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BIOLOGICAL PRETREATMENT OF MUNICIPAL SOLID WASTE PRIOR TO LANDFILLING

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ABSTRACT

The conventional landfilling does not promote sustainable waste management due to uncontrolled emissions which potentially degrade the environment. In this regard, pre-treatment of municipal solid waste prior to landfilling significantly enhance waste stabilization and provides various advantages. So in this regard pre-treatment methods of municipal solid waste were investigated. The major objectives of biological pretreatment are to degrade most easily degradable organic matters of MSW in a short duration under controlled conditions so as to produce desired quality for landfill; and to enhance methanogenic condition in the landfill. Factors affecting the choice of pretreatment processes include the composition of MSW, retention times, odor emissions, fate of toxic chemicals and costs. To investigate the economical pretreatment method prior to landfilling for developing countries four pretreatment simulators were developed at bench scale in the laboratory at different operating conditions forced aeration and leachate recirculation (APSFALR), aerobic pretreatment simulator by natural convection of air with leachate recirculation (APSNCLR), aerobic pretreatment simulator by natural convection of air (APSNC) and anaerobic simulator (AS).The organic matter, pH, temperature, settlement, leachate quantity and quality were monitored regularly. In the leachate quality BOD_5, COD, NH_4-N, pH and trace metals were analyzed. The molecular size distribution of dissolved organic matters (DOM) in leachate was determined after the pretreatment of 45 days. The results of these methods are compared. The APSNCLR method is economically effective method to reduce the organic matters, leachate COD and BOD_5. With the biological pretreatment significant amount of easily biodegradable matters and volume of solids are reduced due to the decomposition of the waste.

Landfilling of pretreated waste improves landfill behavior, characteristics, and operation. Leachate quantity, quality and landfill gas emissions also would be reduced. It is predicted by the comparison of carbon content in the fresh and pretreated MSW that resultantly increases the landfill age and decreases in aftercare monitoring period. The volumes of the solids were reduced and density increased significantly in eight weeks pretreatment of MSW due to biodegradation of organic matters. The BOD, COD_5 and NH_4-N content also reduced significantly as compared to the anaerobic simulator. Pretreatment simulators results are compared and concluded that pretreatment with passive aeration and leachate recirculation is better as compared to the other pretreatment simulators.

KEYWORDS: Biodegradation, Pretreatment Municipal Solid Waste, Sustainable Disposal, Landfilling.

1. INTRODUCTION

Landfilling of MSW can usually lead to uncontrolled emissions of leachate and landfill gas (LFG) as a result of percolation and biological transformation processes (Belevi and Baccini, 1989; Beaven and Walker, 1997). Environmental impact can result from the run-off of the toxic compounds into surface water and groundwater as well as from the gaseous emissions which contribute to the greenhouse effect. Biological pretreatment lowers emissions considerably and a reduced amount of less reactive waste is left for landfilling because the organic waste compounds are degraded and stabilized under optimized and controlled conditions (Komilis *et al*., 1999; Zach *et al.*, 2000) Solid waste pretreatment techniques are traditionally associated with mechanical, thermal and biological pretreatment. These techniques are currently used often in combination, with the objectives of recovering materials, producing the energy and minimizing the amount of waste to be landfilled. Mechanical pretreatment process comprises of size reduction and separation into components and sizes. The major objectives of biological pretreatment are to degrade easily degradable organic components of MSW in a short duration under controlled conditions so as to produce desired quality for landfill; and further to enhance methanogenic condition in the landfill (Zach *et al.*, 2000). Factors affecting the choice of pretreatment processes include the composition of MSW, retention times, odor emissions, fate of toxic chemicals and costs (Komilis *et al*., 1999). Biological pretreatment of MSW reduced both the organic loading of leachate as well as gas production, especially leachate TOC twenty three times lower, compared with leachate from untreated waste. (Komilis *et al*., 1999; Reiger and Bidlingmaier, 1995; Heerenklage and Stegmann, 1996). Tenzin *et al*. (2005) proposed that MSW generated in Asian countries should go under one week of bulk composting prior to landfilling or dumping. This would reduce a substantial volume of waste disposal and further enhance waste stabilization and separation. This study by using 1 m^3 MSW cage and its volume and volatile solids reduction were recorded. However, many other parameters are required to be explored in order to recommend period of pretreatment.

