TREATING WATER CONTAMINATED WITH SUBSTITUTED AROMATICS USING A KENAF-BASED BIOSORPTIVE PROCESS

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ABSTRACT

An innovative process is under development for treatment of contaminated waters. The process involves adsorption of contaminants onto plant materials, kenaf, that are loaded within a packed column. *After* the sorptive capacity of the kenaf is expended, then the spent kenaf fibers will be disposed of using composting. The composting step will not only reduce fiber volume, but this step will also biologically degrade the phenol adsorbed onto the fibers. This process is viewed as a direct competitor to activated carbon, which is one of the most common treatment processes, used for wastewater and groundwater remediation. Results indicate that kenaf has a much lower adsorptive capacity for DCP then activated carbon. However, kenaf had a similar adsorptive capacity, compared to activated carbon, for TNT. *In* the case of DCP, the adsorption isotherm slope factor is steeper for the kenaf than the activated carbon indicating that the loading capacity of the kenaf as an adsorbent is much *more* sensitive to changes in targeted *effluent levels* than activated carbon. However, the adsorptive characteristics of kenaf toward TNT were almost identical to that *of* activated carbon in terms of all model parameters. *Stability* testing of kenaf within a packed column undergoing continual and intermittent hydraulic loading indicated that kenaf is surprisingly stable within a dynamic column setting. Finally, composting of kenaf appears feasible using thermophiles

INTRODUCTION

Many of the contaminated surface waters and groundwaters currently undergoing treatment, or scheduled for treatment, contain organic contaminants as relatively low levels (sub-100ppm levels); yet, these levels are still well above regulation, requiring treatment prior to discharge. Recent pollution prevention initiatives within industry have resulted in wastewaters that do contain lower levels of contamination; however, these waters still contain contamination levels requiring treatment. The treatment of these waters poses both technical and economic challenges to industry and site owners (Acar and Zappi 1995). With regard to Mississippi, many industries are small businesses that are already stressed by the challenges of today's market conditions. Having to face complex environmental compliance issues, such as water treatment, only further exasperates their situation. However, these water sources do require treatment to preserve/restore the resource quality (and keep the company in compliance).

Currently, available treatment technologies usually have problems treating these waters.

Typically, these influents do not contain sufficient organic substrates to adequately support biotreatment units (Zappi et al. 1993). Many of these chemicals cannot be air stripped because of low volatility (Haas and Vamos 1995). **Plus,** current regulatory guidance requires treatment of air exiting air stripper units due to concerns over air pollution. Chemical oxidation offers an alternative; however, these techniques are developing, somewhat costly, and often require highly trained operators due to system complexity (Langlais et al. 1991). **Also,** the presence of hydroxyl radical scavengers within the influents and poor influent UV transmissivity adversely impacts oxidation process performance (Zappi 1995). Activated carbon adsorption offers a viable option. However, activated carbon has limitations in that spent carbon must be transported off-site for disposal or regeneration. Therefore, the state of affairs facing engineers and scientists attempting to treat low level contaminated waters using the above discussed technologies results in the selection of a process within a reduced cost bracket is needed to assist industries in meeting environmental regulations. An operationally simple system would improve the quality *of* endangered water sources because of

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increased usage by industry resulting in cleaner discharges.

The use of novel adsorbents is not new. Kim et al. (1997) used waste tire rubber as an effective adsorbent for removing chlorinated solvents. Eichenmuiller et al. (1997) used porous polymers to remove acenaphthalene from water. Srivastave et al. (1997) evaluated using waste carboneous particles from a fertilizer production facility as a means of removing dichlorophenol from aqueous solutions. All of these innovative approaches showed promise; however, in each case, all adsorbents had to be regenerated using either high temperatures (much like activated carbon) or chemical dissolution using aggressive chemicals that did not ultimately result in the destruction of the contaminant. The kenaf-based bisorptive process differs from these processes in that composting, a technology proven to be much cheaper to implement than thermal processes, will be used to destroy the spent adsorbents and sorbed adsorbates.

