Bioremediation of Oriented Strand Board (OSB) Process Wastewater

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This study investigated the use of bioreactors and constructed wetlands to remediate oriented strand board (OSB) process wastewater. The first study evaluated the use of free cell bioreactors to reduce the biological oxygen demand (BOD). Control samples had significantly higher BOD levels than other treatments, and air+bacteria+nutrients treatment achieved significantly lower in BOD than air-only. Toxicity, total phenol, and total organic carbon concentrations decreased in all treatments. The initial constructed wetland was a screening study to determine which plants could acclimate to OSB process water. Plants that survived were placed into a floating constructed wetland (water hyacinth) or an emergent wetland (soft rush and Chinese water chestnut). A significant decrease in BOD occurred between days 15 and 30, with the emergent wetlands dropping by 51.7% and the floating wetlands by 52.7%. Toxicity, total phenol, and total organic carbon concentrations decreased in all treatments. This research suggests that an OSB facility may want to have an aerated pond that then feeds a constructed wetland. This could not only provide a means to treat and dispose of the wastewater in an environmentally favorable manner, but also provides the secondary benefits of a wetland and its associated land enrichment.

Keywords: Oriented Strand Board (OSB); Constructed Wetlands; Bioremediation of Process Wastewater

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INTRODUCTION

In recent years, the production of OSB (Oriented Strand Board) and other materials such as waferboard worldwide has grown dramatically (over 50%) (Steinwender and Barbu 2009). In the ever-changing industrial environment, one the most serious challenges manufacturers face is the issue of complying with environmental regulations. These regulations are designed and implemented for the protection of the air, soil, and water. Environmental regulations which focus on the protection and quality of the nation's waters are some of the most demanding. This statement is especially true with respect to wastewater that contains a high level of organic matter, as measured by the biological or biochemical oxygen demand. Common wastewaters that are included in the elevated biological oxygen demand category are those from agricultural processes (concentrated animal feeding operations), municipal sources (sewage treatment facilities), and industrial sources (*e.g.* pulp and paper manufacturing). Often, these wastewaters not only have a large amount of organic matter, whether it be in the form of fecal matter or wood wastes, but also the addition of secondary contaminants such as high levels of nitrogen, phosphorus, total suspended solids, increased toxicity, and an altered pH level. In the industrial sector, these contaminants are a concern in the production of oriented strand board (OSB), a composite wood panel product. The production of OSB is a waste-intensive process, emitting large amounts of wood wastes, water wastes, resin and wax wastes, and volatile emissions. Through the production of OSB, these wastes often are deposited in the wastewater stream of the production facility. The manufacturer of OSB must not only limit the generation of these wastes to conserve monetary expenditures in the form of lost inputs, but also control the production of these wastes to limit the amount of waste disposal issues and costs.

Common byproducts and emissions of the OSB or similar manufacturing processes which are found in the process wastewater are volatile organic compounds (VOCs), phenols, and wood wastes. These compounds are emitted throughout the entire manufacturing process but are predominately emitted during the drying and hot-pressing of the OSB mat and the washing of production equipment. Common VOCs emitted from wood include alpha-pinene, beta-pinene, limonine, camphene, benzene, and phenols (Rasmussen and Went 1965; Raemchild 1998). In addition to the VOCs previously listed, the following chemicals can also be released into the water waste stream: formaldehyde, acetic acid, caproic acid, and methanol (Grzanka and Nester 1994). Fine particles of wood wastes enter the wastewater stream, increasing the organic matter in the water. Wastewater is generated throughout the production process. Steam can be collected from the pressing operation and condensed back into water, equipment must be cleaned, and in some cases, the logs from which the flakes are cut from are soaked to "soften" the wood. As wastewater is collected through the production facility, other emissions become a part of the wastewater stream. OSB wastewater containing increased levels of organic matter must be treated before its release.

