J. Korean Wood Sci. Technol. 43(5): 548~557, 2015 pISSN: 1017-0715 eISSN: 2233-7180
http://dx.doi.org/DOI : 10.5658/WOOD.2015.43.5.548

Environmental Assessments of Leachate from Medium Density Fiberboard in a Simulated Landfill[1]

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ABSTRACT

This study investigated environmental assessments of leachate containing formaldehyde from medium density fiberboard (MDF) disposed in laboratory-scale simulated landfills. Environmental impact assessment of leachate was conducted by measuring formaldehyde, toxicity, biochemical oxygen demand (BOD), chemical oxygen demand (COD), bacterial enumeration, and pH. Amount of formaldehyde in leachate from MDF in soil decreased to the level of soil only treatment by 28 days, and toxicity decreased as the amount of formaldehyde decreased. BOD and COD levels in leachate from the treatments containing MDF exceeded permissible discharge levels of BOD or COD throughout the experimental period. The pH levels of all treatment were within permissible discharge range except on day 0. Fewer bacteria were observed in leachate from MDF in soil treatment than other treatments (MDF only, cured UF resin in soil, and soil only). Consequently, the leachate from disposal of MDF in soil detrimentally affect on environment. However, soil buffered formaldehyde leaching and pH on leachate in this study. Waste MDF may be required the pre-water soaking treatment for leaching formaldehyde to reclaim on land.

Keywords : simulated landfill, formaldehyde, leachate, medium density fiberboard, toxicity, environmental impacts

1. INTRODUCTION

The decomposition of municipal solid waste (MSW) in landfills is a very complex and variable process (Schrab *et al*., 1993). Research involving the impact of landfill leachate on the surface and groundwater has increased during the last 20 years (Flyhammar, 1995; DeRosa *et al*., 1996; Christensen *et al*., 1998; Looser *et al*., 1999; Abu-Rukah and Kofahi, 2001; Saarela, 2003). Leachate from MSW landfills may contain various contaminants at high concentration levels that may affect water systems such as groundwater (Johannessen, 1999).

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According to American Wood Council (2013), 1.8 billion square feet (3.3 million cubic meters) of medium density fiberboard (MDF) was produced from 20 different MDF manufacture facilities on North America in 2012. MDF consumption will increase more than 10% every year (RISI, 2014). However, most of MDF waste is burned as fuel source or buried in landfill. US Environmental Protection Agency (2008) estimated total 250 million tons of total MSW was generated, and among the total MSW, wood contributed 6.6% which was 16 million tons. Moreover, more than 50% of wood wastes consisted of wood-based composites (US EPA, 2008). Burning MDF waste cannot cause only other issues like air pollution, but also disposal of MDF has raised an environmental issue because it contains high contents of urea-formaldehyde (UF) resin (US EPA, 2005). Also, the lack of understanding of the environmental fate of formaldehyde from MDF caused difficult to use sawdust from MDF in agriculture (Lee *et al*., 2014).

In our previous study, formaldehyde released from MDF buried in a laboratory-scale simulated landfill was determined and the results indicated that formaldehyde emission was blocked by soil in air and in leachate (Lee *et al*., 2014). However, our previous study did not cover the evaluation of other environmental parameters. The leachate from wood waste containing UF resins is a source of contaminants that may detrimentally affect groundwater or soil because of the formaldehyde, carbon dioxide, and inorganic ammonia from degradation of wood fiber and UF resin by bacteria (Jahns *et al*., 1998).

To evaluate the environmental impacts of leachate from landfill, parameters such as toxicity, pH, BOD, COD, color, levels of chloride, sodium, potassium and heavy metals (Cd, Cr, Cu, Fe, Ni, Pb and Zn), are monitored and reported to the US EPA (Renou *et al*., 2008). To our knowledge, few studies have addressed the environmental impacts of leachate containing formaldehyde released from UF resin bonded wood-based composite waste in landfills. In the USA, California State does not permit burying wood-based composite because of environmental concern. The objective of this study was to evaluate environmental impacts of burying MDF waste in the simulated landfill to water system by using determination of the amount of formaldehyde, toxicity, BOD, COD, bacterial enumeration, and pH.