In China, composition of the MSW is very complicated as it varies from city to city and from season to season. The amount of MSW produced increases rapidly with the rate of 8-10% annually which has made China one of the countries under the biggest burden of waste treatment in the world (Fang 1996; Hu *et al.*, 2003; Zhang, 1998; State Statistical Bureau, 1999). Waste production rate per capita per day in the 10 big cities i.e. Beijing, Shanghai, Tianjin, Guangzhou, Shenzhen, Dalian, Shenyang, Maanshan Hangzhou and Anshan ranges from 0.66 to 2.62 kg (State Statistical Bureau, 1999). Landfilling is dominant method of MSW disposal; about 90% of MSW generated is disposed of in the landfills, 9% composted and only 1% incinerated till 2003 (State Statistical Bureau, 1999). Since 2004, incineration is increasing and composting proportion is decreasing due to the poor quality of compost and less market. The organics, plastic and moisture contents are increasing rapidly. Mixed waste with high moisture content, heating value is also low (Shi, 1998; Zhao 1998; Feng, 1999; Nie, 1999). Further in mixed wastes containing high organics and moisture content, the problems of leachate treatment and LFG emissions are very serious. The conventional landfill technology has caused big economic and social cost (State Statistical Bureau, 1999). Pretreatment of MSW prior to disposal in the landfill is very much necessary and needs to be investigated. Hence there was a need to investigate the proper and economical pretreatment method for sustainable disposal. Especially aerobic treatment with intensive aeration, watering and turning waste, passive aeration with watering and turning waste and shredding waste without watering and turning were also investigated (Fruke *et al.*, 2000). But all the methods are very expensive for those countries where the waste generation rate is very high and they are at the developing stage.

In this study four simulators were developed aerobic pretreatment simulator with forced aeration and leachate recirculation (APSFALR), aerobic pretreatment simulator by natural convection of air with leachate recirculation (APSNCLR), aerobic pretreatment simulator by natural convection of air (APSNC) and anaerobic simulator (AS).Their results are compared and economically feasible method is recommended.

2. MATERIALS AND METHODS

2.1 Experimental setup

The diameter and depth of the pretreatment simulators (PTS) were 60mm and 600mm respectively. At the bottoms of the PTS leachate collection sumps were provided. From the sides of the PTS sample collection ports were provided. In the APSFALR perforated pipe was provided at the bottom and embedded in the gravel to inject the air in the simulator. The rate of air injection was 100 ml min^{-1}. At the top of the simulator exhaust pipe was provided. Thermometers were inserted in the simulators to measure the temperature. In the APSNCLR and APSNC, the ventilation was provided in the center of the simulator through perforated pipe from the bottom to top and was filled with small gravel stone to dissipate the air into the waste mass as shown in Figure 1. In the APSFALR and APSNCLR, leachate collected was re-circulated by alternate day. Further every week tap water was added to the simulators to simulate the rainfalls in all simulators averagely 286ml per week till six weeks. The anaerobic simulator was air tight and from the top only the gas collection pipe was provided to collect the gas through water diverting mechanism. The operating conditions are mentioned in the Table 1.

