Effects of Landfilled MSW Stabilization Stages on Composition of Landfill Leachate: A Review

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Abstract- **The MSW stabilization stages inside a landfill are the key to understand and monitoring the landfill leachate adverse impacts on the environment. Physical, chemical and microbial processes that takes placed in each stages of landfill stabilization released gaseous and dissolved compounds in terms of landfill gas and leachate characteristics which are major pollutant to groundwater and surface water resources. The potential long term environmental impact of a landfill on water resources would depend on leachate composition such as dissolved organic matter, inorganic, and heavy metals. In this paper the composition of landfill leachate variation were reviewed in different stages of landfill stabilization according to published reports. High leachate compositions are produced in the early acid phase of landfill stabilization due to strong decomposition and leaching. In the long methanogenic phase a more stable leachate compositions with lower concentrations of a BOD5/COD-ratio, very low concentrations of heavy metals are observed. In contrast, the concentration of ammonia does not decrease, and often constitutes a major long-term pollutant in leachate.**

Keywords:- Landfilling, Landfill Leachate, MSW Stabilization and Landfill Leachate Compositions

I. INTRODUCTION

Landfilling has been the simplest and most attractive Municipal solid waste (MSW) management option from low-to-medium developing countries, as it is the cheapest and simplest to implement [1,2,3]. Respect to the point where solid waste generation, about 95% of the total MSW collected worldwide has been disposed of in landfill [4, 5]. Even though, there are other top hierarchy MSW management alternatives, such as recycling, composting and incineration; all alternatives have 10-20% residue that ultimately have to again dispose of in a landfill [6, 7]. The MSW after buried in a landfill, a sequence of simultaneous physical, chemical and biological processes occurred that leads landfill leachate and gases generation [8, 4, 9].

Leachate is the liquid effluent from a landfill, is generated through interaction of the biochemical decomposition product of solid waste and external percolated water in a landfill [10, 8, 7]. After a landfill site closure, landfill will continue to produce leachate pollutants and this process would last for 30-50 years [27]. Leachate comprises huge quantity of organic, inorganic and heavy metal elements, and has a potential source for pollute ground and surface water resources [11, 1, 12, 13]. The risk of groundwater pollution is probably the most severe environmental impact from landfills because historically most landfills have been built without liners and leachate collection facilities. The leachate characteristics were found widely varies among a landfill depend on manner of waste placement, nature of soil strata, moisture content, pH and age of leachate [6, 14, 10, 12, 27].

The leachate organic composition history shows an increase in concentration to a peak values followed by a decreases when landfill aging, while the ammonia concentrations trend to increase with time [15, 7, 16]. As Table 1.0 shows that leachate characteristics are varied associated with specific range of the leachate ages, which are categorized into three age groups such as young (< 5 years), medium (5–10 years), and old (> 10 years). In general, leachate generated in younger landfills often characterized by low pH values (5-6), high BOD_5 (4000-13,000 mg/l) and COD (10,000- 60,000 mg/l) as a result of acid phase of fermentation [11,17,18]; whereas leachate produced in matured landfills often contains bulky quantity of non-biodegradable organic compounds, such as humic and fulvic substances and regularly characterized by high pH values (8-9), low BOD_5 (260 mg/dm3), COD(3000 mg/l) and huge quantity of ammonia resulting from the hydrolysis and fermentation of nitrogen containing fractions of biodegradable substrates[1,18].

Regarding the different leachate properties, the ratio BOD_5/COD has been commonly used to know leachate age as the old literatures stated that freshly produced leachates have higher concentration of biodegradable organic matters than older [16,19]. As a result, the ratio BOD_5/COD reduces dramatically based on the ranges of the landfill ages, 0.5–1.0, 0.1–0.5, and less than 0.1, for young, medium, and old leachate respectively [8, 17]. However, recently studies results indicated that leachate even in younger landfills often have low concentration of organic maters because in many bioreactor landfills leachate recirculation has been practiced [3, 27].

To evaluation of the adverse impact of landfill leachate on human and natural resources needs to considered the typical composition of leachate. The composition of leachate would be anticipated to evolve via different stages of leachate stabilization phases. As the landfill leachate passed through aerobic, acetogenic, methanogenic and stabilization stages, heterogeneous leachate compositions and gases in different concentration ranges would be produced in each phase of stabilization.