In the remediation of wastewater, there are a variety of treatment options available for use. Biological treatment is commonly used in the treatment of industrial, agricultural and especially municipal wastewaters. Biological treatment methods are often either suspended growth processes where the microbial medium is allowed to freely mix the wastewater allowing constant contact (Tchobanoglous and Burton 1991), attached-growth processes where the microorganisms responsible for the conversion of the organic matter in the wastewater are attached to some inert medium such as rocks, slag, or specially designed ceramic or plastic materials (Tchobanoglous and Burton 1991), or constructed wetlands in which the plant materials themselves in the wetland generally do not facilitate actual wastewater treatment but only provide a substrate for microorganisms to transform pollutants and reduce their concentration (Jain *et al.* 2011; Zhao *et al.* 2012; Ansola *et al.* 2014). There is a rising interest in the use of constructed wetlands for remediation purposes due to wetlands natural abilities to reduce certain wastewater contaminants such as total suspended solids, BOD_5, chemical oxygen demand (COD), ammonia, nutrients such as nitrogen and phosphorus, and other pollutants such as metals (EPA 2000; Kadlec 2003; Pastor *et al.* 2003).

Constructed wetlands are divided into two categories based on their hydraulic design, surface flow wetlands and subsurface flow wetlands. Surface-flow wetlands or free water wetlands are those which typically resemble and simulate a cattail (*Typha* L. spp), sedge (*Cyperus* L. spp or *Carex* L. spp) or rush (*Scirpus* L. spp or *Juncus* L. spp) dominated marsh. In a surface flow wetland, plants are embedded into a substrate and water is applied and controlled at a specific depth (EPA 2000).

Subsurface wetlands are those where water is directed through a vegetated gravel or soil bed. There are other variations of these wetlands such as a floating aquatic plant wetland, which mimics the surface flow wetland with the exception of using highly productive floating plant species such as water hyacinth (*Eichhornia crassipes* (Mart.) Solms) or duckweed (*Lemna* L. spp) (Kadlec 2003; Vymazal 2011).

Plant species often used in the design of surface flow wetland are chosen for their affinity for survival in low oxygen environments such as natural wetlands and ditches. Some common plant species used are bulrush (*Scirpus americanus* = *Schoenoplectus americanus* (Pers.) Volkart ex Schinz & R. Keller), cattail, soft rush (*Juncus effusus* L.), water hyacinth, duckweed, and Chinese water chestnut (*Eleocharis dulcis* (Burm.f.) Trin. ex Hensch). These species are used to treat a variety of wastewaters, municipal, industrial, and agricultural (Mitsch and Gosselink 1993). In the United States and Canada, wetlands systems have been designed mostly for use in the large scale treatment of municipal wastewater.

Often municipal wastewater is not unlike industrial wastewater, containing elevated BOD, total suspended solids (TSS), and increased nitrogen and phosphorous levels similar to agricultural wastewater. In 1993, a survey was completed on more than 300 wetland cells which treated municipal wastewater in North America. The survey concluded that BOD was reduced on average by 73% to 8 mg/L, TSS was reduced 72% to 13 mg/L, total nitrogen was reduced 53% to 4.5 mg/L, and total phosphorous was reduced 56% to 1.7 mg/L (Cole 1998).

Constructed wetlands are chosen for remediation purposes not just for their ability to reduce contamination but also for a number of other "non-treatment" related reasons. Under appropriate use, constructed wetlands can provide water quality improvement, mitigation of flooding risks, cycling of nutrients and minerals, habitat for fish and wildlife, passive recreation such as bird watching or photography, active recreation such as hunting, education and research, aesthetics, and land enrichments (Brix 1995; Pastor *et al.* 2003; EPA 2009). These reasons alone give politicians and industrial representatives numerous incentives to promote the use of constructed wetlands technology. In addition, constructed wetlands are among less expensive treating technologies to build and operate, easy and efficient to operate, facilitate water recycling and reuse; they are able to handle fluctuations in effluent volumes (Brix 1995; EPA 2000).