2. MATERIALS and METHODS

2.1. Materials

MDF (10 years old, 100 cm × 100 cm × 1.27 cm, Georgia-Pacific, NC) used in this study was provided by Forest Products Department at Mississippi State University. MDF was cut into 3 cm × 1.5 cm × 0.5 cm. Silty clay soil that collected from Starkville, Mississippi was used in this study after sieving through a screen (0.5 cm). Urea-formaldehyde (UF) resin was provided from Georgia Pacific Chemicals (Portland, OR). A 2,4-dinitrophenylhydrazine (DNPH), formaldehyde solution (37%), hexane, and acetonitrile (HPLC grade) were purchased from Sigma-Aldrich Co. (St. Louis, MO) for formaldehyde determination.

2.2. Methods

2.2.1. Simulated landfill design

Laboratory-scale simulated landfills were constructed with cylindrical plastic containers (15.24 cm diameter, 22.86 cm high) purchased from Wal-mart (Starkville, Mississippi, USA). Fig. 1 shows diagram of the simulated landfill, and each container consists of distinctively separated but contacted layers of silty clay soil (870 g) and MDF (120 g) or cured UF resin (12 g). There were four treatments with three replicates per treatment: 1) cut pieces of MDF wrapped in polyethylene fabric and covered in soil, 2) cut pieces of MDF only, 3) cured UF resin wrapped in polyethylene fabric and covered in soil and 4) soil only. Soil only (treatment 4) had 870 g of silty clay soil, and MDF only (treatment 2) had 120 g of cut pieces of MDF. The 12 g of cured UF resin was calculated based on typical UF resin content (10% of total MDF weight) in MDF. Cut pieces of MDF and cured UF resin were wrapped with polyethylene fabric (0.5 mm, Wal-Mart, Starkville, MS). All opened containers were stored in an incubator set at 34℃ to accelerate bacterial activity.

2.2.2. Preparation of cured UF resin

The UF resin was cured by adding ammonium sulfate (2.0% of total resin weight) and then pressed at 180℃ for 1 minute using a Carver Laboratory press (Carver Inc., Wabash, IN). Cured UF resin was ground approximately to less than 1 mm with a mortar.

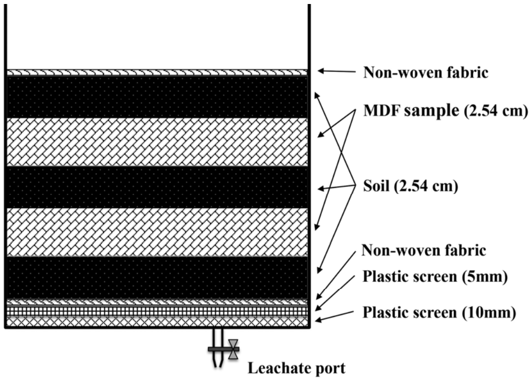

Fig. 1. Simulated landfill design for leachate sampling (treatment 1: MDF with soil).

2.2.3. Leachate sampling and pH

Deionized water (750 mℓ) was added to each constructed landfill then collected the leachate (Fig. 1). The leachates were filtered through a 0.22 μm nylon filter and analyzed for formaldehyde (day 0 sample). Additionally, deionized water (200 mℓ) was added to the container and allowed to soak for 1 hour then collected and filtered through a 0.22 μm nylon filter (day 1 sample). At day 7 and on subsequent sampling times, 200 mℓ of deionized water was added to each treatment, allowed to soak for 1 hour and then collected as described above. Leachate was sampled weekly for 56 days. The pH of each sample was determined at each sampling time using an Accumet® AB15 Basic pH/mV meter (Fisher Scientific, Waltham, MA).

