Natural attenuation, biostimulation and bioaugmentation of landfill leachate management

X Y Er¹, T W Seow², C K Lim³ and Z Ibrahim⁴

¹,²,³ Faculty of Technology Management and Business, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, Malaysia.
⁴ Faculty of Biosciences and Medical Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor Bahru, Johor, Malaysia.

E-mail: erxinyi1992@gmail.com

Abstract. Landfills used for solid waste management will lead to leachate production. Proper leachate management is highly essential to be paid attention to protect the environment and living organisms' health and safety. In this study, remedial strategies used for leachate management were natural attenuation, biostimulation and bioaugmentation. All treatment samples were treated via 42-days combined anaerobic-aerobic treatment and the treatment efficiency was studied by measuring the removal rate of COD and ammonia nitrogen. In this study, all remedial strategies showed different degrees of contaminants removal. Lowest contaminants removal rate was achieved via bioaugmentation of B. panacihumi strain ZB1, which were 39.4% of COD and 37.6% of ammonia nitrogen removed from the leachate sample. Higher contaminants removal rate was achieved via natural attenuation and biostimulation. Native microbial population was able to remove 41% of COD and 59% of ammonia nitrogen from the leachate sample. The removal efficiency could be further improved via biostimulation to trigger microbial growth and decontamination rate. Through biostimulation, 58% of COD and 51.8% of ammonia nitrogen were removed from the leachate sample. In conclusion, natural attenuation and biostimulation should be the main choice for leachate management to avoid any unexpected impacts due to introduction of exogenous species.

1. Introduction

Use of landfill will accompanied with leachate production due to waste decomposition and leaching occurs when rainwater percolates through the landfill [1]. Leachate leaching will lead to significant adverse impacts such as environmental pollution and living organisms’ health risks [1]. Key factors such as waste heterogeneity will affect the leachate quality [2] and poor leachate quality will attribute to leachate adverse impacts. Several parameters including COD and ammonia nitrogen can be used to illustrate the leachate quality. COD used to measure the amount of oxygen needed for organic matters oxidation by oxidizing agent [3] and high COD level indicated presence of high amount of both biodegradable and non-biodegradable organic matters in the leachate sample [4-5]. In the leachate sample, ammonia nitrogen can be found in the form of organic nitrogen, ammonium, nitrate, and nitrite [6]. The adverse impacts of releasing high levels of ammonia nitrogen into the environment are eutrophication, algal blooming and so on [7].
To minimize the adverse impacts of leachate sample, leachate needs to be collected and treated properly via biological, physical and chemical methods [8-9]. Although both physical and chemical treatment methods able to treat the leachate sample efficiently within short duration, the disadvantages of both methods are costly and may lead to unexpected secondary pollution. Hence, biological method involves use of microorganisms or microbial metabolic pathway for pollutants removal is recommended for long-term leachate treatment [10]. Microorganisms able to assimilate the pollutants present in the leachate sample to support microbial growth and metabolic activities [11]. Biological treatment can be divided into aerobic and anaerobic treatment. As reported by Abbas et al [12], organic matter degradation mainly occurs during anaerobic treatment, while aerobic treatment mainly involved ammonium and partial organics removal. Hence, both anaerobic and aerobic treatments are suggested to be used together as combined anaerobic-aerobic treatment for leachate management.

To survive in the extreme environment, microorganisms may possess bioremediation potential or ability to utilize certain pollutants as carbon and energy sources for growth [13]. Hence, bioremediation efficiency of contaminated site is expected to depend on native microbial consortium. At the contaminated site, native microbial population is expected to adapt better and metabolically active when comparing to exogenous species [14-16]. Use of native microbial consortium for contaminated site management without any amendment or human input is known as natural attenuation [15]. When relying on natural attenuation is not enough to trigger the contaminants removal rate, other remediation strategies such as biostimulation and bioaugmentation should be considered for better biodegradation efficiency by increasing the living microbial cell population present at the contaminated site [15, 17-18].