Table 1: Classification and composition of landfill leachate with age

	Young	Medium	Old
Age (year)	<1	1.5	>5.0
pH	<6.5	6.5-7.5	>7.5
COD (g/l)	>15	3.0-15	<3.0
BOD_5/COD	0.5-1	0.1-0.5	<0.1
TOC/COD	<0.3	0.3-0.5	>0.5
NH_3-N (mg/l)	<400	400	>400
Heavy metals (mg/l)	>2.0	<2.0	<2.0
Organic compound	80% VFA	5-30% VFA+ HA+FA	HA+FA

Beside to this, as MSW landfilled is being placed over many years in a series of cells and lifts, it often produced varies leachate compositions in the same landfill from different phases of leachate stabilization. Therefore, seeing of leachate compositions among different stages of leachate stabilizations are essential for monitoring the long-term impacts of landfill leachates on the natural resources. The objective of this article was to deliver an overview of leachate composition and gases that generated through the different phases of landfill stabilization based on published report. Moreover, a brief highlight of landfill leachate stabilization factors also discussed as a second objectives.

II. LANDFILL STABILIZATION STAGES

Biodegradation of MSW in a landfill occurred in chronological phase till it changes to the simplest fraction of leachate characteristics and landfill gases. According to Farquhar and Rovers [20] biodegradations of MSW which produced liquid and gases occurred in a landfill through five or more sub-phases [21]. Being landfilled MSW buried over many years in an arrangement of cells and lifts are in different points of decomposition and produced heterogonous composition of leachate and gases. Therefore, the theoretical sequence of anaerobic degradation processes applied only for a homogeneous volume of MSW which produced nearby uniform leachate composition and gases. Fig 1.0 show the pathway of an anaerobic degradation processes which are occurred in landfill ecology after MSW landfilled. The detailed descriptions of homogenous volume of MSW degradation and its state of art decomposition for liquid and gas production are as follows:

A. Phase I-initial adjustment phase (lag phase)

The initial adjustment phase accomplished only for a short period after MSW landfilled. It is the time taken by microbes till adopts their new environment and food as well as sufficient moisture contents developed in landfill ecology [22]. In the initial adjustment stages easily biodegradable organic fraction of MSW aerobically decomposed by aerobic microbes via consuming free available oxygen that were trapped in cover soil and solid waste porosity [11,23,24]. This aerobic decomposition process produces carbon dioxide and higher temperature in landfill ecology. The generation of landfill leachate in this phase only accompanied with compaction of MSW during landfilling and short-circuiting of external and/ or recirculated leachate through water pipe line of MSW matrices [8]. Anaerobically digested sludge or an anaerobically decomposed MSW could be the primary source of microbial community in landfill ecology.

B. Phase II: transition phase

It is a period of shifting from aerobic to anaerobic degradation process caused by depletion of oxygen that were trapped in the refuse and development of excessive moisture content over the filed capacity of MSW. As landfill ecology changed, nitrate and sulphate could be served as electron accepter in the reduction reaction of oxygen that reduced nitrogen gas and hydrogen sulphate [22].The reduction/ oxidation values expected in the range of -50 to 100 millivolts for the reduction of nitrate and sulphate but for methane gas generation the reduction/ oxidation values should be in the range of -150 to -300 millivolts [25]. The continuous drop of reduction/ oxidation values in the landfill ecology would boost anaerobic microbes to convert organic matters into methane and carbon dioxide gases in the subsequence phase. The unique leachate compositions that manifest the transition phase of anaerobic degradation processes are the presence of huge quantity of COD, volatile organic acids (VOA), BOD, and low pH values which would help heavy metals easily mobilized in the leachate [23,24]. Moreover in the transition period the concentration of nitrogen gas dramatically reduces but the concentration of carbon dioxide gradually increases.

C. Phase III: acid phase

It is the sub sequence phase of the transition period in which anaerobic microbes continue and accelerate significant amount organic acid and hydrogen gas producing. The first stage of acid formation phase is enzyme-mediate transformation or (Hydrolysis), which is the process of converting complex organic compounds (lipids, polysaccharide, proteins and nucleic acids) into the smallest elements. In the second phase of acidic formation is the molecular compounds of the hydrolysis processes converted into the simplest molecular compounds and then into acetic acid (CH_3COOH), fluvic and other complex organic acids by acid former microbial (acidogenes) community. The principal leachate characteristics which is generated in this phases are excessive amount of BOD_5, COD which could further lower the pH values and increase the values of heavy metals. Besides, huge quantity of hydrogen gas and small quantity of nitrogen gas generated.