2.2.4. Determination of formaldehyde

Formaldehyde was determined according to U. S. Environmental Protection Agency Method 8315A (US EPA, 1996) using a Waters 2695 and Waters 996 high-performance liquid chromatography (HPLC) system at 370 nm (Waters Corporation, Milford, MA). HPLC chromatographic conditions were as follows: 40/60 acetonitrile/water (v/v), hold for 1 min; 40/60 acetonitrile/water to 100% acetonitrile in 3 min; 100% acetonitrile for 10 min; flow rate: 1.0 mℓ/min; injection volume: 20 μℓ. The analytical column was a 3.9 × 150 mm HPLC column (Nova-Pac® C18 60Å 4 μm, Waters Corporation, Milford, MA).

2.2.5. Toxicity

The toxicity of the leachate was measured weekly for 56 days using a toxicity auto analyzer (Microtox m500, Microbics Corporation, Carlsbad, California). Toxicity was determined according to Microtox™ tests method (Johnson, 2005). Toxicity was calculated based on the average of triplicates by the luminescence reduction of a marine bacteria (*Photobacterium phosphoreum*, NRRL number B-11177) monitored at 15 minutes.

2.2.6. Biochemical oxygen demand (BOD)

A 5-day BOD (BOD5) of the leachates was determined and calculated weekly for 56 days according to the U. S. Environmental Protection Agency Method 5210 B (US EPA, 1999) using a dissolved oxygen meter (YSI 5000, YSI Inc., Yellow Springs, OH) and a BOD Probe (YSI 5010, YSI Inc., Yellow Springs, OH). BOD seed inoculums (PolySeed, InterLab Supply, TX) was used for BOD5 test.

2.2.7. Chemical oxygen demand (COD)

The dichromate reactor digestion method (Analysis of Water and Wastes, US EPA Method 410.4-1 1993) was used for determination of COD levels in leachate sample using the CHEMetrics COD vial kit (Range: 0 - 15,000 ppm (HR+) Mercury Free, K-7376, CHEMetrics Inc., Midland, VA). The COD was determined at 620 nm using a DR 2000 COD spectrophotometer (Hach, Loveland, CO) and was determined weekly for 56 days.

2.2.8. Bacterial enumeration

Bacterial enumeration of leachate was determined using the plate count method on nutrient agar (NA, BD Difco™ Franklin Lakes, NJ) plates with 3 replicates per treatments. The bacterial colonies in these plates were counted after 48 hours of incubation at 30℃, and corrected for dilution factor.

3. RESULTS and DISCUSSION

3.1. Formaldehyde in leachates

At each sampling time, total amount of leachates were different on each sample, therefore amount of formaldehyde in whole leachates was presented rather than presenting as mass per volume. Total amount of formaldehyde in leachates from each sample were shown in Fig. 2.

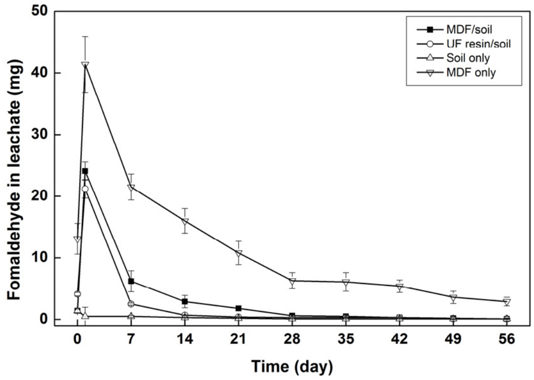

Fig. 2. Formaldehyde concentrations in leachate from MDF in soil (■), MDF only (▽), cured UF resin in soil (○), and soil only (△) for 56 days.