Biostimulation can induce native microbial growth via physiochemical and environmental factors adjustment including nutrient addition [17-19]. As reported by the study of Simpanen et al [15], when compared to natural attenuation, biostimulation able to remove more pollutants from the leachate sample. Bioaugmentation refers to seeding of microorganisms with degrading capability to induce the degradation rate [16, 19] and highly recommended when natural attenuation and biostimulation unable to perform efficient degradation rate [19-20]. However, use of bioaugmentation strategy may lead to uncontrolled adverse impacts due to introduction of exogenous species [20]. In this study, B. panacihumi strain ZB1 is used for bioaugmentation. Members from genus Brevibacillus might carry genes related to environmental stress responses such as nitrifying-denitrifying properties as reported by other researchers [21-22]. Since the members belong to genus Brevibacillus possess different degrees of degrading ability [23], B. panacihumi strain ZB1 is expected to possess certain biodegradation potential in this study.

2. Materials and Methods
The landfill selected for this study was currently operated landfill located in the north-west region of Johor. This landfill received more textile waste as compared to domestic waste. The leachate sample was collected via composite sampling method, homogenized as single sample and kept in the cold room at -80 °C. The leachate treatment samples were prepared in the 200 mL conical flasks as shown in the table 1. Nutrient broth used for biostimulation process was prepared by using nutrient broth powder (Merck, Cat. number 105443), which is an universal medium for microorganisms cultivation and B. panacihumi strain ZB1 was kindly provided by Lim et al [22].

The leachate sample was treated anaerobically for 21 days in the incubator at static condition and followed by 21-days aerobic treatment in the incubator shaker with 150 rpm [22]. Leachate samples were treated at 37 °C and assessed in triplicate samples. After treatment session, the leachate samples were centrifuged at 4000 rpm for 15 minutes [22]. The supernatant were used for ammonia nitrogen analysis (Nesslerization method) and COD analysis (reactor digestion method) by using HACH DR 6000 spectrophotometer [22]. Ammonia nitrogen and COD were selected for treatment efficiency measurement due to quick analysis and these parameters were also concerned when referring to leachate discharge limit.
Table 1. Treatment conditions in this study

| Treatment sample       | Treatment condition                                      |
|------------------------|----------------------------------------------------------|
| Natural attenuation (NA)| Raw leachate without any amendment                       |
| Biostimulation (BS)    | Raw leachate + 10% (v/v) nutrient broth                  |
| Bioaugmentation (BA)   | Raw leachate + 10% (v/v) B. panacihumi strain ZB1      |

3. Results and discussion

COD and ammonia nitrogen concentrations of each treatment samples were measured before and after the treatment as presented in the figure 1.

![Figure 1](image_url)

Figure 1. The average concentration of COD presents in the treatment sample for three treatment conditions. The COD concentration in the BS sample and BA sample were slightly higher as compared to NA sample before any treatment process.

As shown in figure 1, BS sample had 18% higher COD concentration as compared to NA sample and this might be contributed by introduction of organic matters present in the nutrient broth. The COD concentration in BA sample was 21% higher than NA sample after introduction of B. panacihumi strain ZB1 pre-grown in the nutrient broth. This might be contributed by presence of high microbial cells (OD$_{600}$ > 1.0), microbial metabolic products [24] and carbon sources in the solution that augmented into the BA sample. After 21-days anaerobic treatment, the COD removal rate achieved by NA, BS and BA sample were 22%, 36% and 36.5% respectively. The COD removal rate was further increased to 41%, 58% and 39.4% for NA, BS and BA samples respectively after 21-days aerobic treatment. Throughout the treatment session, COD levels were proportionally decreased with time in all treatment samples. This might be contributed to degradation of readily and slowly biodegradable COD that present in the leachate sample by the microorganisms to support biomass growth [17, 25-26]. The residual COD concentration in NA, BS and BA samples was 2060, 1805 and 2708 mg/L. Non-biodegradable COD present in the raw leachate sample especially textile waste would attribute to the residual COD [24, 26].
Figure 2. The average concentration of ammonia nitrogen presents in the treatment sample for three treatment conditions

