Slovak Society of Chemical Engineering
Institute of Chemical and Environmental Engineering
Slovak University of Technology in Bratislava

PROCEEDINGS

38th International Conference of Slovak Society of Chemical Engineering

Hotel Hutník
Tatranské Matliare, Slovakia
May 23 – 27, 2011

Editor: J. Markoš

ISBN 978-80-227-3503-2

Ćosić, I., Kolačko, K., Vuković, M., Kopčić, N., Briški, F.: Aerobic treatment of leachate from tobacco waste, Editor: Markoš, J., In *Proceedings of the 38th International Conference of Slovak Society of Chemical Engineering*, Tatranské Matliare, Slovakia, 196–203, 2011.

AEROBIC TREATMENT OF LEACHATE FROM TOBACCO WASTE

Ivana Ćosić, Kristijan Kolačko, Marija Vuković, Nina Kopčić, Felicita Briški

Faculty of Chemical Engineering and Technology, University of Zagreb, Marulićev trg 19, HR-10000 Zagreb, Phone: +385 1 4597 270, Fax: + 385 1 4597 260, E-mail: icosic@fkit.hr

Keywords: aerobic treatment, leachate, tobacco waste

This research was initiated to characterize the biodegradability of leachate from composting tobacco waste. Leachate that originated from tobacco waste has high concentrations of chemical oxygen demand (COD). Experiments were conducted in a batch reactor with different initial concentrations of leachate (500, 1000, and 1500 mg dm^{-3}), and initial concentration of activated sludge (5.8 g dm^{-3}) during of 48 hours. The results of the mixed liquor suspended solids (MLSS) concentrations were between 6.38 g dm^{-3} – 6.74 g dm^{-3}. The ratio of MLVSS/MLSS was in the range 0.69 – 0.70. The pH values and dissolved oxygen (DO) were about 7.02 and between 5.90 to 5.44 g dm^{-3}. The COD was reduced by 62 % and resulted to 13.9 % increase in MLSS. The feed to microorganism (F/M) ratio varied from 0.29 to 0.49 g COD (g MLSS) $^{-1}$ d^{-1}. The specific oxygen uptake rate, SOUR varied between 0.16 and 1.31 mg O_2 (g MLVSS)$^{-1}$ d^{-1}. Mean floc size increased by about 24 % within the first 24 h.

Introduction

Solid waste generated by tobacco industry poses an important environmental problem as some main components of tobacco waste are harmful and toxic. Nicotine, the principal alkaloid of tobacco, is both toxic and harmful to health (Buerge, 2008). Also, tobacco industry wastewater contains some toxic contaminants. Investigations carried out showed that the most important sources of these toxic contaminants are nicotine, flavoring chemicals containing glycogen and alcohol, absorbable organic halogens (AOX), and pesticides from tobacco leaves (Sponza, 2002).

Total elimination of nicotine can be achieved by aerobic composting of tobacco waste. Whilst composting technology has successfully facilitated the diversion of organic waste from landfill, and can produce a very high quality end-product, it is associated with some potential environmental hazards, one of which is the production of compost leachate. A leachate may be formed at certain times of the year when, following periods of wet weather, the windrow can exceed its drainable limit leading to seepage from the base. Leachate can also be generated by high moisture content wastes as it decomposes. Due to the high solubility of nicotine in water, there is a serious risk that when stored, nicotine may be leached from the wastes and may migrate to water-bearing strata (Briški et al., 2003a; Wang et al., 2005; Tyrrel et al., 2008).

Treatment of municipal landfill leachate presents unique problems from engineering point of view mainly because of high chemical oxygen demand (COD) (6000 – 15000 mg dm^{-3}) contents. Usually a combination of physical, chemical and biological methods is used for effective treatment of landfill leachate, since it is difficult to obtain satisfactory results by using anyone of those methods alone (Jun, 2006; Kargi & Pamukoglu, 2003). Biodegradation is carried out by microorganisms, which can degrade organics compounds to carbon dioxide and sludge under aerobic conditions and to biogas (a mixture comprising chiefly CO_2 and CH_4) under anaerobic conditions (Renou et al., 2008). Leachate is often treated biologically, for example with the activated sludge process (ASP). The diversity of the microbial community in activated sludge (AS) is very large. The ability of microorganisms to form flocs is vital for the activated sludge treatment of leachate. It is a flexible, reliable process, capable of producing a high quality effluent (Nguyen, 2007; Vuković et al., 2006).