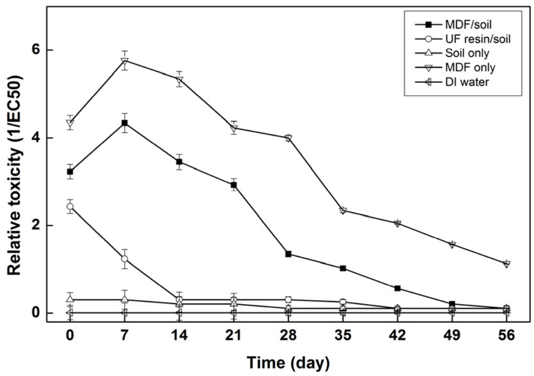

Fig. 3. Relative toxicity of DI water (◁) and leachate from MDF in soil (■), MDF only (▽), cured UF resin in soil (○), and soil only (△) for 56 days.

As control sample (soil only) had less than 0.2 mg of formaldehyde in leachate at the all sampling time. In the UF resin in soil, formaldehyde in leachate was reduced 95% from day 1 after day 14. In the MDF with soil, the formaldehyde was reduced by 95% at day 28. Lower amount of formaldehyde on UF resin in soil than that of MDF in soil was observed as result of more curing on UF resin than UF resin in MDF. Therefore, more free formaldehyde possibly existed in MDF than cured UF resin. Reduction rate also was slower on MDF in soil than cured UF resin in soil because formaldehyde may be trapped or interfered by wood fiber. At the end of the study (56 days), formaldehyde in leachate from treatments containing soil and MDF or UF (treatments 1 and 3) was 0.1 mg, which was the same as in the soil only. However, in the MDF only treatments, the formaldehyde determined at least 50 times higher than the soil only treatment. The leachate data indicated that soil may restrict formaldehyde leaching or may contain resources that convert formaldehyde to other compounds.

3.2. Toxicity

Fig. 3 shows the relatively toxicity of the leachate from treatments throughout the study. The relative toxicity of MDF in soil and MDF only initially increased from day 0 to day 7 but decreased during the study. In soil only, a relatively low toxicity was observed at all sampling times. At the end of the study (56 days), MDF in soil, UF resin in soil, and soil only treatments had the same low relative toxicity of leachate except MDF only treatment. During the 56 days, 74% of the relative toxicity was reduced in MDF only, while 97% was reduced in MDF in soil. Toxicity of MDF in soil treatment required 49 days to decrease to the level of soil, while the leachate from MDF only treatment was still toxic than others at the end

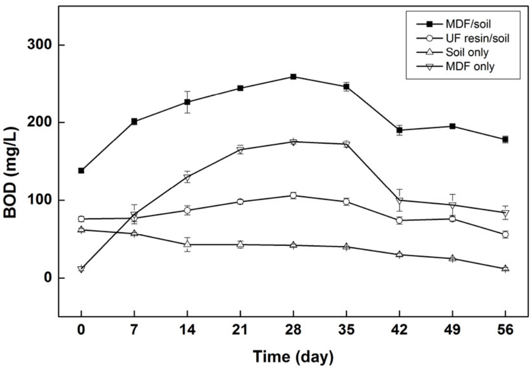

Fig. 4. BOD of leachate MDF in soil (■), MDF only (▽), cured UF resin in soil (○), and soil only (△) for 56 days.

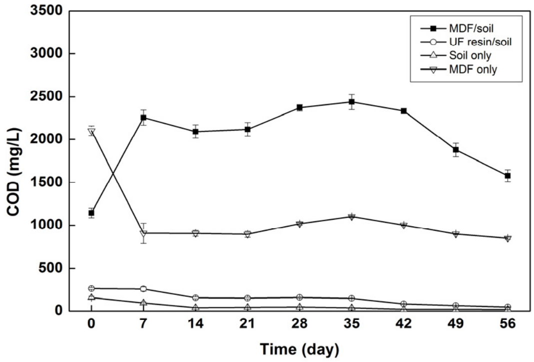

Fig. 5. COD of leachates from MDF in soil (■), MDF only (▽), cured UF resin in soil (○), and soil only (△) for 56 days.

of study. The toxicities in the leachate from soil only, MDF in soil and MDF only treatments were significantly different from each other over the 56 day study. These results indicated that MDF negatively affects the toxicity of the leachate most likely due to the formaldehyde or water-soluble extractives released from MDF. Moreover, the toxicity reduction in the MDF in soil treatment indicated that soil may be responsible for the reduction in the relative toxicity of leachate by trapping the formaldehyde. However, formaldehyde was not only a factor for contribution on toxicity, so other factor should be considered on toxicity.

