the reactors was supplemented with powdered activated carbon (PAC) of 75-150 µm size to observe its effect on leachate biodegradation. The results showed enhanced reactor performance due to PAC addition COD, NH_4-N, NO_3-N, TKN, BOD and colour removals was higher.

Key words: Semi-aerobic leachate, powdered activated carbon, activated sludge process

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INTRODUCTION

Sanitary landfill leachate is typically considered to be a very strength wastewater containing many organic and inorganic components. A previous study on combined landfill leachate and domestic wastewater treatment demonstrated that these could be treated at suitable mixing ratio. However, an increase in leachate ratio caused diminution in the overall organic substrate removal rate in batch reactors (Cecen and Aktas, 2001). More to the point, severe nitrification inhibition may be observed in high–strength leachates due to high free ammonia levels and presence of other inhibitors (Aktas and Cecen, 2001). Activated carbon addition in the form of powdered activated carbon (PAC) is known for its ability to enhance biological treatment efficiency, removing refractory organic compounds as well as enhancing nitrification (USEPA Manual, 1995; Kang, *et al.*, 1990). Consequently, PAC addition to activated sludge has been examined by several researchers. Organic matter removal in a PAC treatment system is made possible by a combination of adsorption and biodegradation. Activated carbon in conjunction with activated sludge increases the removal efficiency by adsorbing non-biodegradable, toxic and/or inhibitory organics and also some metals (Metcalf and Eddy, 2004). The mechanism consists of the stimulation of biological activity by bio-regeneration of PAC. Activated carbon provides an attachment surface for micro-organisms to bio-regenerate the activated carbon (Sublette, *et al.,* 1982; Orhansky and Narkis, 1997). This study was conducted to determine the effectiveness of PAC supplementation to (Activated Sludge Process) ASP for improvement of nitrification in semi-aerobic leachate treatment. It was also aimed to determine appropriate reactor operating conditions. No studies have been reported on nutrient removal (COD, NH_4^-N,) removal from landfill leachate using an activated sludge in conjunction with activated carbon process to date. This study was conducted to determine the effectiveness of PAC supplementation to Activated Sludge Process (ASP) for improvement of COD, NH_4^-N, NO_3^-N, TKN, BOD and color removal in semi-aerobic leachate treatment.

MATERIALS & METHODS

Leachate samples were collected from a municipal waste semi-aerobic landfill (Pulau Burung Landfill Site, PBLS), situated within Byram Forest Reserve at 5º 24' N, 100º 24'E in Penang, Malaysia. The total area of the landfill is 23.7 ha and it is equipped with a leachate collection pond. This site has a natural marine clay liner.The site was developed semi-aerobically and is one of the only three sites of its kind in Malaysia. The leachate was characterized and the results are presented in Table 1. The samples were stored at 4 ºC. The low BOD_5/COD ratio (0.17) and high ammoniacal nitrogen concentration (1225 mg/L) indicate low biodegradability and high degree of stabilization of leachate within the landfill, implying high refractory fraction of the COD contents (Kurg and Ham, 1997). A sludge sample as seed was taken from a sedimentation tank of wastewater treatment plant in a textile industry, Penang, Malaysia. The characteristics of the seed are as shown in Table 2. In order to acclimatize the seed, it was stepwise exposed under different dilutions of Leachate. Figure 1 shows the experimental setup used in this study. Two activated sludge reactors were fabricated by plexiglass. The aeration tanks and secondary clarifiers had volumes of 16 L and 1.8 L, respectively. One of the reactors was operated as an AS reactor and to the other, PAC was also added (AS+PAC). Leachate was continuously fed to the system with a peristaltic pump.