The aim of this work was to study the efficiency of biodegradation of organic pollutants of leachate from composting tobacco waste in batch bioreactor, and investigate changes of activated sludge during the experiment.

Experimental

The activated sludge sample was taken from the Wastewater Treatment Plant in Zagreb, ZOV, Croatia. The sludge sample from WWTP is collected from aeration tank, centrifuged (Sigma 3K15, Germany) at 5,000 ×g for 10 min and 0 °C. The initial activated sludge concentration was 5.8 g dm^{-3}.

The leachate used in the research came from composting tobacco waste following the method of Briški et al. (2003b), which is produced during biodegradation of organic fraction of solid waste. The production of leachate was 800 cm^3 and COD value was 14000 mg dm^{-3}. For the set of experiments, the leachate sample was diluted to initial concentrations of 500, 1000, and 1500 mg dm^{-3}.

Batch biodegradation experiments were conducted in 500 cm^3 conical flasks using 250 cm^3 of diluted leachate and inoculated with 15 g of the centrifuged activated sludge. Samples were taken every 12 h for determination of chemical oxygen demand (COD), mixed liquor suspended solids (MLSS), mixed liquor volatile suspended solids (MVLSS), pH value and dissolved oxygen (DO), and for microscopic investigation. All experiments were performed at 25±2°C and were maintained in aerobic conditions agitated on a rotary shaker at 160 rpm for 48 hours.

Analytical Methods

Mixed liquor suspended solids (MLSS) and mixed liquor volatile suspended solids (MVLSS) were determined gravimetrically and the chemical oxygen demand (COD) was determined by means of the dichromate method using Standard Methods (APHA, 1998). Dissolved oxygen (DO) and pH values were measured with an oxygen meter and pH meter (WTW Multi 340i, Germany). All determinations were averages of duplicate samples.

Microscopical Examination

The morphology of the activated sludge was investigated by light microscopy. Floc development in the bioreactor was monitored by examining sludge samples from the bioreactor under a light microscope (Olympus BX50, Olympus Optical Co. Ltd., Japan, with Olympus DP 10 camera) and by measuring particle size distribution using particle sizing software. A drop of mixed liquor was carefully deposited on a glass slide and covered with a cover slip before being observed through the microscope.

Results and discussion

Legal regulation dictates that wastewater and leachate must be treated before it can be discharged. Activated sludge process has been widely applied to treat wastewater and leachate due to its advantages including low running cost and high degradation efficiency (Renou et al., 2008).

The effect of pollutant removal performance was investigated by batch test in rotary shaker incubator. The biodegradation was conducted for three different initial concentrations of leachate. The purpose of this paper was to examine biodegradation of leachate, changes of sludge concentration, sludge particle size during the experiment, and changes of pH values and dissolved oxygen (DO).

The leachate sample that was obtained from the tobacco solid waste contained high COD, 14000 mg dm^{-3}. Therefore it was diluted to initial concentrations of 500 mg dm^{-3}, 1000 mg dm^{-3}, and 1500 mg dm^{-3} for experiments S1, S2, and S3, respectively. COD value is used to evaluate the organic strength of leachate. It measures the amount of oxygen necessary to completely oxidize organic matter. One limitation of the experiment is that it does not differentiate between biologically oxidizable and biologically inert organic matter.