D. Phase IV: methane fermentation phase

It is the phase where intermediate acids are consumed by methanogens (methane forming) microbes and converted into methane and carbon dioxide gases [23]. The consummation of excessive organic acid concentration in this stage increased the values of pH (6.8-8.0), and reduced the concentration of BOD_5, COD and conductivity. The other manifest of this phase is the reduction of heavy metals concentration and mobilization in the leachate due to complexation and precipitation cause by higher pH value [26].

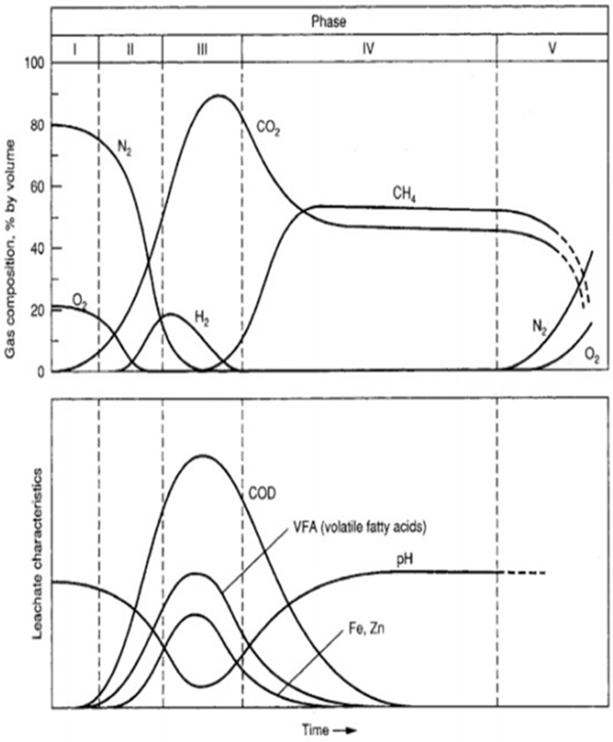

Fig: 1 Sequence of Leachate Stabilization (Source: [25])

E. Phase V – maturation phase

This phase is the last phase of anaerobic degradation processes of MSW. In this phase biodegradable organic matter already diminished and more refractory organic carbon remains, a landfill gas production drop, and the landfill leachate characteristics stay at a constant level. According to the post closure management of landfill, reappearance of oxygen and oxidized species exists but in the landfill leachate non degradable organic fractions such as humic and fluvic acid may remain, and sulphate and nitrate could reduce to sulphides and ammonia.

III. FACTOR AFFECTING LANDFILL STABILIZATION

The fundamental environmental factors which are affecting the efficiency of MSW stabilization in landfill ecology summarized in Fig 2.0., and its detailed descriptions are mentioned below:

A. Moisture

Moisture content is one of a predominate factors in a landfill ecology that influence MSW stabilization and gas production rates [22, 5]. The preferable moisture contents to enhance methanogenic processes are anticipated in the range of 40-70 percent on a wet weight basis [20]. The minimum moisture contents in landfill ecology could lag initial biodegradation stages.

B. Waste Composition

Waste composition is one of the parameters that affect MSW degradation process. The presence of easily biodegradable organic matter such as Rubbish, food waste, paper and crop and animal residues in a landfill enhance yield of gas production compared to non-biodegradable solid waste matrices. The percentage of biodegradable and non-biodegradable matter in a landfill determined according to waste segregation and management practices.

C. Compaction

Higher degree of compaction under will mixed static conditions delivered higher methane gas volume for relatively dry MSW, because higher moisture content presence in compacted solids that can enhance distribution of nutrient, substrates and bacteria. However, in wet MSW increment of dry density through compaction slow down methane gas yields, due to undesirable early intensive acid phase development by high moisture.