3.3. BOD

The leachate from MDF in soil had a higher BOD value than leachate from MDF only, UF resin in soil, and soil only treatments overtime (Fig. 4). The BOD range of MDF in soil was between 139 - 259 mg/ℓ which is close to the BOD level of raw sewage (Nemerow, 1991). In MDF only, BOD increased from 12 to 175 mg/ℓ during the first 28 days and reduced then decreased to 84 mg/ℓ during the last 28 days. During the 56 day study, the BOD of the leachate from the UF resin in soil remained around 80 mg/ℓ, while the BOD values from soil only decreased from 62 to 12 mg/ℓ. Higher BOD values from MDF in soil was most likely due to the activity of soil microorganisms that were absent in the MDF only treatment. Moreover, MDF caused an increase in BOD by providing a carbon source for growth of microorganisms, and soil was a source of a large number of microorganisms that can degrade carbon, thereby increasing the oxygen demand and the BOD. The BOD range from the treatments containing MDF was above the allowable discharge limit that is 40 mg/ℓ for BOD (FOA, 2002).

3.4. COD

The COD results from 4 treatments during 56 days are shown in Fig. 5. Overall, COD of each treatment was higher than the BOD as expected. The range of COD in MDF in soil was between 1114 - 2439 mg/ℓ which indicates poor water quality (Nemerow, 1991). Higher COD values were observed from MDF in soil than other treatments such as MDF only, UF resin in soil, and soil only except on day 0. On day 0, MDF only had a higher COD value than MDF in soil. At the second sampling time, day 7, and thereafter however, COD values of MDF in soil were higher than MDF only. The decrease in COD of MDF only by almost 50 percent on day 7 and remained until the end of study may have been due to the decrease in water-soluble materials from the MDF being removed on day 0. UF resin in soil and soil only had lower COD values overtime compared to MDF in soil and MDF only. COD decreased from 156 to 18 mg/ℓ over the 56 day study on soil only, while COD decreased from 261 to 47 mg/ℓ at 56 days on UF resin on soil. The COD levels in treatments containing MDF were above the allowable discharge limit of 140 mg/ℓ for COD (FOA, 2002). More organic compounds from the MDF were possibly discharged to the leachate at the first sampling time which may have caused the initial higher COD from MDF only than MDF in soil.

3.5. Bacterial enumeration

The rationale for doing bacterial enumeration were to obtain an idea on how much organisms or biomass were present and the bacterial enumeration in leachate from the 4 treatments over

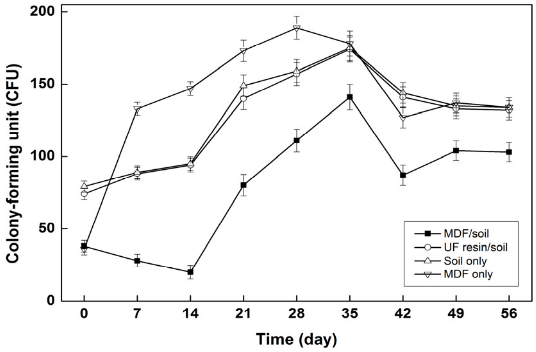

Fig. 6. Bacterial enumeration of leachate from MDF in soil (■), MDF only (▽), cured UF resin in soil (○), and soil only (△) for 56 days.