As shown in figure 2, the ammonia nitrogen concentration in all treatment samples increased after anaerobic treatment and decreased with further aerobic treatment. The ammonia nitrogen concentration of NA, BS and BA samples increased by 10.2% to 1080 mg/L, 17.8% to 1125 mg/L and 62% to 1813 mg/L respectively after anaerobic treatment. Degradation of nitrogenous portions of organic matters such as proteins might contribute to increase of ammonia nitrogen concentration [12, 25]. After anaerobic treatment, the ammonia nitrogen concentration was reduced by 63% to 400 mg/L in NA sample, 59% to 460 mg/L in BS sample and 62% to 697 mg/L in BA sample via aerobic treatment. Reduction of ammonia nitrogen concentration from the treatment sample might be caused by use of ammonia nitrogen by microorganisms for growth and metabolism activity [27].

In this study, all treatment samples showed different degrees of COD and ammonia nitrogen removal indicated that both native microbial population and *B. panacihumi* strain ZB1 able to remove certain degrees of target contaminants from leachate sample. Both NA and BS samples showed higher contaminants removal rate as compared to BA sample. This indicated that native microbial population have the waste remediation potential to remove certain degrees of target contaminants and removal efficiency could be further improved by biostimulation [19, 28]. Biostimulation allows introduction of biodegradable nutrient source as co-substrate to stimulate native microbial growth and maintain microbial metabolic activity and accelerate the decontamination rate [16, 23].

4. Conclusion
To protect the environment and improve public health and safety, more attention should be paid to leachate management. In this study, removal of COD from leachate sample achieved via natural attenuation, biostimulation and bioaugmentation after 42-days combined anaerobic-aerobic treatment were 41%, 58% and 39.4% respectively. Besides that, natural attenuation, biostimulation and bioaugmentation allowed 59%, 51.8% and 37.6% removal of ammonia nitrogen from the leachate sample after 42-days combined anaerobic-aerobic treatment. As a conclusion, native microbial population play more significant role in pollutants removal from leachate sample as compared to *B. panacihumi* strain ZB1 in this study.

Acknowledgements
The completion of this research study required nice support and the authors gratefully acknowledge the Faculty of Technology Management and Business (FPTP UTHM), Office for Research, Innovation,
Commercialization and Consultancy Management (ORICC UTHM) and Fundamental Research Grant Scheme (FRGS) grant vote 1550 for financial support.

References

[1] Djogo M, Dvornic A, Miloradov M V, Radonic J and Vujic G 2011 Determination of pollutant parameters in landfill leachate water of Vojvodina region *Ann. Fact. Eng. Hunedoara- Int. J. Eng.* **9** 87

[2] Raghab S M, Meguid A M A E, and Hegazi H A 2013 Treatment of leachate from municipal solid waste landfill *HBRC J.* **187**

[3] Akpor O B and Muchie M 2011 Environmental and public health implications of wastewater quality *Afr. J. Biotech.* **10** 2379

[4] Reinhart D R and Grosh C J 1998 *Analysis of Florida MSW Landfill Leachate Quality Data* (Gainesville: Florida Centre for Solid and Hazardous Waste Management)

[5] Mes T Z D, Stams A J M and Zeeman G 2003 Methane production by anaerobic digestion of wastewater and solid wastes *Biomethane and Biohydrogen: Status and Perspectives of Biological Methane and Hydrogen Production* chapter 4 58

[6] Oman C B and Junestedt C 2008 Chemical characterization of landfill leachates- 400 parameters and compounds. *Waste Man.* **28** 1876

[7] Abu Bakar A, Daud Z, Ahmad Z, and Othman A R 2012 Treatment of leachate using sequencing batch reactor (SBR) *The International Conference on Civil and Environmental Engineering Sustainability (Iconcess 2011)* Malaysia

[8] Seow T W and Lim C K 2015 A mini review on landfill leachate treatment technologies *Int. J. Appl. Environ. Sci.* **5** 20167

[9] Seow T W, Lim C K, Nor M H M, Mubarak M F M, Lam C Y, Yahya A and Ibrahim Z 2016 Review on wastewater treatment technologies *Int. J. Appl. Environ. Sci.* **11** 111