D. Shredding / Size Reduction

Shredding is often applied before MSW landfilled so as to increase surface area accessibility by microbes. Furthermore, size reductions have to significantly accelerate anaerobic digestion and gas production rates through removing of barriers that limited uniformly distribution of moisture, microbe and nutrients. However, some scholars noticed MSW size reduction has some negative impacts by promoting excessive initial hydrolysis and acid formation that inhibited onset of a methanogenic environment.

E. Seeding of Microorganisms

seeding of external activated microbes from sewage sludge and old anaerobically decomposed MSW into a landfill increased slow growing number microbes that would enhance biodegradation rate of MSW but low pH septic tank sludge feeding into landfill ecology created a negative impact on M SW stabilization processes.

F. Buffering Capacity

Addition of buffer solution to landfill ecology has a positive effect on MSW stabilization by raising pH of landfill ecology to neutral phase. Addition of calcium carbonate, sodium carbonate, and potassium carbonate into a landfill are effective solution to avoid excessive accumulation of acid that delayed MSW degradation processes.

G. Pre-Treatment of Wastes

To minimize the concentration of easily biodegradable organic substrate and excessive acid accumulation in landfill ecology, pre-treatment of MSW has been practiced by aerobic conditioning (composting) proceeding to MSW landfilled.

H. Oxygen

In the landfill ecology, the methanogenic microbial are significantly affected by the concentration of free oxygen, and they desires a redox potential lower than -300mV [23, 25].

I. Temperature

The quantity and quality of leachate generation in a landfill highly influenced corresponding with spatial and temporal variation of temperature. Rovers and Farquhar [20] observed from domestic MSW leachate generation in open dumping cell that maximum leachate generated in spring after precipitation while the minimum leachate occurred when in late spring and summer due to evapotranspiration.

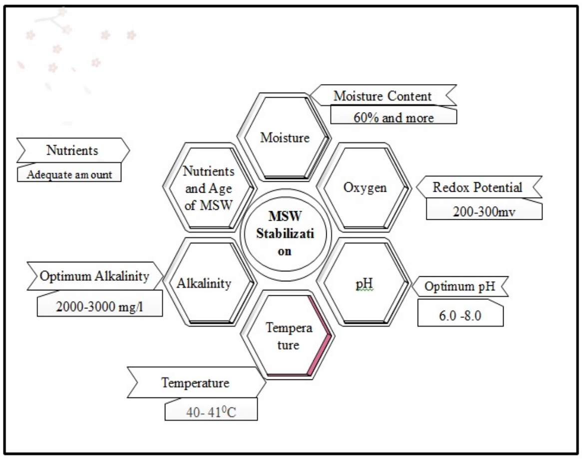

Fig: 2 Environmental factors that affect Landfill Stabilization

IV. CONCLUSION

The target of this paper was to review a landfill leachate composition variation through different stages of anaerobic landfill stabilization. The anaerobic degradation process of organic waste in a landfill is a complicated series of processes undertaken by a consortium of microorganisms and dynamic change of leachate compositions are being observed in each stages of landfill stabilization. In the acid phase, leachate composition shows low values of pH and higher concentration of organic pollutants as volatile fatty acids such as BOD_5, COD, as well as dissolved heavy metals. In later methanogenic stages of landfill, the concentration of degradability of the organic carbon dramatically lowered as the values of pH increased the lowered values of BOD_5/COD. The concentration of ammonia does track increasing trend during landfilling aging and it may constitute one of the major long-term pollutants in landfill leachate. The content of heavy metals in the leachates is generally decreasing when landfill aging as a result of attenuating processes (sorption and precipitation) by higher pH values that take place within the disposed waste.