Table 1. Characteristics of leachate taken from PBLS (February-August 2005)

Parameters	Variation Range	Average
pH	8.3-8.8	8.5
TCOD (mg/L)	2533-2880	2680
SCOD (mg/L)	2310-2850	2360
BOD_5 (mg/L)	252-730	377
BOD_5/COD	0.09-0.29	0.17
Alkalinity (mg/L as $CaCO_3$)	5658-5662	5660
Colour (Pt.Co.)	4000-4560	4200
Ammoniacal nitrogen (mg/L)	1188-1812	1400
TKN	1440-2191	1745
Nitrate (mg/L)	1-50	14.2
Nitrite (mg/L)	20-110	40
Turbidity (FAU)	418-420	419
Sulphate (mg/L $SO_4^{=}$)	90-110	100
Phosphate (mg/L PO_4^{3-})	38-40	39
T.S.S (mg/L)	78-80	79
Fe (mg/L)	6.60	6.60
Zn (mg/L)	0.26	0.26
Pb (mg/L)	0.34	0.34

Table 2. Characteristics of activated sludge

Parameters	Variation range	Average
pH	7-7.66	7.33
TCOD (mg/L)	13800-13879	13839
SCOD (mg/L)	224-232	228
MLSS (mg/L)	9748-9752	9750
MLVSS (mg/L)	8058-8062	8060
SVI(mL/g)		98.5

Pre-experiment was firstly conducted to determine the optimum dosage of PAC for the continuous experiments. Powdered activated carbon with size 75-150 µm was used for this purpose. PAC was pre-dried at 103ÏC before being used in the experiments. The study was carried out in a batch experiment involving six 1-L beakers with 600 mL leachate and 200 mL activated sludge. Different amounts (0-4 g/L) of PAC was then added to the beakers and the contents were aerated for two days. The results (Fig. 1) suggested the use of 3 g/L PAC in the continuous flow study.

The effect of PAC on the activated sludge process (ASP) was examined via aerated batch reactors (ABR) and continuous flow studies (CF). The reactor was initially operated in batch wise for 10 days and then run in continuous mode. Detail information about the reactor operation is as follows:

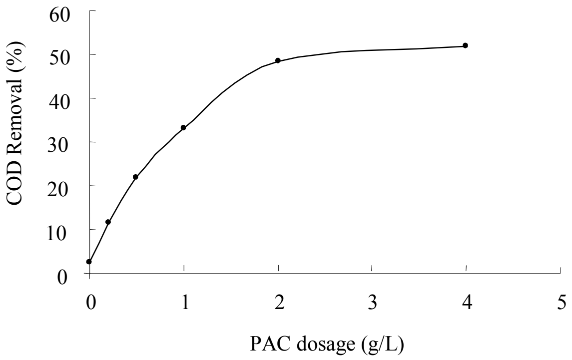

Fig. 1. Optimum dosage of PA

In a batch experiments, the reactor was daily fed following effluent withdrawal. For the purpose of comparison, two reactors, AS and AS+PAC, was simultaneously run in batch mode for 10 days. In this period, some process and operating factors like pH, temperature, and dissolved oxygen (DO) concentration were fixed based on the literature at values of 7, 28 ºC and more than 3 mg/L, respectively. In an interval of 24 h, the mixed liquor content of the reactor was allowed to settle for 1 h. and 0.7 L of the supernatant was then discharged. The same amount of leachate was charged for next batch. The reactor performance was investigated in terms of TCOD, SCOD removal efficiency. Since PAC was wasted daily with the withdrawn sludge, PAC supplementation was made daily with the feed to maintain almost 3 g PAC/L of the mixed liquor.

In this step, experiments were continued in continuous-flow (CF) activated sludge reactors (AS and AS+PAC) with sludge recycling. Two continuous flow (CF) systems were employed to study the effect of PAC addition on the ASP. The reactors were operated under hydraulic retention time of 2.7 days in the course of the experiments (up to 30 days). The sludge was recycled to the aeration tank manually. Both reactors, PAC and NON-PAC were run concurrently. The reactors were operated at room temperature of 25± 2 °C. In this step, the feed concentrations on average were: TCOD: 903 mg/L, SCOD: 804 mg/L, NO_3^--N: 6 mg/L, Colour: 1530 mg/L, Turbidity: 92 FAU, NH_4^-N: 560 mg/L and the loading rate was 0.2 g (SCOD)/L.d. During operation, both reactors were adjusted at pH of 7.0±0.5 by adding 6N NaOH or 6N H_2SO_4. Sufficient air was provided by aquarium pumps to maintain the DO level above 4 mg/L. The MLVSS concentration was maintained constant at about 4000 mg/L. Influent and effluent TCOD, SCOD, pH, MLSS, MLVSS, NH_4^-N, NO_3^-N, Color and Turbidity were measured regularly. A variation less than ±5% in effluent COD concentration was considered as steady state condition.