[10] Silva-Bedoya L M, Sanchez-Pinzon M S, Cadavid-Restrepo G E, and Moreno-Herrera C X 2016 Bacterial community analysis of an industrial wastewater treatment plant in Columbia with screening for lipid- degrading microorganisms *Microbiol. Res.* **192** 313

[11] Kamaruddin M A, Yusoff M S, Aziz H A, and Hung Y T 2015 Sustainable treatment of landfill leachate *Appl. Water Sci.* **5** 113

[12] Abbas A A, Guo J S, Liu Z P, Pan Y Y, and Al-Rekabi W S 2009 Review on landfill leachate treatments *Am. J. Appl. Sci.* **6** 672

[13] Dhall P, Kumar R and Kumar A 2012 Biodegradation of sewage wastewater using autochthonous bacteria *Sci. World J.* **2012**

[14] Tyagi M, da Fonseca M M R and de Carvalho C C 2011 Bioaugmentation and biostimulation strategies to improve the effectiveness of bioremediation processes *Biodegradation* **22** 231

[15] Simpanen S, Dahl M, Gerlach M, Mikkonen A, Malk V, Mikola J, and Romantschuk M, 2016 Biostimulation proved to be the most efficient method in the comparison of in situ soil remediation treatments after a simulated oil spill accident *Environ. Sci. Pollut. Res.* **23** 25024

[16] Yu K S H, Wong A H Y, Yau K W Y, Wong Y S and Tam N F Y 2005 Natural attenuation, biostimulation and bioaugmentation on biodegradation of polycyclic aromatic hydrocarbons (PAHs) in mangrove sediments *Mar. Pollut. Bull.* **51** 1071

[17] Ghaly A E, Yusran A and Dave D 2013 Effects of biostimulation and bioaugmentation on the degradation of pyrene in soil *J. Bioremediat. Biodegradation* **5** 1

[18] Abdulsalam S and Omale A B 2009 Comparison of biostimulation and bioaugmentation techniques for the remediation of used motor oil contaminated soil *Braz. Arch. Biol. Technol.* **52** 747

[19] Adams G O, Fufeyin P T, Okoro S E and Ehinomen I 2015 Bioremediation, biostimulation and bioaugmentation: a review *Int. J. Environ. Bioremediat. Biodegradation* **3** 28
[20] Lee E H, Kang Y S and Cho K S 2011 Bioremediation of diesel contaminated soils by natural attenuation, biostimulation and bioaugmentation employing Rhodococcus sp. EH831 Korean J. Microbiol. Biotechnol. 39 86
[21] Pourcher A M, Sutra L, Hébé I, Moguedet G, Bollet C, Simoneau P, and Gardan L 2001 Enumeration and characterization of cellulolytic bacteria from refuse of a landfill FEMS Microbiol. Ecol. 34 p 229
[22] Lim C K, Seow T W, Neoh C H, Md Nor M H, Ibrahim Z, Ware I, and Mat Sarip S H 2016 Treatment of landfill leachate using ASBR combined with zeolite adsorption technology 3 Biotech 6
[23] Wang D, Ji M, and Wang C 2014 The stimulating effects of the addition of glucose on denitrification and removal of recalcitrant organic compounds Braz. J. Chem. Eng. 31 9
[24] Ciner F and Sarioglu M 2006 Determination of inert chemical oxygen demand (COD) fractions of Cumhuriyet University wastewater Global NEST J. 8 31
[25] Magnaye F A, Pag-asa D G, and Auresenia J L 2009 Biological nitrogen and COD removal of nutrient-rich wastewater using aerobic and anaerobic reactors J. Water Res. Prot. 1 376
[26] Orhon D and Çokgör E U 1997 COD fractionation in wastewater characterization—the state of the art J. Chem. Technol. Biotechnol. 68 283
[27] Kundu P, Debsarkar A, and Mukherjee S 2013 Treatment of slaughter house wastewater in a sequencing batch reactor: performance evaluation and biodegradation kinetics BioMed Res. Int.
[28] Cosgrove L, McGeechan P L, Handley P S and Robson G D 2010 Effect of biostimulation and bioaugmentation on degradation of polyurethane buried in soil Appl. Environ. Microbiol. 76 810