At the same time as providing numerous benefits, constructed wetland do offer limitations. These include land requirements, inconsistent performance due to temperature/climate variations (Werker *et al.* 2002), and susceptibility to surges of toxic materials (Kadlec and Wallace 2008; Albuquerque *et al.* 2009; Lu and Huang 2010). Removal of nitrogen and phosphorous are especially problematic (Vymazal and Kröpfelová 2008).

Despite constructed wetlands limited drawbacks, it is considered a reliable wastewater treatment and an ever increasing treatment technology applicable in many areas (Vymazal 2011). It has been shown efficient even for removal of heavy metals from landfills, tannery and pulp and paper industry (Calheiros *et al.* 2007; Kamarudzaman *et al.* 2011; Arivoli *et al.* 2015). Weyerhaeuser pulp and paper plant in Columbus, MS has been treating almost six million gallons/day of their wastewater using native plants since 1990. The purpose of this study was to investigate the use of bioreactors and constructed wetlands to remediate oriented strand board (OSB) process wastewater.

EXPERIMENTAL

OSB Process Wastewater

A total of 182 L of water used in the bioreactor study and the initial plant efficacy-constructed wetlands study was collected by personnel at an OSB manufacturing facility from the process wastewater storage tank and placed at 4 °C until use. This process wastewater was collected throughout the entire facility, including water used to wash production equipment and machinery and steam collected from the hot-pressing of the OSB mats. An additional 273 L was collected from the same location three months later for the constructed wetlands portion of this study. BOD analysis revealed that the second batch of OSB process wastewater contained much higher levels than the first batch.

Bioreactor Study

The objective of the bioreactor study was to determine how to reduce the level of BOD in the OSB process wastewater to levels the plants could tolerate. Twelve 1-L, amber colored, narrow neck glass bottles were used as the bioreactor vessels. There were four treatments with three replications per treatment. Each replicate contained 900 mL of OSB process wastewater. Treatment 1 was the control with process wastewater only (TRT 1). Treatment 2 containers were aerated (TRT 2). Treatment 3 containers were aerated plus received 1 mL of an unidentified microbial consortium (TRT 3). This microbial consortium was isolated from the OSB process wastewater and grown in nutrient broth. Treatment 4 containers were aerated, received 1 mL of the microbial consortium, plus received 10 mg fertilizer composed of 30:10:10 (N:P:K) (TRT 4). All treatments ran for 105 days. At Day 0 and every 15 days, samples were collected for BOD_5 analysis and bacterial counts. At Day 0 and Day 105, samples were also processed for toxicity, Total Organic Carbon (TOC) and Total Phenols (TP).

Water samples were processed for BOD_5 according to EPA Method 405.1 (EPA 1983). Water samples were diluted as needed to fit within the testable range of the method. TOC and TP were run by an outside analytical laboratory according to Standard Method 5310 (Clesceri *et al.* 1998) and EPA Standard 420.1 (EPA 1983), respectively. Bacteria were enumerated by spread plate method. Serial dilutions were plated onto nutrient agar, incubated for two days at 28 °C, and colonies counted. Toxicity levels were measured using a Microtox Model 500 (Microbics Corporation, Carlsbad, CA) following the Microtox Acute Toxicity Basic Test protocol or the 100% Screening Test depending on level of toxicity. Acute toxicity values are represented as the effective concentration that decreased the light output by 50% (EC50) when compared to clean water or as the percent difference when compared to clean water. Measurement of water toxicity by Microtox is an EPA approved method that is highly reproducible because it uses pre-prepared freeze-dried bacteria, plus does not require animal care and use oversight. It also shows that treated wood extractives in process water do not convert into toxic compounds.

Constructed Wetlands Study

Plant Screening Study

The objective of this study was to evaluate which plant species survived growing in the OSB process wastewater. Plant species were selected for their relative affinity for low oxygen environments. These plants were collected with permission from local private wetlands.