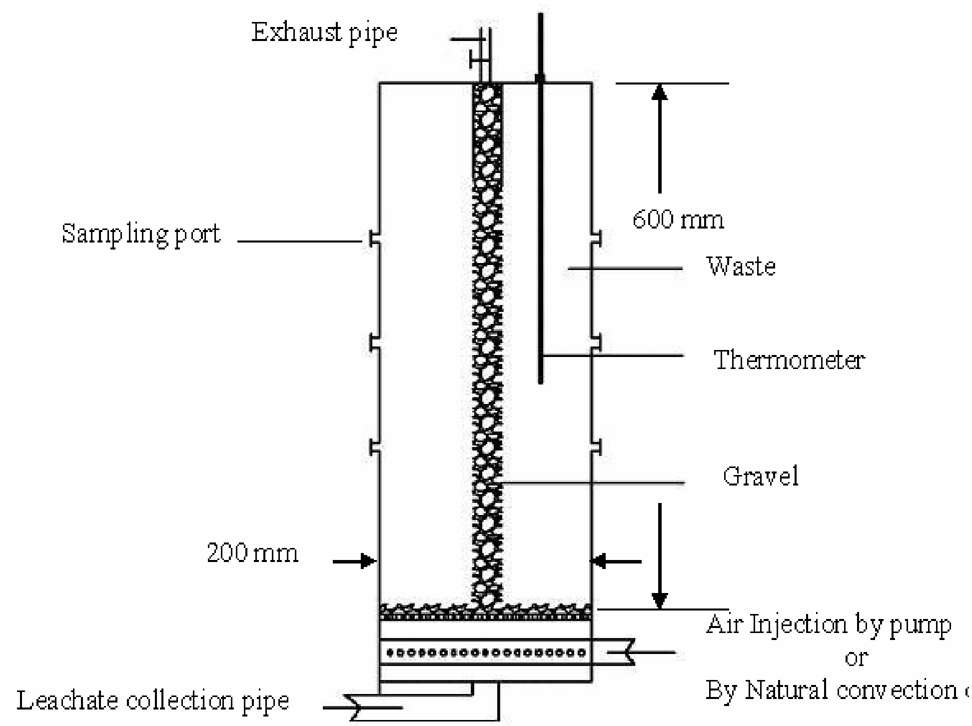

Figure 1. Sectional view of pretreatment simulators (PTS)

Table 1. Pretreatment simulators run at different operational modes

Types simulators	Modes of aeration	Modes of leachate recirculation	Water added to simulate the rainfall
AS (R_1)	No	No	Yes
APSNC (R_2)	Natural convection of air	No	Yes
APSNCLR (R_3)	Natural convection of air	Yes	Yes
APSFALR (R_4)	Forced continuous aeration	Yes	Yes

2.2 Composition of MSW

The composition of the MSW was mixed and contained about organic content including kitchen waste, fruit and vegetable skins, plastic, polythene bags, papers, yard waste and the remaining portion was inorganic. After separating the plastics, glasses and metals, residual waste was placed in the simulators. Organic content was about 50.5%.

2.3 Leachate and solid phase analysis

2.3.1 Solids phase analysis

In the solid phase analysis moisture content, temperature, bulk density and organic matters were analyzed. These parameters are determined in fresh and during the course of pretreatment but for the bulk density only analyzed for the fresh and pretreated waste. pH was determined by preparing the slurry by adding of distilled water to the waste sample. The calibrated pH meter was used for measuring the pH value of the sample. Temperature was measured with a thermometer manufactured in Shanghai China by inserted inside the PTS. The moisture content was determined by using the standard method (APHA, 1992). Bulk density was determined by filling cylinder (known volume) with waste and weighed. Organic matters were determined by measuring the volatile solids by Standard Method (APHA, 1992). Approximately one gram dry sample were used to analyze the carbon, hydrogen and nitrogen by using elemental analyzer (Equipment CE-440, EAI U.S.). For the analysis manufacturer's recommended procedure was adopted.

2.3.2 Leachate quality analysis

The leachate samples were collected at various stages and analyzed for COD and NH_4-N and trace metals. COD was determined by using potassium chromate (COD, K_2CrO_7 oxidation) standard method (APHA, 1992). NH_4-N is determined by using UV spectrophotometer after pretreatment with acid. The metals concentrations were measured on ICP-AES (Thermo Electron Co.). In the metals only Cd, Co, As, Ni, Zn, Cu, Fe, Mn, Cr and Pb were analyzed .HNO_3 digestion method is used for the dissolution metals in leachate. The leachate quality was analyzed by using standards methods. The molecular size distribution of dissolved organic matters (DOM) in leachate was determined by ultra-filtration method (UF) method (Xu *et al.*, 2006). A series of flat sheet circular UF membrane (GE-Osmonics, Polyamide membrane) with the 7.6 cm diameter and molecular weight cut-offs (MWCOs) of 100, 10 and 1 kDa in a stirred 300-ml cell (Shanghai Yadong Resin Co. Ltd.) were used. Nitrogen gas was applied to pressurize the UF cell at 0.3 MPa. The permeate obtained from each membrane was analyzed for dissolved organic carbon (DOC). The fractions of the leachate in terms of molecular weight were separated into three groups, which included (1) >100 kDa, (2) 10–100 kDa, and (3) 1 -10 kDa. The results of the simulators were compared.