56 days is shown in Fig. 6. In general, bacterial population increased from day 0 to day 35 and decreased to the end of the study in all treatments. The bacterial enumeration of UF resin in soil and soil only followed a similar pattern for 56 days. Leachate from MDF in soil had lower bacterial populations than other treatments, while higher bacterial populations were observed on MDF only. Lower bacterial populations in leachate from MDF in soil may have been the result of the anaerobic environment. In contrast, the higher bacterial population in MDF only may have been the result of being aerobic bacteria which exist in the air. The UF resin did not affect bacterial populations in this experiment when compared to the soil only. In our experiment, BOD increased but bacterial counts did not correlated with the BOD measurements. This result may be caused from nutrient agar which used in bacterial enumeration methods. Soil containing treatments showed similar trend, but MDF only had different trend. We assumed that different

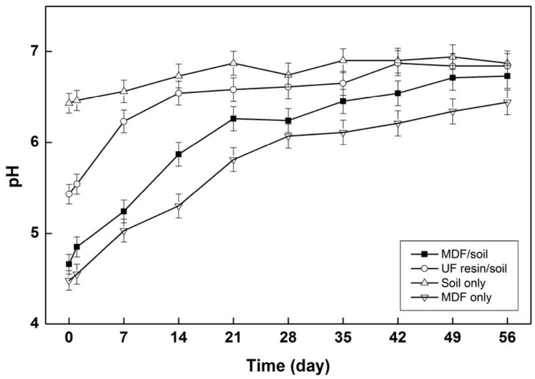

Fig. 7. pH of leachates from MDF in soil (■), MDF only (▽), cured UF resin in soil (○), and soil only (△) for 56 days.

trend may be resulting of bacterial species on soil containing treatments or MDF only treatment. Additionally, use of different culture medium or identification of bacteria using microbiology technology will be needed in order to answer this non-correlative result between BOD and bacterial enumeration.

3.6. pH

The pH of the leachate from the 4 treatments over the 56 day test period is shown in Fig. 7. The initial pH of the leachate from soil without MDF was 6.43, increased to a maximum of 6.90 on days 35 and 42 and remained at approximately 6.87 through 56 days. The pH in the leachate from MDF in soil was initially 4.48 and increased to 6.73 by day 56. Lower pH of leachates from treatments containing MDF was due to the acid catalyst in MDF. Overtime the pH of leachates from treatments containing MDF increased and by the end of the study their pH equaled that of the soil only treatment. Soil may buffer pH due to the presence of organic materials in soil (James and Riha, 1986). After the first week, pH values of leachates from all the treatments were within the allowable discharge limit which is pH 5 - 9. Based on pH results, we would think the bacteria cells acclimated to low pH environments would have a hard time growing back up. Perhaps that is why there was a discrepancy between BOD and bacterial enumeration at early time points.

4. CONCLUSION

Disposal of MDF in soil may be a possible pollutant to water systems by generating leachate that contains formaldehyde and water-soluble materials from MDF decomposing in soil. Under our experimental conditions, the MDF buried in the simulated landfill negatively affected to environment by increasing formaldehyde, toxicity, BOD, and COD of the leachate. Formaldehyde and toxicity from treatment 1 (MDF in soil) decreased overtime, while BOD and COD remained above permissible discharge levels of BOD or COD. These results indicated that soil may help to decrease formaldehyde and toxicity but not the BOD and COD. Higher BOD and COD in leachate from treatment 1 (MDF in soil) than treatment 2 (MDF only) may have been caused by decomposition of MDF. Increasing or decreasing of toxicity may be correlated with the period of formaldehyde from MDF. Future studies should include chemical analysis of leachate and MDF in order to determine the decomposition of MDF in soil. In addition, bacterial identification, gene expression and enzyme activity will also be needed to determine how the microbial community reacts to the MDF.

ACKNOWLEDGEMENT

This work was funded through a United State Department of Agriculture Wood Utilization Research grant and the Mississippi State University Department of Forest Products. Approved for publication as Journal Article no. FP 694 of the Forest and Wildlife Research Center, Mississippi State University.

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