The plants screened were floating plants: water fern (*Azolla caroliniana* Willd.), small duckweed (*Lemna minor* L.), and water hyacinth (*Eichhornia crassipes*), and emergent plants: Chinese water chestnut (*Eleocharis dulcis*), soft rush (*Juncus effusus* L.), bulrush (*Scirpus americanus*), beakrush (*Rhynochospora globularis* Chapm.), bald cypress (*Taxodium distichum* (L.) Rich.), and black willow (*Salix nigra* Marshall).

Wetlands were established in fiberglass tubs. Each tub was divided into three sections measuring 61 x 91 x 23 cm (L x W x D) (Fig. 1). Each section served as a replicate. Pea gravel was added to the bottom of each tub to a depth of 5 cm (1915 L pea gravel per tub).

Control wetlands contained 34 L of lake water added to a depth of 7.6 cm. Constructed wetlands contained 34L of OSB process wastewater added to the same depth. The roots of the emergent plants were imbedded into the pea gravel. Floating plants were placed on the water surface. These wetlands were located inside a greenhouse in order to maintain temperatures around 30 °C. Plant survival was accessed for 60 days.

Simulated Constructed Wetland Study

The objective of this study was to evaluate the potential of constructed wetlands to reduce the BOD levels in OSB process wastewater to acceptable discharge levels. This study compared two types of constructed wetlands, floating versus emergent. Each wetland type was run in triplicate in the same fiberglass tubs described in the Plant Screening Study. Each tub contained 5 cm (1915 L) of pea gravel. A 303 L/h pump was placed into each tub in order to provide water circulation. The wetlands were located outside. The floating plants, small duckweed and water hyacinth, and the emergent plant, Chinese water chestnut were purchased from garden supply houses. The emergent soft rush was obtained from the United States Department of Agriculture's Whitten Plant Material Center in Coffeeville, MS. Ten water hyacinth plants and 0.5 L of small duckweed were added to each of the floating replicate tubs. Two rows of water chestnut and four rows of soft rush were planted in the gravel of the three emergent tubs. OSB process wastewater was added to all tubs to a depth of 8 cm.

Within two weeks all plants died except the duckweed. BOD analysis revealed that this batch of OSB process wastewater contained much higher BOD levels than that used in the prior studies. In order to reduce the BOD levels to that of the plant screening study, battery operated aerators were placed into each tub in order to mimic the bioreactor study and reduce the BOD levels. The aerators consisted of 10-cm-long aquarium aerators. After 45 days the BOD levels matched that of the plant screening study. The aerators were removed, and the tubs were replanted as before, except the small duckweed was not included.

Although the duckweed survived the high BOD levels, it continuously clogged the pumps. The study ran for 75 days and water levels were adjusted according to rainfall and evaporation. At Day 0 and every 15 days, samples were collected and processed for BOD_5 analysis and bacterial counts as described previously. At Day 0 and Day 75, samples were processed for toxicity, TOC and TP as described previously.

Statistical Analysis

The data were analyzed for significant differences at 5% level through Tukey ANOVA using SAS software.

RESULTS AND DISCUSSION

Bioreactor Study

In the bioreactor study, TRT 1 (control) samples had overall significantly higher BOD levels than other treatments, and the BOD levels of TRT 4 (air+bacteria+nutrients) samples were significantly lower than TRT 2 (air only) samples. All treatments including the control experienced a significant decrease in BOD levels over the 105 days (Fig. 1). In the TRT 1 samples, there was a significant BOD decrease by Day 30, followed by a second significant drop by Day 90. The significant drop in BOD after 30 days was also seen in TRT 2, TRT3, and TRT4 samples, and although the mean values continued decreasing, the consistent significant decrease was not seen in these treatments after that. The percent decrease in BOD levels by Day 30 were 58%, 72%, 79%, and 84%; by Day 60 were 66%, 77%, 79%, and 93%; by Day 90 were 92%, 93%, 96%, and 97% for TRT 1, TRT 2, TRT 3, and TRT 4, respectively.