3. RESULTS AND DISCUSSIONS

Temperature of the every PTS was measured as well as room temperature was also recorded. The temperature variation was observed significantly but due to small size of the simulators and room temperature, leachate recirculation and forced aeration has affected the temperature of the simulators as shown in Figure 2. Pretreatment simulators temperature was remained in the range 28-37ºC till 6th week with some fluctuation, which was caused by the water addition and aeration. On 50th day as heating bed plugged off temperature of simulator R_2, R_3 and R_4 was reached to room temperature and remained in the same range for a week. However anaerobic simulator R_1 its temperature was remained higher than the room temperature. This shows that R_2, R_3 and R_4 simulators were stabilized.

The organic matters during the pretreatment significantly reduced. Organic matters reduction trend was observed less in the anaerobic simulators R_1 as compared to aerobic simulators. The decrease of OM trend was observed with this trend $R_4>R_3>R_2>R_1$ as mentioned in the Figure 3. This shows that PTS R_4 worked better than R_3, R_2 and R_1, similarly R_3, is better than R_2 and R_1 and also R_2 is better than R_1. This shows that some organic matters which were degraded with leachate recirculation and forced aeration effectively than the passive aeration. When the OM degradation rate, was become slower, that moment further treatment was stopped.

Elemental carbon, hydrogen, nitrogen and C/N ratio were decreased as mentioned in the Table.2. The R_4 simulator only 10% is better than R_3 in reduction of carbon and C/N ratio, but more energy is required to inject the air. However in R_3 only the passive aeration and leachate recirculation, no additional energy is required to pump air in it. From the carbon balance it is observed that residual carbon in the waste is not degradable, so more than 50% LFG would be reduced with pretreatment. The similar results of LFG reduction were reported by (Mahar *et al.*, 2007). The bulk density was also increased more than 50%. With increase of density obvious landfill volume would be reduced. With decrease of carbon and nitrogen content in the waste after landfilling the pretreated waste leachate COD and ammonia nitrogen would be reduced. Such results also reported by (Mahar *et al.*, 2007).

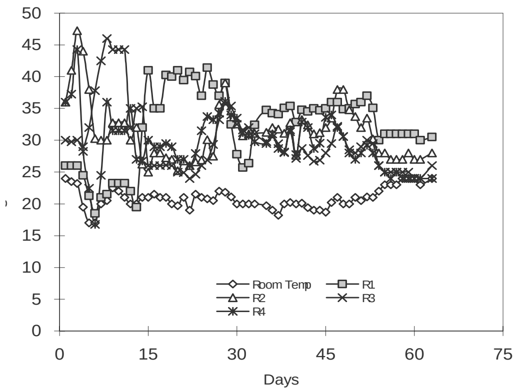

Figure 2. Temperature variation of pretreatment simulators during the pretreatment

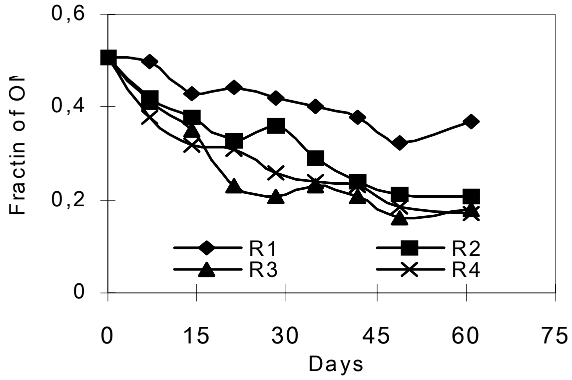

Figure 3. Temperature variation of pretreatment simulators during the pretreatment

In the leachate pH was monitored regularly from the PTS. The pH value of all the simulators increased from 5.4 to 6.5 with in three days and further R_1 simulator's pH starts decreasing in second week reached to 6, further decreased and remained below 6 till study period. However in first week increase of pH in simulator R_1 caused by addition of high amount of water, due to that volatile fatty acids (VFA) were washed. In the aerobic simulators R_2, R_3 & R_4, pH value was reached to 8 remained in the range of 7.5 to 8.5 as shown in Figure 4. Simulator R_1 was remained acidogenic state. However simulators R_2, R_3 & R4 were remained ventilated and due to aerobic digestion; and organic matters were decomposed and converted into CO_2.