Composting is a well-established process that is gaining increased attention for its simplicity and effectiveness (Goldstein and Steuteville 1996). Composting of the kenaf is expected to be successful for both the reduction of spent kenaf fiber volume and the degradation of the adsorbed phenols. Several well-documented studies clearly showed that compost systems are very capable of rapidly achieving high levels of volume reduction of plant wastes, many of which were more recalcitrant than kenaf, due to their composition of more stable cellulose and high bark content (Reinhart and Tanner 1995). Liao et al. (1995) reported volume reductions after composting in excess of 50% and 40% for sawdust and peat moss, respectively.

In terms of organic chemical degradation, composting has been successfully used for degradation of very complex organic compounds including explosives (Tuomi et al. 1997). herbicides (Dooley et al. 1995). biosolids (Reinhart and Tanner 1995), and petroleum wastes (Epstein and Wu 1997). In fact, Semple and Fermor (1995) determined that cornposting was effective in the treatment of chlorophenol-contaminated soils. Finally, since the proposed treatment process must be operated year-round, including winter months, some concern was felt toward the ability of a compost system to properly function during this period. However, Lynch et al. (1997) proved that composting during severe winter conditions is not only possible, but successful.

CONCEPTUALIZED PROCESS

A novel process is conceptualized that will address the shortcomings of the technologies discussed above, while meeting the needs of industry. The envisioned process involves adsorption of organic contaminants onto crushed kenaf fibers. Kenaf is an agricultural crop that has recently been found to have many uses including animal litter, paper manufacturing, and composite material construction. The fibers of the kenaf plant are resistant to water logging and are structurally stable when exposed to overburden loads allowing tight, yet sturdy packing. Kenaf fibers will be packed into a column where contaminated water will be passed through the column using up-flow hydraulics to provide intimate contact between contaminated water and the kenaf fibers (all three fiber types of the plant will be tested [surface fibers, core, and mixed chop]). The contaminants will adsorb onto the adsorptive sites on the kenaf and the column operated until all of the kenaf fibers within the column are completely spent (i.e. all sorption sites filled). This approach is very similar to that used with activated carbon adsorbers; however, once the kenaf becomes spent, then the fibers will be removed and placed into a compost bed. The compost bed will be used to reduce waste kenaf volume and degrade the adsorbed chemicals via biotreatment. Benefits expected with the development of the proposed process are:

a. The kenaf-based biosorptive process is expected to be much cheaper than activated carbon in that kenaf is a renewable resource that is easily cultured within the Southeastern United States. The plant fibers are easily prepared using processing techniques that economically wash, crush, and segregate the various fractions. Alternatively, activated carbon requires aggressive processing of carboneous materials (nutshells, bone, or coal) that involve high temperatures and pressures; both of which are very costly. Cost estimates place carbon at $1.50 per lbs. versus less than $0.10 per lbs. of kenaf.

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b. Kenaf fibers are easily stored and extremely stable under high impact and overburden stresses. Activated carbon is easily crushed to useless fines under similar handling conditions. In fact, to retain structural stability, activated carbon is usually loaded into and out of adsorber vessels using water-carbon slurries which increases system complexity and cost.

c. Composting is a well-developed process that has been widely used for disposal of plant debris and stabilization of municipal biosolids. The final product from compost systems, including the type proposed within the process, is a humus-based material that has a marketable value as an agricultural amendment (Maynard 1995). Using composting to dispose of the spent kenaf fibers will also result in the on-site degradation of the adsorbed contaminants, meaning that the proposed process *is* a destruction treatment process that will eliminate the pollutants as an environmental and regulatory problem. Carbon must be transported off-site and regenerated using special equipment that utilizes high temperature and pressures to destroy the contaminants.