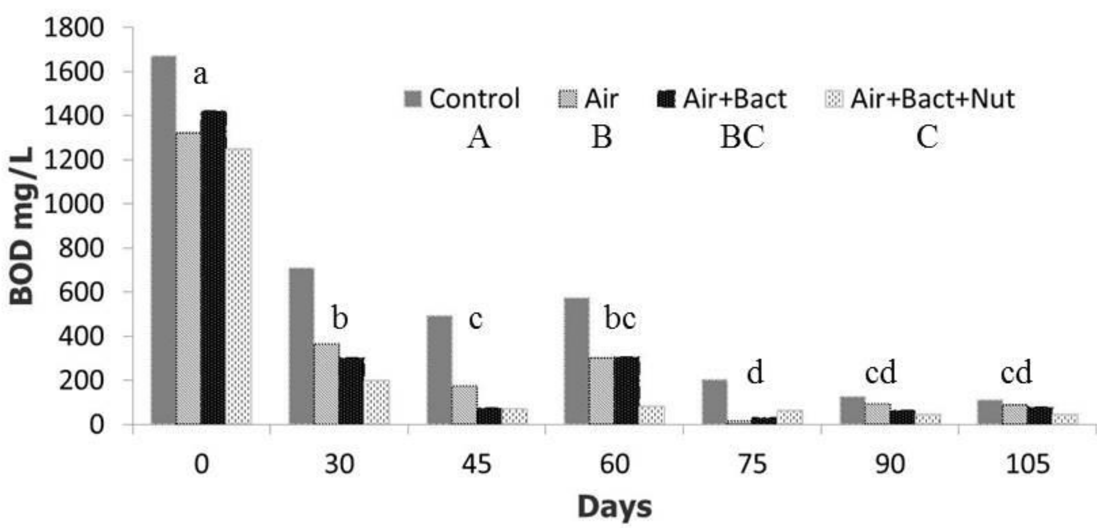

Fig. 1. Decrease in organic material content as measured by BOD analysis in the four bioreactor treatments over 105 days. Each point is an average of three replicates. The capital letters beneath the treatments indicate significant differences at alpha 0.05 among treatments when all days for each treatment were averaged. The small letters above the bars indicate significant differences at alpha 0.5 among days when all treatments were averaged for each collection date.

The bacterial population increased 10-fold by Day 105 when only air was added (Fig. 2), while the population in the control samples decreased slightly. In the two treatments where additional bacteria was initially added, the populations fluctuated over time ending at Day 105 with no change in total numbers (treatment with air+ bacteria) or a slight increase (air+ bacteria+ nutrients) (Fig. 2). Ultimately at Day 105, the air only treatment contained similar numbers of bacteria compared to the two treatments where bacteria were added.

When all replicates for each collection date were pooled and compared among treatments, only TRT 4 bacterial numbers were statistically greater than the other three treatments. This implies that addition of bacteria and air alone, did not sustain the inoculated bacteria.