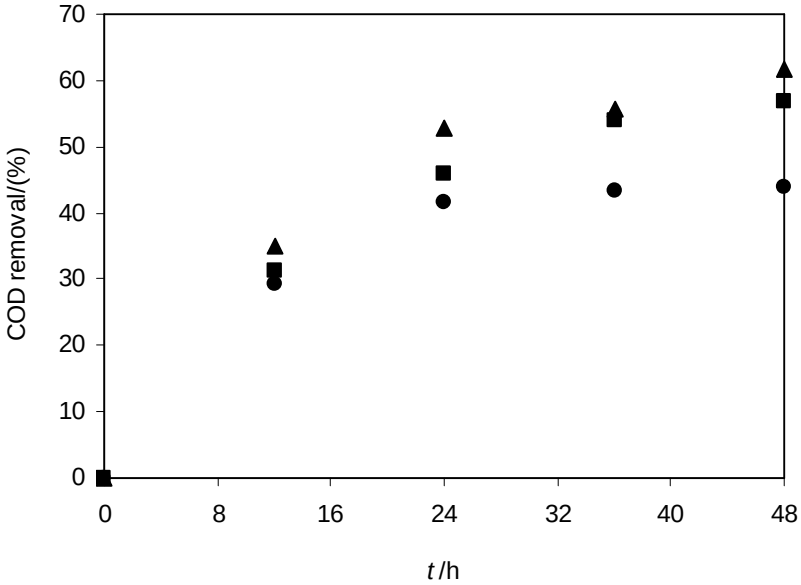

Fig. 1. Biodegradation of leachate at starting COD concentrations of 500 mg dm^{-3} (●),1000 mg dm^{-3} (■), and 1500 mg dm^{-3} (▲).

COD removal efficiency increased with time in all experiments (Fig. 1). Leachate samples were found to be biodegradable with more than 60 % COD removal. After 24 hours, the removal of COD in the sample with the lowest concentration had a value 42 % and, the highest concentration had a value 53 % for COD removal. After 48 hours of treatment, the COD was reduced to 43.8 %, 56.8 %, and 61.7 % of initial value for experiments S1 – S3, respectively. These experiments demonstrated that the leachate was biologically treatable.

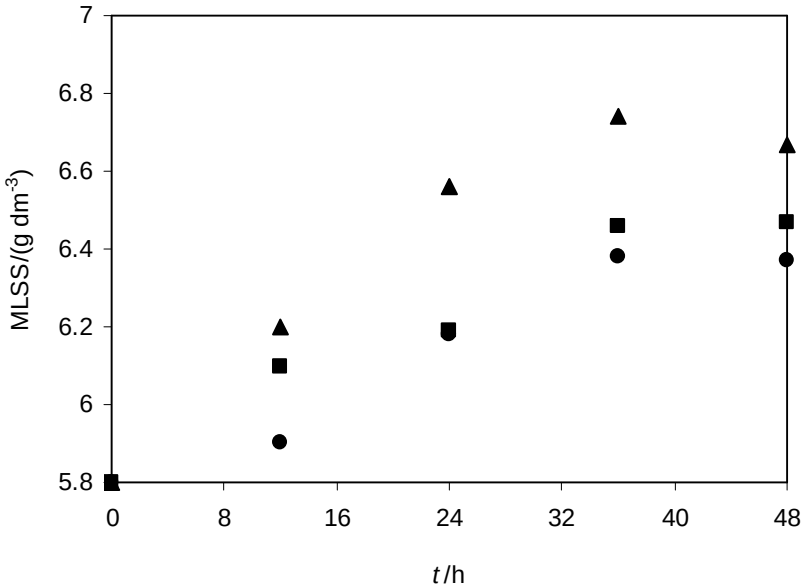

Fig. 2. Changes in concentrations of activated sludge during biological treatment of leachate for S_1 (●), S_2 (■), and S_3 (▲).

Use of activated sludge is an effective way of treating leachate high concentrations of organics. In a biological treatment process, sludge concentration is an important factor to ensure biological treatment ability. A sufficient sludge concentration will ensure good performance in pollutant removal (Huang et al., 2001). The mixed liquor suspended solids (MLSS) were used to characterize the biological mass in the activated sludge. It should be noted that the MLSS consists mostly of microorganisms, non-biodegradable suspended organic matter, and other inert suspended matter. Therefore, the MLSS is an indirect measure of biomass (Vuković et al., 2006). The initial MLSS concentration in all these experiments was 5.8 g dm^{-3}. Fig. 2 shows sludge concentration changes during the experimental period compared under different initial substrate concentration. In all experiment during 36 hours concentration MLSS was gradually increased to 6.38 g dm^{-3}, 6.46 g dm^{-3}, and 6.74 g dm^{-3} for S1 – S3, respectively. The increase in initial concentration of substrate resulted in the increase in MLSS up to a value of 13.9 % for experiment S3. In 48th hour of the experiment MLSS was unchanged for S1 and S2, and slightly reduced for S3 (6.67 g dm^{-3}). This result can be explained as biomass adaptation to the processing conditions.