RESEARCH OBJECTIVES

The overall objectives of this project were to develop and prove the potential of using kenaf as an adsorbent within an integrated biosorption process to be used for treating contaminated waters. Secondary objectives for this study included:

a. Evaluation of the adsorptive capacity of candidate kenaf fibers composed of various plant fractions and/or fibers made from differing processing techniques for dichlorophenol (DCP) and 2,4,6-trinitrotoluene (TNT).

b. Evaluation of the stability of the kenaf fibers within saturated column reactors under long-term, dynamic operational flows.

c. Evaluation of various composting approaches for reduction of plant mass (pollutant fate within a compost reactor is being addressed within another on-going project at MSU).

Dichlorophenol was selected to represent phenols which are of interest because: [a] phenols were listed by the USEPA in the 1993 Toxics Release Inventory (USEPA 1995) as one of the top 25 chemicals most discharged by US industries (This report also states that the Southern US (TX, LA, MS, AL, and TN) was among the largest contributors to these releases), [b] phenols are listed on many target regulatory lists as a contaminant of primary interest, and [c] phenols have been the subject of many research topics in the past; unfortunately, most of this work was targeted toward high level contaminated waters with little attention focused on low level contamination that now constitutes a large fraction of the phenolic mass released into the environment or discharged into POTWs. Phenols are biodegradable with increasing chlorination posing more difficulty for biotreatment (Baker and Herson 1994). Therefore, DCP represents a medium chlorinated phenol.

The explosive, TNT. is a major pollution problem for Department of Defense (DoD) sites. They contaminate both groundwater and surface waters. To date, no single technology is considered optimum for TNT removal. Zappi (1995) discusses the pros and cons of current technology for explosives treatment within water matrices. The proposed technology may offer a more efficient treatment option from both an economic and technical standpoint and, as such, was selected as the second test absorbate for this study.

EXPERIMENTAL METHODS AND RESULTS

Analytical Techniques

Both test adsorbates, DCP and TNT, were analyzed during this study using a Model 1100 Hewlett-Packard High Performance Liquid Chromatography (HPLC) unit equipped with a diode array detector following USEPA approved analytical methods. Appropriate standards and instrument calibration were performed following equipment manufacturer recommendations.

Evaluation of Kenaf Stability Under Dynamic Column Operation

Objective- The objective of this effort was to evaluate the stability of kenaf under continual passage of an aqueous influent through an

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adsorption column packed with kenaf as an adsorbent.

Experimental Approach- Crushed whole kenaf was tested for its stability under dynamic flow conditions within a packed column. The crushed whole stalk represents the cheapest kenaf source (approximately $0.05 per pound versus $1.50 per pound of activated carbon). This material was also thought to be the most likely to decompose within a wetted column because of on-going work at MSU using kenaf as a bioreactor support media. These efforts indicate that the core material is much more stable within aerobic bioreactors than the outer stalk. Since only crushed whole stalk and core material are being treated as potential adsorbents within this study, the crushed whole stalk was selected for the stability tests because this material known to be the least stable of the two (from on-going studies by the PI using kenaf as a bioreactor structural substrate).

Prior to loading the kenaf into the test column, the stalk was picked clean of any particularly obscure stalk material (i.e. longer than 3 inches in length and diameters greater than 0.5 inches). The packed kenaf stalk was then dried at 60°C for at least 24 hours. Drying was performed in pyrex brownie pans to provide an open container exposing a large amount of surface area. The kenaf was mixed periodically to provide a homogenous drying effort. The drying step was performed to provide a reproducible technique of weighing out equal quantities of adsorbent loadings (eliminates difference in stalk moisture content) allowing for direct comparison of adsorptive loading capacities (i.e. X/M from the Freundlich Model). After removal from the oven, the stalk was cooled within a bench-top desiccator to prevent absorption of moisture from the ambient air. Once dried and cooled, the kenaf stalk was stored within Ziploc bags until used in the experiments. These efforts indicated that the kenaf used in this project to date had a water content of approximately 14%.