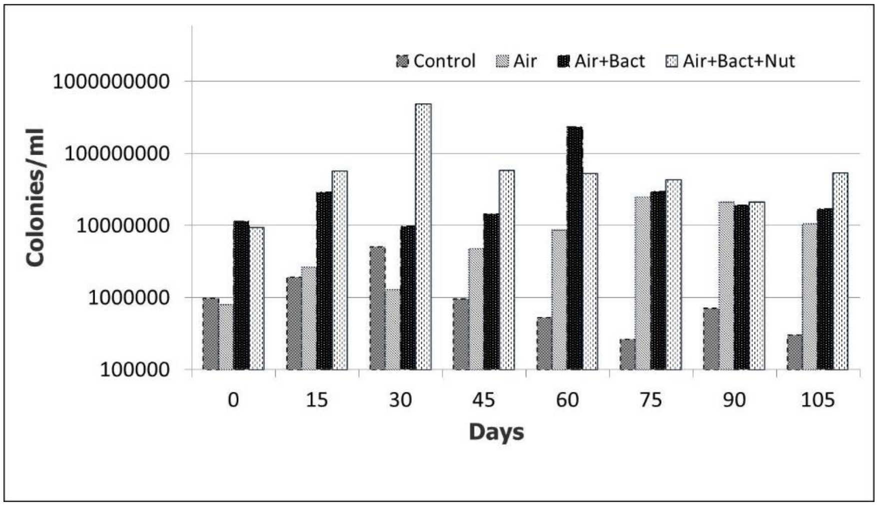

Fig. 2. Changes in the number of bacteria colonies in each of the four bioreactor treatments measured over 105 days. Each point is an average of three replicates

Toxicity levels as measured by the acute toxicity test decreased by Day 105 in all treatments (data not shown). Toxicity levels in the control decreased by 40.9%, while the other three treatments showed a decrease in toxicity levels of 100%. Concentrations of TOC and TP decreased from Day 0 to Day 105 in all treatments (Table 1). For TOC, the decrease was 46.1% in the control, 77.9% when air was added, 82.7% when air+ bacteria were added, and 75.0% when air+ bacteria+ nutrients were added. For TP, the overall decrease was larger with 97.3% decrease in the control, 99.2% decrease in the treatments with air and air+ bacteria, and 99.4% decrease in the air+ bacteria+ nutrients treatment. No significant difference in organic matter content was seen among the samples of bioreactors after 105 days, but a significant, progressive decrease in total phenols was seen with successive addition of air, bacteria, and nitrogen, respectively.

Table 1. Levels of Total Organic Carbon (TOC) and Total Phenols in the Bioreactor Treatments at Day 0 and Day 105

	TOC mg/L	Total Phenol mg/L
Day 0	520	107.4
Day 105		
Control	280 A	2.9 A
Air	383 A	0.9 B
Air+Bact	90 A	0.9 BC
Air+B+Nt	130 A	0.7 C

The capital letters beside the treatments indicates significant differences at alpha 0.05 among treatments.

Constructed Wetlands Study

At the end of the plant screening study, five of the nine plant species had died in the OSB process wastewater. A similar result was found when testing the process water from a different wood composite manufacturing process (Mangum *et al.* 2010). The plants that survived and were chosen for the next study were the floating plants, small duckweed and water hyacinth, and the emergent plants, Chinese water chestnut and soft rush. A new batch of the OSB process wastewater was obtained and the constructed wetlands established. Unfortunately, all plants died within two weeks. The new batch of OSB process wastewater was approximately 2-fold higher in organic material than the first batch of OSB process wastewater and this higher BOD level killed all plants. In order to reduce the organic material to levels equivalent to the first batch of water, aerators were added to each tub. BOD levels decreased from 3337 mg/L at the start to 1977 mg/L after 30 days and 1000 mg/L after 45 days. At this point the tubs were replanted with the same species minus the duckweed which had continually clogged the circulating pump.

The constructed wetlands were evaluated for 75 days (Fig. 3). Both the floating and emergent wetlands experienced a decrease in BOD levels over the 75 days (Fig. 4).