The MLVSS is a measure for the amount of volatile suspended solids found in a sample of MLSS. Most of the volatile solids in a sample of MLSS will consist of microorganisms and organic matter. As a result, the volatile solids concentration of MLSS is approximately equal to the amount of microorganisms in a leachate and can be used to determine whether there are enough microorganisms present to digest the sludge. Variations in MLVSS/MLSS ratio indicate a change in biomass share.

Table 1. Mean values of leachate parameters analysis

Exp.	MLVSS/MLSS	pH (-)	DO (mg dm^{-3})
S1	0.69±0.03	7.13±0.21	5.90±0.66
S2	0.70±0.02	7.17±0.31	5.57±0.52
S3	0.69±0.02	7.17±0.45	5.44±0.91

Tab. 1 shows values obtained for the activated sludge under batch conditions. In conducted experiments, MLVSS/MLSS ratio was between 0.69 – 0.70. This shows that there was no obvious accumulation of inorganic matter and no significant change in the amount of viable sludge. The important environmental factor that affects the activity of microorganisms in activated sludge is pH value (Coello Oviedo et al., 2003). The pH value for all three experiments varied only slightly and ranged in optimal limits (7.13 – 7.17) over the whole experimental period.

In aerobic bioprocesses, oxygen is a key substrate employed for growth, maintenance and in other metabolic routes, including product synthesis (Witzig et al., 2002). Average values of DO concentration (Tab.1) decreased to values 5.90, 5.57 and 5.44 mg dm^{-3} in experiments S1 – S3, respectively. The low value of the average concentration of dissolved oxygen in experiment S3 is the result of increased oxidation of the substrate due to its higher initial concentration.

Table 2. Mean values of biokinetic parameters

Exp.	$Y_{X/S}$ (g g^{-1})	F/M (g g^{-1} d^{-1})	SOUR (mg g^{-1} d^{-1})

S1	0.28±0.07	0.29±0.02	0.16±0.12
S2	0.25±0.05	0.44±0.06	0.94±0.11
S3	0.22±0.05	0.49±0.09	1.31±0.14

Data obtained from batch biodegradation experiments are shown in Tab. 2. Growth yield is defined as increase in biomass which results from the utilization of amount of substrate. The growth yield coefficient, $Y_{X/S}$, is defined as the ratio of maximum mass of cells formed to the mass of substrate utilized. The overall biomass yield Y, at time t_{end} is $Y_{X/S}$ = $MLVSS_{max}$ - $MLVSS_0$ / COD_0 - COD_{max} where $MLVSS_0$ and $MLVSS_{max}$ are biomass concentration at the start of the experiment and maximum biomass concentration reached throughout the experiments. Similarly, COD_0 and COD_{min} are corresponding substrate concentrations (Drews & Kraume, 2002; Sahinkaya & Dilek, 2005). Mean values of $Y_{X/S}$ decreased from experiments S1 to S3. For activated sludge process sludge yield is normally in the range 0.22 – 0.28 g MLVSS (g COD)$^{-1}$ (Huang et al., 2001).

The food to microorganism (F/M) ratio tells us something about growth and cell condition. In biological wastewater treatment process, F/M is calculated through dividing the amount of treated organic material per unit time by the amount of microorganisms (Yoon, 2003). As can be seen from Table 2, in this study the values of F/M ratio increased by increasing initial concentration of substrate from 0.29 to 0.49 g COD (g MLVSS)$^{-1}$ d^{-1}. In experiment S1 value of F/M ratio was lower than in experiments S2 and S3. Low F/M ratio equals little substrate per unit biomass, which leads to competition among microorganisms and results in reduction of the net sludge production. This is in accordance with the maintenance which demands that biomass growth slows down with decreasing nutrient supply (Rosenberger, 2002; Sahinkaya & Dilek, 2005).