A single pass through column system was used. The column has a diameter of 2 inches (ID) and a wetted flow length of 24 inches. Stainless steel screen with 0.1 inch openings was cut into circular pads that were inserted at the inlet and outlet of the column. Teflon end caps were used

to contain all of the components within the column. The column was loaded by tightly compressing the dried kenaf stalk into the column until no voids greater than a 0.5 inch diameter were observed anywhere within the column. A laboratory LMI stroke pump controlled by a micrometer control rod equipped with a vernier scale was used to very accurately feed tap water (the influent) into the bottom of the column (operated under up-flow mode). Except during intentional shut-down **tests,** the column was operated continuously (i.e. 24 hours a day, seven days a week). A flow rate of 6.6 ml/minute was used to provide an empty bed contact time (EBCT) of three hours (i.e. 2.5gpd). When the influent reservoir was full, the flow rate through the column was calculated by timing a given volume of effluent into a 50 ml graduated cylinder (the pump settings were never adjusted). Comparing volumetric flow rate at the same hydraulic head allowed for evaluation of significant changes in packing permeability over time (potentially caused by fiber degradation and/or microbial fouling).

Results- The column was operated (single replicate) for a period of six months. During the first two days of operation, the effluent exiting the column had a color very similar to that of tea. This coloration was believed to be caused by dissolution of stalk pigments into the permeant (i.e. the plant material was leaching color much like tea leaves do). After 48 hours, the effluents became almost clear and remained clear throughout the remainder of this experiment. The flow rate of the packed column under a consistent dark brown and remained that color until approximately 2 months of operation, upon which the column was operated with intentional shut-downs to evaluate the impact of intermittent use on fiber stability. This on/off operation appeared to cause the column to become deeply anaerobic as witnessed by conversion of the column from brown to dark black and the generation of hydrogen sulfide within the column packing (checked via periodic opening of the column and the observation of the characteristic sulfide odor).

After approximately 2 additional months of periodic shutdowns (about two eight hour events per week), the column was generally operated at continual flow conditions through Month 6. Over time, after returning to continuous flow operations,

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the column contents returned to a dark brown color with little or no odors noted. After completion of the experiment, the structural characteristics of the aged stalk fibers were surprisingly strong with little **loss** in strength observed. However, the finer filaments typically protruding from fresh stalks were not present, indicating that they were likely biodegraded and/or eroded during column operation. In general, the stalk fibers appear to have been stripped of superficial fine filaments (as if acid washed). No **loss** in solids was observed within the effluents (the effluents were collected within white plastic buckets to facilitate improved visual observations [provides white background against the dark filaments and other fiber components]).

Adsorption Isotherms

Objective- The objective of this experimental phase is to generate adsorption data on the ability of various kenaf fiber sources for adsorption of various adsorbates.

Experimental Approach- The approach used in this experimental phase generally followed the techniques successfully used for many years with the evaluation of activated carbon for treatment of aqueous solutions (Faust and Alley 1987). During these experiments, both dried kenaf core and crushed whole stalk were used as **test** adsorbents. The two kenaf materials were dried and stored following the same procedures described above. The accomplishment of this experimental phase was approached through performance of a series of tasks detailed below:

Equilibrium Time Determinations- Initially, experiments were performed to determine the contact time required for the kenaf-aqueous matrix to reach adsorptive equilibrium. This test was performed by mixing 0.5 grams of dried kenaf core with 40 ml of 10 mg/1 aqueous solutions of DCP within 60 ml vials. Approximately six glass beads were also added to facilitate mixing. Since kenaf floats, as opposed to activated carbon which sinks, concern was felt over the contact efficiency of the kenaf with the adsorbate solution. After testing numerous shaking techniques and contacting vessels, it was found that 60 ml VOA vials charge with the adsorbentladsorbate solutions and approximately six (6 mm) glass beads agitated on a rotary wrist shaker table provided the most efficient mixing tested (based on visual observation). The following conditions were tested using duplicate vials: experimental control (DCP solution without kenaf), system control (kenaf in clean water), and 0.5 g kenaf dosed into 40 ml of 10 mg DCP/1 aqueous solutions that were sampled (duplicates analyzed) at contact times of 0.5, 1, 1.5, 2, 2.5, and 3 hours. The kenaf was separated from the aqueous phase by using all glass filtration vessels fitted with glass A/E filters. The aqueous phases were then analyzed by HPLC for DCP concentration. Note that a system control was maintained by challenging kenaf with uncontaminated distilled water (i.e. no adsorbate added) using the same protocol described above. This test indicated no measurable quantities of DCP (or TNT). This **test** was performed to ensure no plant components would elute at the same time as the targeted analytes (adsorbates) under the HPLC conditions utilized.