Analyses were carried out in accordance with Standard Methods for the examination of water and wastewater, (APHA, 1999). COD analyses were performed by the dichromate closed refluxed method. As nitrite ions interfere in COD analyses, therefore COD data were corrected by considering the nitrite nitrogen concentrations. Soluble COD (SCOD) was determined after filtering the sample by GFC filter (Advantec). NH_4^-N analysis was carried out by the Nessler method. NO_3^-N, NO_2^--N and TKN concentrations were determined by a HACH DR/2010 spectrophotometer. MLSS analysis was carried out by drying the residue on GFC filter for one hour at 105 ºC.

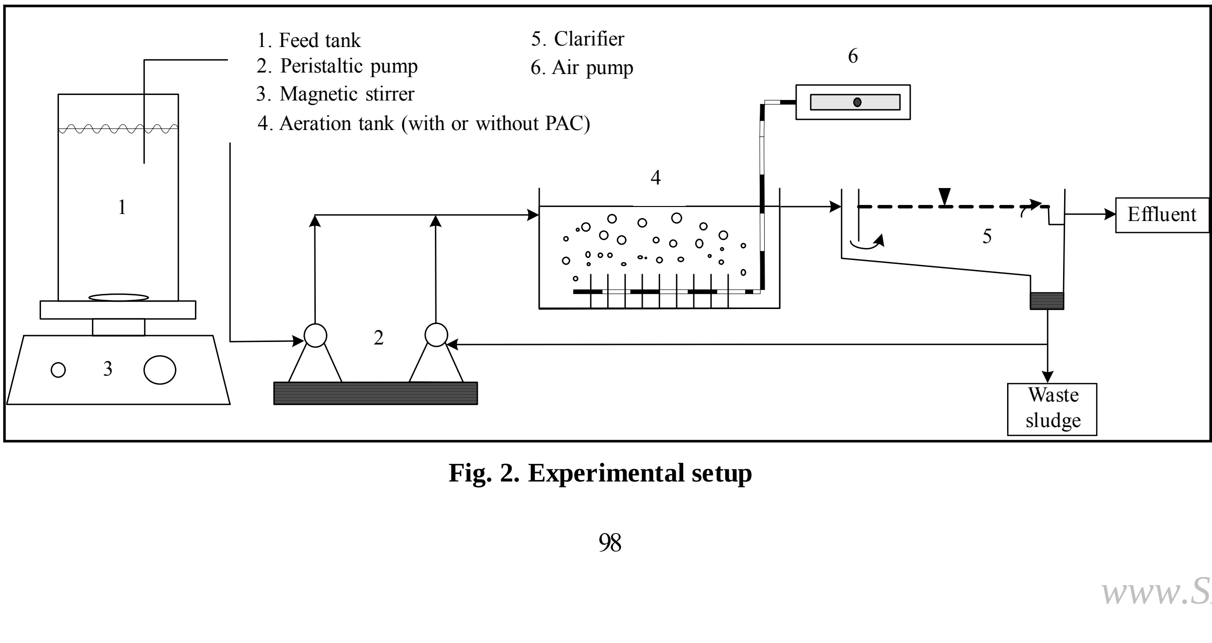

Fig. 2. Experimental setup

MLVSS analyses were carried out by igniting the MLSS analysis residue for 15 min at 550 ºC. For pH measurement, a HACH pH meter was used. BOD_5 analysis was performed by modified Winkler's method, (APHA, 1999).