COD concentration in the leachate of simulator R_1 was 76000 mg l^{-1} in first week and then increased in three weeks reached to maximum level 109000 mg l^{-1} and then decrease remained in the range of 60000 to 80000 mg l^{-1} till study period and in further 7 months study only reduced to 20,000 mg l^{-1}. However in the aerobic simulators, COD increased in second week from 10,000 to 39000 mg l^{-1}, 15000 to 44000 mg l^{-1} and 32,000 to 55000 mg l^{-1} in R_2, R_3 and R_4 respectively and then further decreased in third week very rapidly about 3000-10000 mg l^{-1} in R_3 and R_4; however in the R_2 simulator COD remained 10000 mg l^{-1} up to sixth week as shown in Figure 5. The end of the study period COD of all the aerobic PTS was in the same range of 1000-2000 mg l^{-1}. From the COD analysis results it is concluded that passive aeration and leachate recirculation is the best methods to reduce COD from leachate. Ammonium nitrogen in leachate was increasing in all the PTS till fourth weeks and then starts decreasing but in the simulator R_1 was continually increasing till the study period and reached to 2400 mg l^{-1}. However in the aerobic simulators R_3 & R_4 ammonium nitrogen starts to decrease after fourth week remained in the range of 200 to 400 mg l^{-1} till study period but in the R_2 simulator ammonium nitrogen was remained in the 500 to 1000 mg l^{-1} as shown in Figure 6, but it was less than anaerobic simulator. Such results of COD and Ammonium Nitrogen reduction were reported by Bilgili, M.S (Mahar *et al.*, 2007).

Table 2. Showing the organic matters, bulk density, elemental analysis and carbon nitrogen ratio results in fresh waste and pretreated waste

Parameters	Unit	Fresh waste/untreated waste	Pretreated waste			
			R_1	R_2	R_3	R_4
OM	% DM	50.6	38	22	21	17
C	% DM	28	21	14.09	14.24	14.23
H	% DM	2.1	1.87	0.50	0.63	0.69
N	% DM	1.24	1.00	0.71	0. 75	0.78
C/N	Unit less	22.58	21	19.84	18.49	18.24
Density	kg m^{-3}	496.89	Nd	950	1005	1059

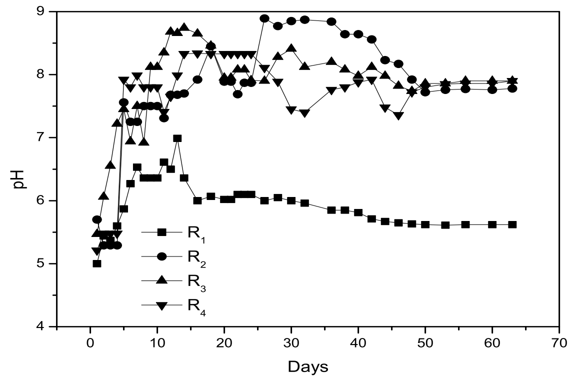

Figure 4. Variation of pH value during the pretreatment MSW

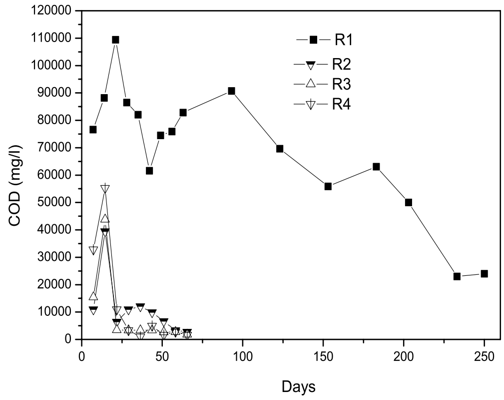

Figure 5. Variation of COD in the pretreatment simulators during the pretreatment