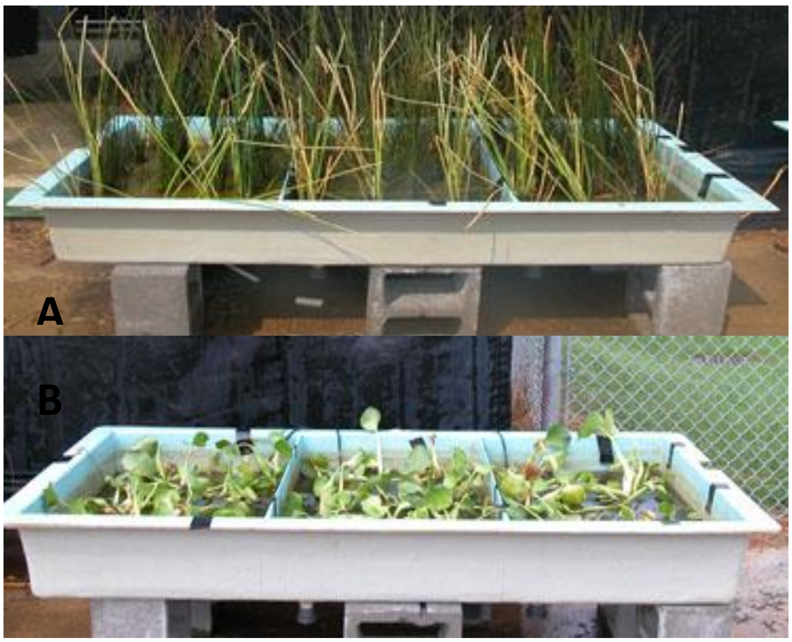

Fig. 3. Emergent (A) and Floating (B) wetlands were established in fiberglass tubs divided into three sections. Each section was filled with OSB process wastewater plus plants and served as a replicate.

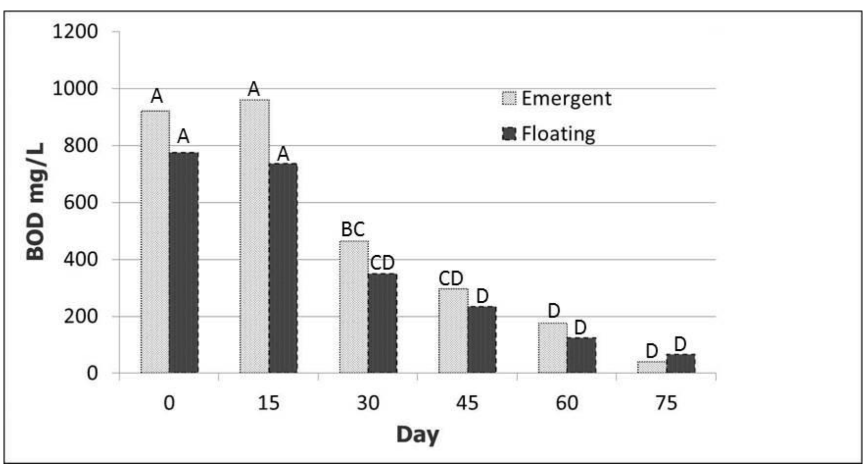

Fig. 4. Decrease in organic material content as measured by BOD analysis in the emergent and floating wetlands over 75 days. Each point is an average of three replicates. The capital letters indicate significant differences at alpha 0.05 within a treatment for each collection date. There

were no statistically significant differences between treatments when all collections dates for each treatment were averaged.

A significant decrease occurred between Days 15 and 30 with the emergent wetlands dropping by 51.7% and the floating wetlands by 52.7%. The significantly lowest levels in emergent wetlands were obtained at 60 days (84.2% decrease), and in floating wetlands at 45 days (70% decrease). Although not statistically different, BOD levels decreased to 96.0% and 92.8% for the floating and emergent wetlands, respectively by Day 75. There were no statistically significant differences between the two wetlands when all collections dates for each treatment were averaged.

The bacterial populations fluctuated in both wetlands without a consistent significant difference (Fig. 5). Toxicity levels as measured by the acute toxicity test decreased by Day 75 in both wetlands (data not shown) by 100% (to non-toxic levels). Concentrations of TOC and TP decreased from Day 0 to Day 75 in both wetlands (Table 2).

For TOC, the initial concentration was greater than in the bioreactor study, but the decrease was still 86.7% for the emergent wetlands and 83.9% for the floating wetlands, with no significant difference among the emergent and floating wetlands at Day 75. For TP, the overall decrease 99.5% for the emergent wetlands and 99.2% for the floating wetlands also did not show significant difference at Day 75.