RESULTS & DISCUSSIONS

Fig. 3. shows a fluctuation in TCOD removal efficiency from 3% to 14% in ABR NON-PAC reactor for first 10 days. It shows that most part of organic matter content of leachate is not biodegradable (corresponding to OLR of 0.1 g COD/L.d). A14% removal efficiency in TCOD was achieved on day of 4th. of reactor operation. It was then decreased to about 4%. This was attributed to high refractory fraction of influent TCOD which causes inhibition to the biological process. At the same time, COD removal efficiency was measured in the ABR PAC reactor where maximum efficiency of 38% was achieved on 4th. day (Fig. 4). COD removal was then maintained at about 30%. Evaluation of effluent COD data led to the conclusion that a decrease in COD removal efficiency resulted from an accumulation of non-biodegradable organic compounds in the system. COD removal by PAC was 3.1%. The feeding mode was changed from batch to continous after 10 days. The COD removal results are presented in Figures 3 and 4. The steady state effluent SCOD concentrations in this period were about 650 mg/L. Figure 3 represents the COD removal in PAC reactor. After 10 days of batch study, continuous flow run was carried out in AS+ PAC. The positive effect of PAC was most pronounced in the stage of aeration where SCOD became adsorb onto PAC. This was in similar with the value (25%) reported by Cecen, *et al.* (2003). The results shown in Figure 4 indicated that in the AS reactor, the COD removal was first increased when readily biodegradable COD was removed. This trend was drastically decreased when mainly non-biodegradable matter was present. Figure 5 and 6 depict the variation of NH_4-N and TKN removal efficiency as the process responses. A slight increasing trend from a minimum value of about 45 % to maximum 60% was achieved for both responses. Figure 7 shows the changes in NO_3-N removal during the continuous operation. The concentration of NO_x-N in the influent was not detected, while it was noticeably significant in the effluent as a consequence of NH_4-N conversion to NO_x-N. Regarding the high concentration of colour in the leachate, it was shown that in aerated activated sludge reactor PAC the colour removal was much higher (50%) than in the NON-PAC reactor (1%) (Fig. 8). A statistic approach to compare the differences of the variation trends of each pair of the responses was carried out using the One-Way ANOVA test available in the SPSS 13.0 software. The One-Way ANOVA procedure produces a one–way analysis of variance for a quantitative dependent variable by a single factor variable. The Levene statistics obtained for each pair of the responses (TCOD removal, NH4-N removal and TKN removal in PAC and NON PAC reactors) to test the equality of group variances are given in Table 3. The Levene statistics of the TCOD removal in PAC and NON PAC reactors with significance value of less than 0.05 rejects the null hypothesis that the group variances are equal (Wong, *et al.*, 2006, Zinatizadeh, *et al.*, 2006).