V. REFERENCES

[1] M.J. Bashir, H. A. Aziz and M. S. Yusoff, “New sequential treatment for mature landfill leachate by cationic/anionic and anionic/cationic processes: Optimization and comparative study." Journal of hazardous materials vol. 186, 2011, PP. 92-102.
[2] J. Wiszniowski, et al. "Landfill leachate treatment methods: A review." Environmental Chemistry Letters vol. 4, 2006, pp. 51-61.
[3] H.A. Aziz et al. "Colour removal from landfill leachate by coagulation and flocculation processes." Bioresource Technology vol. 98, 2007, pp.218-220.
[4] R. Rajput, G. Prasad and A.K Chopra. ""Scenario of solid waste management in present Indian context"." Caspian Journal of Environmental Sciences vol.7, 2009, pp. 45-53.
[5] M. El-Fadel, Angelos N. Findikakis and James O. Leckie. "Environmental Impacts of Solid Waste Landfilling". Journal of Environmental Management vol. 50, 1997, pp. 1-25.
[6] A. Kouzeli-Katsiri, A. Bosdogianni and D. Christoulas. "Prediction of leachate quality from sanitary landfills." Journal of environmental engineering vol. 125, 1999,pp. 950-958.
[7] A.A. Abbas et al. "Review on landfill leachate treatments." journal of Applied Sciences Research vol.6, 2009, pp. 534-545.
[8] P. Kjeldsen et al. "Present and long-term composition of MSW landfill leachate: a review." Critical Reviews in Environmental Science and Technology vol. 32, 2002, pp.297-336.
[9] M. El-Fadel et al. "Temporal variation of leachate quality from pre-sorted and baled municipal solid waste with high organic and moisture content." Waste management vol. 22, 2002, pp.269-282.
[10] P. Andrés and M. Cortijo. "Stabilization of leachates from municipal solid waste landfill by sedimentation." Journal of Environmental Science & Health Part A vol.35, 2000, pp.883-897.
[11] H.J. Ehrig, "Quality and quantity of sanitary landfill leachate." Waste Management & Research vol.1, 1983,pp. 53-68.
[12] D.L. Jones, K. L. Williamson and A. G. Owen. "Phytoremediation of landfill leachate." Waste Management vol. 26, 2006,pp. 825-837.
[13] A. Spagni and S. Marsili-Libelli. "Nitrogen removal via nitrite in a sequencing batch reactor treating sanitary landfill leachate." Bioresource Technology vol. 100, 2009,pp. 609-614.
[14] D. Kulikowska, "Nitrogen removal from landfill leachate via the nitrite route." Brazilian Journal of Chemical Engineering vol. 29, 2012,pp. 211-219.
[15] R.K. Rowe, Leachate characteristics for MSW landfills. Geotechnical Research Centre. Ontario: University of Western Ontario, 1995.
[16] P.H. Chen, "Assessment of leachates from sanitary landfills: impact of age, rainfall, and treatment." Environment International vol. 22, 1996,pp. 225-237.
[17] F.N. Ahmed and C. Q. Lan. "Treatment of landfill leachate using membrane bioreactors: A review." Desalination vol. 287, 2012,pp. 41-54.
[18] D. Kulikowska and E. Klimiuk. "The effect of landfill age on municipal leachate composition." Bioresource Technology vol. 99, 2008,pp. 5981-5985.
[19] J.E Chang, "Treatment of landfill leachate with an upflow anaerobic reactor combining a sludge bed and a filter." Water Science & Technology vol. 21,1989,pp. 133-143.
[20] G.J Farquhar and F. A. Rovers. "Gas production during refuse decomposition." Water, Air, and Soil Pollution vol. 2, 1973,pp. 483-495.
[21] T.H. Christensen and P. Kjeldsen."Landfill emissions and environmental impact: An introduction." In Sardinia 95-Fifth International Landfill Symposium. 1995,pp. 3-12.
[22] D.R. Reinhart and A. B. Al-Yousfi. "The impact of leachate recirculation on municipal solid waste landfill operating characteristics." Waste Management & Research vol. 14, 1996, pp.337-346.
[23] T.H Christensen and P. Kjeldsen. Basic biochemical processes in landfills. Technical university of denmark. Denmark, 1989.
[24] C. Chiemchaisri et al. Sustainable Solid Waste Landfill Management in Asia. Enhancment of Solid waste degradation using different operating techniques in bioreactor landfill. Asian institute of Technology. Bangkok, Thailand: ARRPET, 2004.
[25] G. Tchobanoglous, H. Theisen and S. Vigil. "Integrated solid waste management: engineering principles and management issues". McGraw-Hill, Inc., 1993.
[26] H. Kim, Jang, Y. C. and Townsend, T. “The behavior and long-term fate of metals in simulated landfill bioreactors under aerobic and anaerobic conditions. Journal of hazardous materials”, Vol. 194, 2011, pp. 369-377
[27] A.T. Tamru and S.Chakma, "Mathematical modelling for landfill leachate pollution index error estimation." Journal of Discovery vol. 41, 2015 pp. 123-129.