The rate of oxygen uptake, OUR, can be taken as a measure of the biological activity. The OUR value is obtained by taking a sample of MLSS and measuring the concentration of DO with time. OUR (mg O_2 dm^{-3} d^{-1}) is evaluated as: (DO_2 - DO_1) / t_2 - t_1, where DO_1 and DO_2 are DO concentrations at time t_1 and t_2; respectively. From OUR data and MLVSS concentration, the specific oxygen uptake rate, SOUR, is evaluated as SOUR = OUR / VSS (Tomei et al., 2003). The SOUR values (Tab. 2) were 0.16, 0.94, and 1.31 mg O_2 (g MLVSS)$^{-1}$ d^{-1} for S1, S2, and S3, respectively. Since oxygen is required by microorganisms to decompose organic matter in an aerobic biological treatment process, sludge activity can be characterized by the sludge specific oxygen consumption rate (Vuković et al., 2006). Mean values of SOUR indicate an increase of sludge activity by increasing initial concentration of substrate.

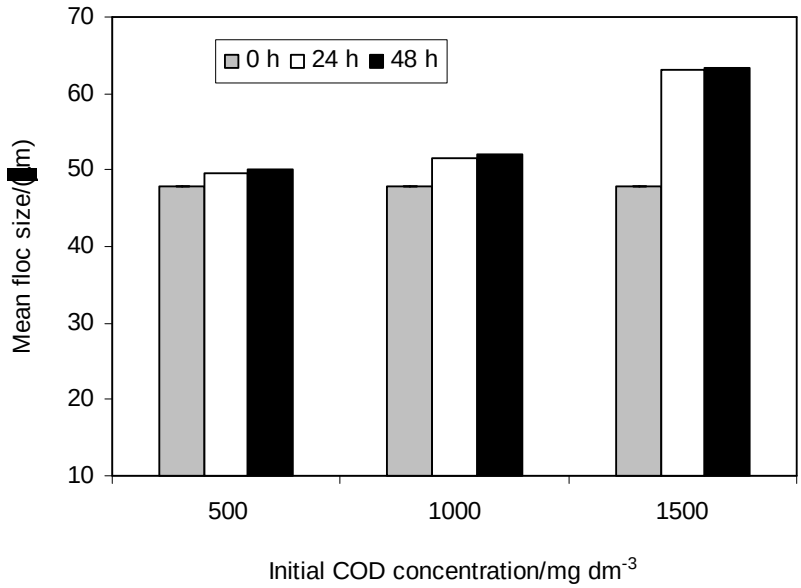

Fig. 3. Comparison of mean floc size values with initial COD concentrations during biological treatment of leachate.

Apart from biochemical activity of activated sludge microorganisms, the physical properties of sludge flocs play also an important role in biological treatment. The morphological properties of sludge were characterized by floc size (Liwarska-Bizukojc & Bizukojc, 2005; Wu et al., 2009). The results of microscopically examination are shows in Figs. 3 and 4. Sludge samples at the start of the experiments (Figs. 3 and 4-left) were characterized by regular formed flocs of mean sizes from 48 μm in all experiments. The growth of flocs is registered within the first 24 h and it is associated with the presence of easily available, biodegradable substrate. Figs. 3 and 4-right show increased mean floc size by about 3, 7, and 24 % with respect to the initial concentrations of COD, S1 – S3. This is explained by the fact that there is a sufficient supply of substrate what enables microorganisms to use energy for the degradation process, as well as growth and reproduction as evidenced by increasing floc size (Huang et al., 2001). During those experiments, within the second 24 h, mean floc size was not significantly changed. This indicates that the removal of substrate was well correlated with the change of sludge concentration and floc size. This points out that biomass has adapted well to the process conditions.