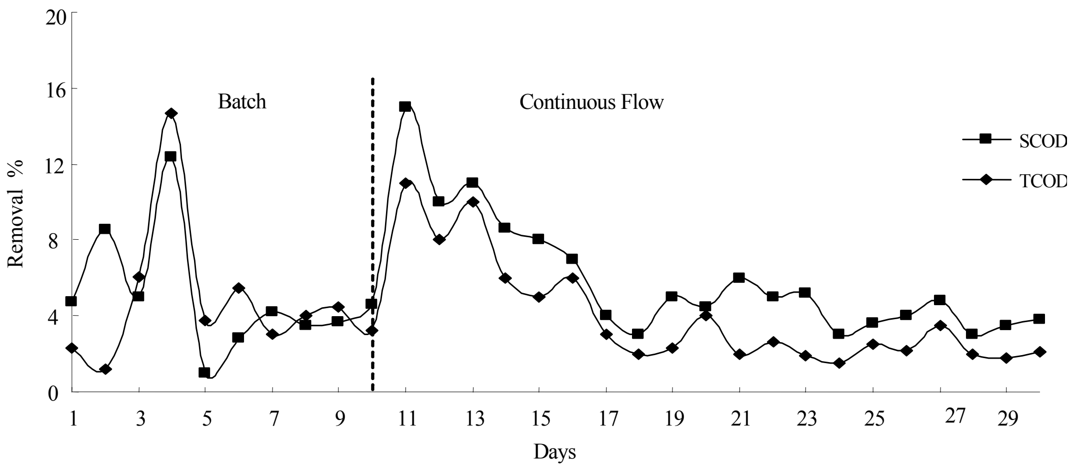

Fig. 3. COD removal efficiency in NON-PAC reactor

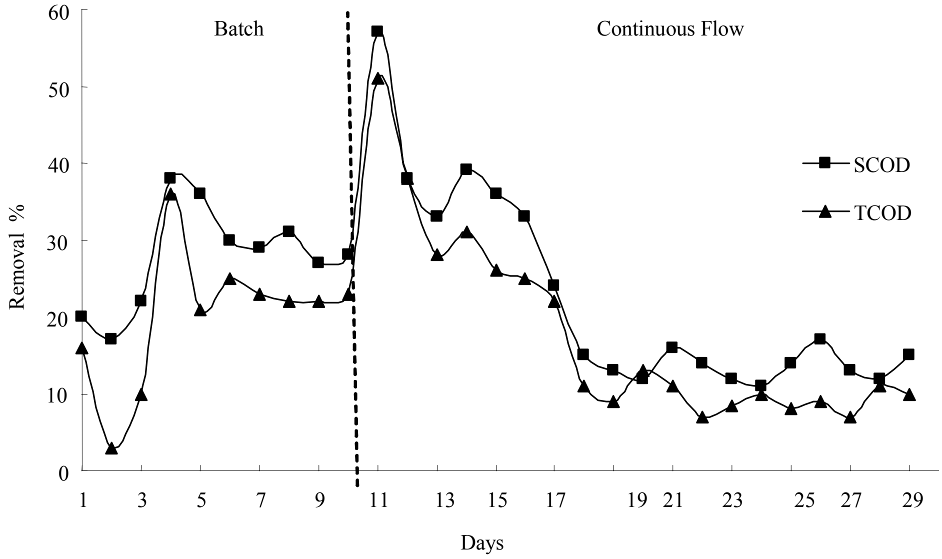

Fig. 4. COD removal efficiency in PAC reactor

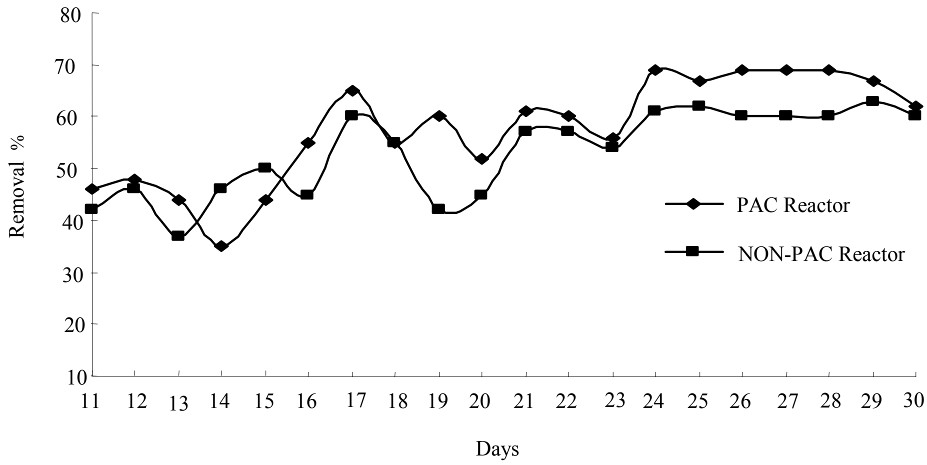

Fig. 5. NH_4-N Removal in PAC and NON-PAC reactors

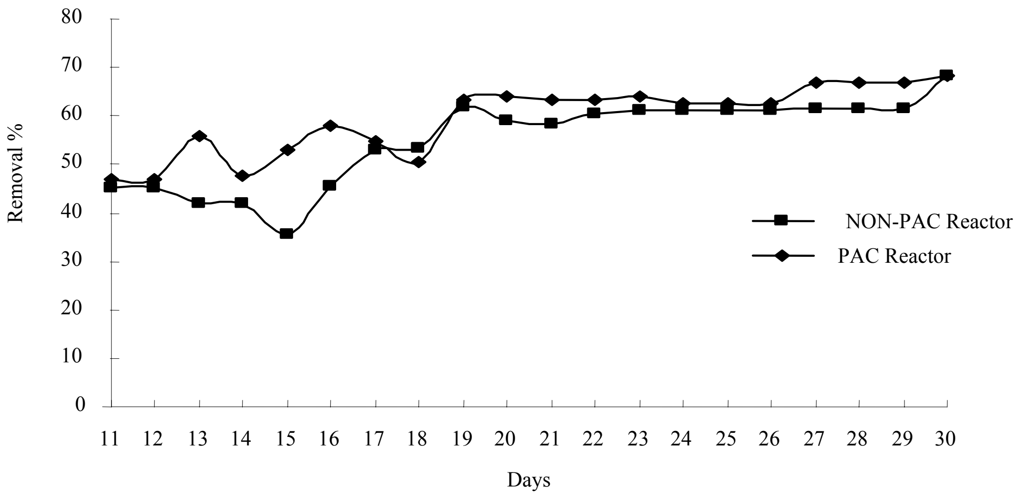

Fig. 6. TKN Removal in NON-PAC and PAC reactors

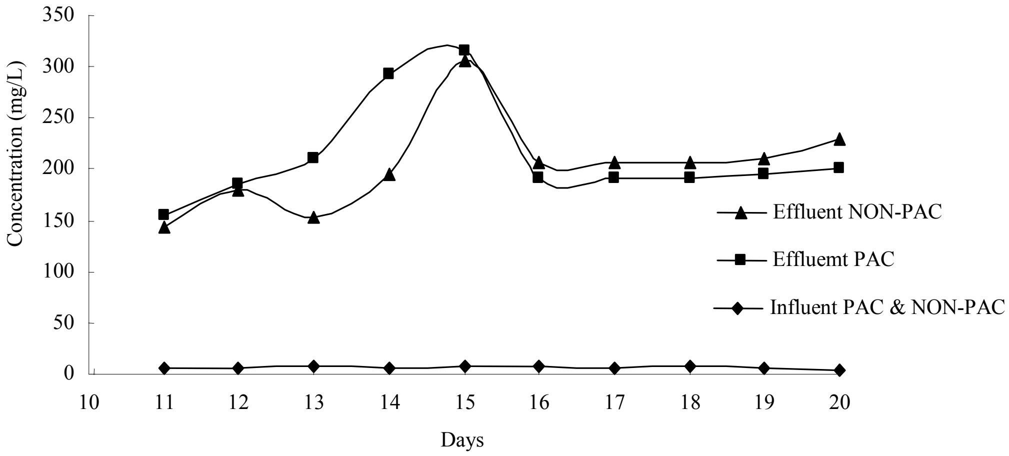

Fig. 7. Concentration of Nitrate in PAC and NON-PAC reactors

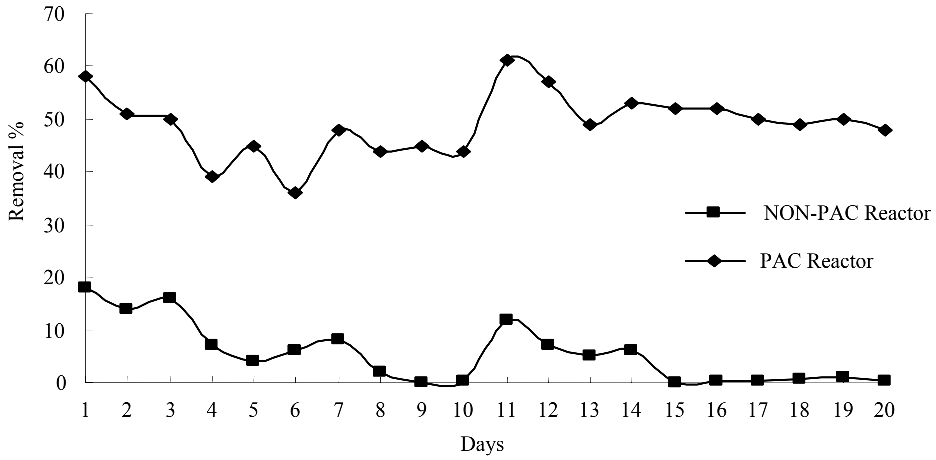

Fig. 8. Color removal in NON-PAC and PAC reactors

Table 3. Levene statistics of the studied parameters

Parameter	Levene Statistics	Significance
(TCOD removal in PAC AS)-(TCOD removal in NON-PAC AS)	41.945	<0.0001
(NH_4-N removal in PAC AS)-(NH_4-N removal in NON-PAC AS)	0.716	0.403
(TKN removal in PAC AS)-(TKN removal in NON-PAC AS)	1.901	0.176

The Levene statistic for comparison of the trends of NH_4-N removal and TKN removal in the two reactors is greater than 0.05 which indicated that the group variances of the responses were equal and PAC reactor showed almost similar effect on the removal of NH_4-N and TKN. The results are corroborated with the findings as shown in Figs. 3, 5 and 6.