In the metals only As, Cd, Cr, Ni, Cu, Pb and Zn were analyzed .HNO_3 digestion method is used for the dissolution metals in leachate (Xu *et al.*, 2006). The results of heavy metals were found with in range of standard limits. In order to know the effect of different pretreatment on leachate, leachate was analyzed for molecular weight distribution as shown in Figure 7 In the simulator R_1, lower molecular weight fractions were higher than the high molecular weight fractions, and this shows that fatty acid concentration was high. . It also can be confirmed from by the COD value of R_1 and this indicates young leachate (Calace *et al.*, 2001). Simulator R_2 had comparatively less low molecular weight fractions than the R_1 and also intermediate compounds were also low between 10k Da to 1k Da. However higher molecular weight fraction compounds were more as compare to $R_{1.}$

Simulator R_3 lower weight fraction had less and also having the intermediate compounds more than the R_1 & R_2. Also same trend was observed in the simulator R_4. This data confirms that easily degradable matters during the pretreatments are degraded and converted into the CO_2 and left matters were hardily degradable matters which can not be further degraded by aerobic treatment. The presence of higher molecular weight fraction in the leachate is due to humic type substances, which confirms the results of various researchers (Bilgili *et al.*, 2006).

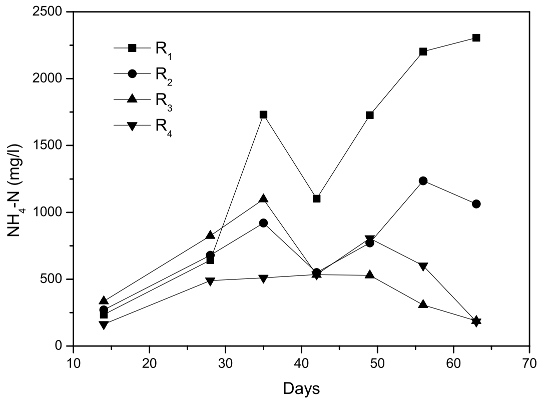

Figure 6. Variation of NH_4-N in the pretreatment simulators during the pretreatment

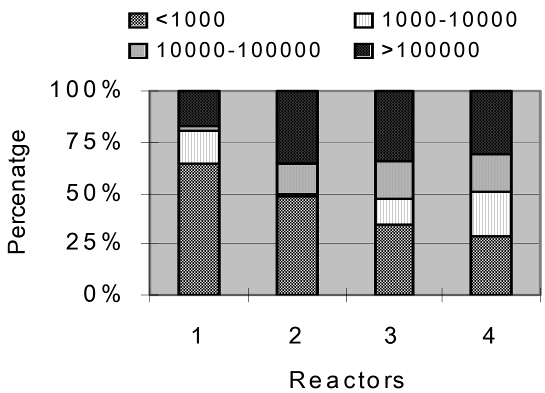

Figure 7. Comparison of dissolved organic matters (DOM) in the leachate

4. CONCLUSIONS

The significant amount of organic matters degraded with the aerobic pretreatment of MSW. Same trend in reduction of carbon, nitrogen and C/N ratio was observed. Leachate quality was improved during the pretreatment. Residual COD in the leachate was caused by high molecular organic humic type substances. Aeration and leachate recirculation have converted volatile organics acids to CO_2 during the pretreatment. NH_4-N content also reduced significantly as compared to the anaerobic simulator. However in case of anaerobic simulator COD was not reduced remained in the range of 20,000-60,000 mg l^{-1} for 9 months and NH_4-N was remained 2400 mg l^{-1} till 2 months.

An aerobic pretreatment simulator with passive aeration and leachate recirculation (R_3) is economical feasible pretreatment method for developing countries. This method is significantly effective in reducing the organic matters and carbon >50% and 50% respectively. Also leachate quality was improved as compare to anaerobic simulator more than 80% by reduction of COD and NH_4-N. Landfilling of pretreated waste improves landfill behavior, characteristics, and operation. Leachate quality and landfill gas emissions would be reduced. The waste volume reduces due to the reduction of organic matters. Resultantly increases the landfill volume and decreases in 'after closure' monitoring period.

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