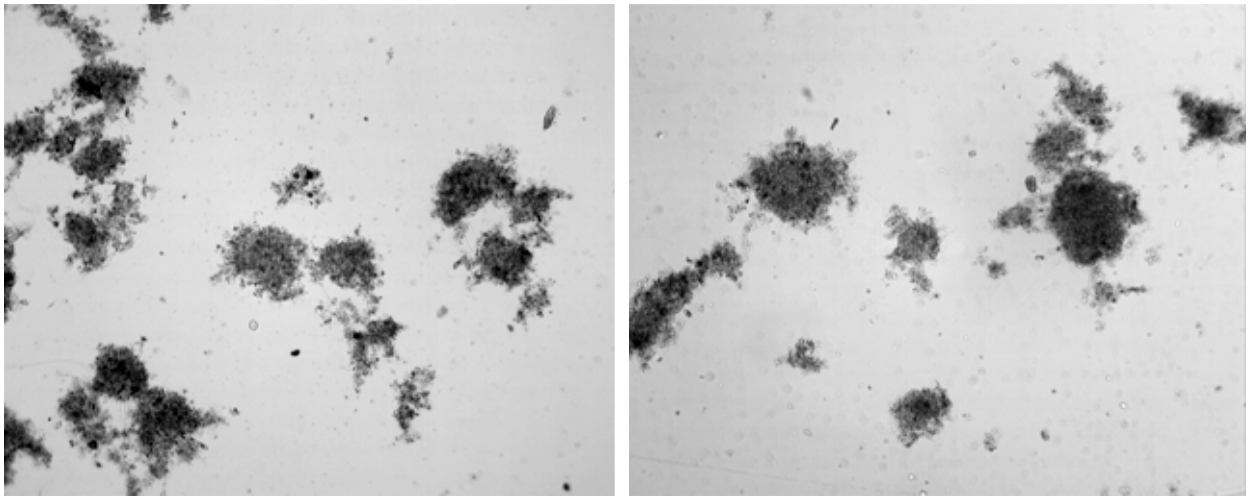

Fig. 4. Microphotographs of activated sludge flocs in batch conditions: left- at the start of the experiment and right- after 24 h of the experiment (100 × magnification).

Flocs present in water play an important part in all issues related to water quality and treatment. The small sludge flocs can provide a favorable environment for enhancement of mass transfer, thus enabling the system to show a higher organic removal rate (Wu et al., 2009).

Conclusions

The obtained results have shown biodegradability of leachate from composting tobacco waste. The results of MLSS concentrations increased between 6.38 g dm^{-3} – 6.74 g dm^{-3}. The ratio of MLVSS/MLSS was in the range 0.69 – 0.70. The pH values and DO were about 7.02 and between 5.90 to 5.44 g dm^{-3}. The COD was reduced by 62 %. The F/M ratio was between 0.29 and 0.49 g COD (g MLSS) $^{-1}$ d^{-1}. The SOUR varied between 0.16 and 1.31 mg O_2 (g MLVSS)$^{-1}$ d^{-1}. Mean floc size increased by about 24 % within the first 24 h.

Nomenclature

COD	chemical oxygen demand	mg dm^{-3}
COD_0	initial substrate concentration	mg dm^{-3}
COD_{min}	minimum substrate concentration	mg dm^{-3}
DO	dissolved oxygen concentration	mg dm^{-3}

F/M	food to microorganism ratio	$g\ g^{-1}\ d^{-1}$
MLSS	mixed liquor suspended solids	$g\ dm^{-3}$
MLVSS	mixed liquor volatile suspended solids	$g\ dm^{-3}$
$MLVSS_0$	initial biomass concentration	$g\ dm^{-3}$
$MLVSS_{max}$	maximum biomass concentration	$g\ dm^{-3}$
OUR	oxygen uptake rate	$mg\ dm^{-3}\ d^{-1}$
SOUR	specific oxygen uptake rate	$mg\ g^{-1}\ d^{-1}$
$Y_{X/S}$	growth yield coefficient	$g\ g^{-1}$

Acknowledgements

This work was supported by the Ministry of Science, Education and Sports of the Republic of Croatia under the Research Project 125-1251963-1968.

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