The difference in the process performance between batch and continuous conditions could be justified by the following explanation. Due to the once-a-day feeding pattern in the ABR reactor, PAC was initially exposed to high substrate levels and probably became saturated with biodegradable COD, thereby decreasing its effectiveness. In the ABR reactors, micro-organisms were exposed to higher concentrations of toxic and inhibitory organics after each once-a-day feeding. However, in a CF condition they were exposed to lower toxic and inhibitory concentrations owing to the more gradual feed and therefore a better COD removal was observed.

The most striking effect of PAC was the achievement of high levels of nitrification. Hence, an additional factor in nitrification inhibition seemed to be also the presence of inhibitory organics in leachate. Colour removal was more than 54% in the PAC reactor but in NON-PAC reactor very little colour removal was demonstrated (Fig. 8). The near 100% BOD_5 removal in both reactors shows biological treatment has high efficiency and demonstrates microbial activity as is evident in high removal of TKN, and ammoniacal nitrogen.

CONCLUSION

The study brought a novel approach in leachate treatment by showing how and under which circumstances the negative impact of leachate could be relieved by PAC addition in semi-continuous and continuous-flow operations. Generally, PAC addition had a more pronounced effect on organic carbon removal (BOD) than nitrification. The study also emphasized on the differences between CF operations with PAC and NON-PAC reactors. The positive effect of PAC on COD reduction and significantly on colour removal was more striking in CF operation with PAC than in NON-PAC operation. Besides, ammoniacal nitrogen removal was high in CF reactors. For practical purposes, the results in ABR operation implied that under intermittent substrate loadings the effect of PAC would be less compared to steady CF operation.

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NOMENCLATURE

DOE:	design of expert
RSM:	response surface methodology
CCD:	central composite design
CCFD:	central composite face entered design
X1:	initial PHE concentration (mg/l)
X2:	reaction time (h)
Y1:	removal of PHE (mg/mg)
Y2:	extent of biodegradation relative to initial PHE concentration and biomass (mg/mg/mg)
Y3:	specific growth rate (1/h)
R^2	coefficient of determination
ANOVA:	analysis of variance
β_0:	intercept coefficient of Eq. 1
β_i, β_j:	linear coefficient of Eq. 1
β_{ij} :	interaction coefficient of Eq. 1
β_{ii}, β_{jj}:	quadratic coefficient of Eq. 1
K:	the number of factors studied
e:	random error Eq. 1
μ:	specific growth rate (h^{-1})

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