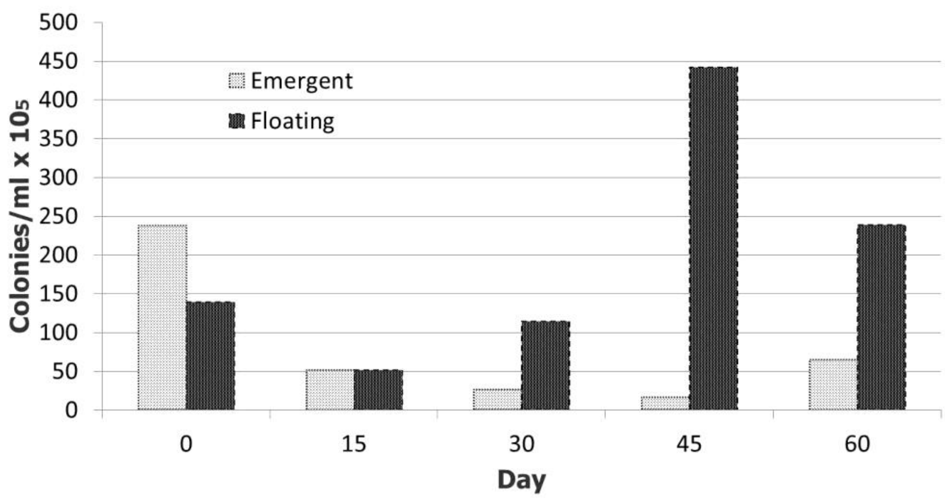

Fig. 5. Changes in the number of bacteria colonies in emergent and floating wetlands measured over 60 days. Each point is an average of three replicates.

Table 2. Levels of Total Organic Carbon (TOC) and Total Phenols in the Constructed Wetlands at Day 0 and Day 75

	TOC mg/L	Total Phenol mg/L
Day 0	1600	167.2
Day 105		
Emergent	213	0.8
Floating	257	1.3

CONCLUSIONS

1. In the bioreactor study, the addition of air significantly increased the removal of organic matter as measured by BOD during the first 30 days of treatment. Addition of bacteria plus air did not significantly increase the removal of organic matter; however, the addition of nutrients did significantly increase this removal when compared to control and air alone.
2. It should also be noted that in the control, there was still a significant drop in organic matter concentrations within the first 30 days, implying that even passive volatization is a major route for organic matter removal.
3. Bacteria levels remained higher after 30 days when air was added to the system. The addition of air also significantly increased the removal of total phenols, as did the addition of nutrients. Therefore, the use of air by itself could be enough in certain situations to reduce BOD significantly and should be considered a major part of remediation on this type of process water.
4. Overall, the bioreactor study shows that addition of air alone enhances the removal of organic matter, and the addition of air plus nutrients provides even greater levels of removal.
5. The differences in the organic matter concentrations of the two batches of OSB process wastewater obtained in this study highlight the variability of contaminant concentrations that can occur in this water. Thus it is unlikely that constructed wetlands alone can adjust to, survive, and remediate the varying concentrations of process water. However, once the concentration of organic matter reaches a survivable level, the wetland plants were able to reduce the organic matter content and total phenols to approximately the same level as the bioreactors.
6. There were no noted significant differences between a floating wetlands compared to an emergent wetlands. Since after 30 days BOD levels were still higher than the discharge levels, constructed wetlands could be used as secondary or tertiary treatment, but cannot likely be used as a sole treatment method.
7. This study suggests that an OSB manufacturing facility could establish an aerated pond to treat the initial discharge of process wastewater, and then release the treated pond water into a constructed wetland. This could not only provide a means to treat and dispose of the wastewater in an environmentally favorable manner, but also provide the secondary benefits of a wetlands and its associated land enrichment.

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