Adsorption Capacities- Adsorption isotherm data was generated by contacting various kenaf doses (w-based) with 40 ml of aqueous adsorbate solutions. These experiments were performed using the same contact protocol used in the equilibrium time experiments. The contact time used in these experiments was one hour. All of the data represented above were generated from replicated runs (duplicates) with the data shown being the averaged values for each test condition. An experimental control consisting of adsorbate-charged water with no kenaf present was maintained throughout the experiments along with a system control which involved the addition of kenaf into non-contaminated water (i.e. no adsorbate added). Note that an experimental and system control was maintained with each experiment. The experimental control indicated no significant adsorbate losses, while the system control indicated no compounds were released from the kenaf that eluded at the same time as the **test** adsorbates during chemical analyses.

Water Absorption Experiments- A water absorption **test** was also performed to determine the amount of water absorbed by the dried kenaf over a one hour period within the same conditions used for generating the isotherm data. This experiment involved contacting 1.0 g of dried kenaf core with 40 ml of water for one hour. The kenaf was filtered from the aqueous solution and

the recovered aqueous phase volume (filtrate) measured using a 100 ml graduated cylinder. This experiment was performed in duplicate.

Equilibrium Time Determinations- The results of the contact time experiments are listed in Table 1. From this table, it can be seen that equilibrium was reached after one hour of contact. Therefore, a one hour contact time was selected for generation of isotherm data for all of the adsorption experiments.

Adsorption Capacities- The adsorption of adsorbates onto an adsorbent can be modeled using several adsorption models. The most popular is the Freundlich Model which is detailed below:

$$X/M = K \cdot C^{1/n}$$

where,

X/M = Adsorbent loading, weight adsorbate/weight adsorbent

C = Equilibrium aqueous phase concentration of adsorbate, mg/l

K and n= Freundlich Coefficients

These coefficients can be determined from laboratory data by plotting X/M versus C using a log-log plot. The equation below illustrates the linear version of the above equation that when plotted on log-log plots can be used to calculate the coefficients using simple linear regression:

$$\ln X/M = \ln K + (1/n \cdot \ln C)$$

The K constant generally represents the loading characteristics of the adsorbent, while the $1/n$ value represents the horizontal stability of a loading over a range of effluent concentrations. The aqueous phase concentration is determined from chemical analysis of samples collected from the kenaf-water slurries that are separated using centrifugation and filtration. The adsorbent loading capacity for the test adsorbate, X/M is then calculated as follows:

$$X/M = (C_o - C_e) / (AD/V_{ts})$$

where,

X/M =Adsorbent loading, mg/g

Co = Adsorbate concentration prior to mixing with the adsorbent, mg/l

Ce = Equilibrium adsorbate concentration (after contacting adsorbate), mg/l

AD =Adsorbent dose, g

Vts = Total liquid volume, L

Table 2 summarizes the isotherm data generated from the adsorption experiments performed during this study. Comparison of the values in Table 2 to those reported for commercial activated carbon indicates that kenaf has a much lower adsorptive capacity for DCP than activated carbon. For example, LaGrega et al. (1994) list DCP as having K and n values of 157 (mg/g) compared to the 0.2 to 0.5 mg/g levels found for DCP in the current study (Table 2).   The adsorptive loadings determined in this research are much lower than those found in earlier work by this research group. The rationale for this differential is not fully known; however, a difference source of kenaf was used in the early experiments which yielded a DCP K of approximately 100 mg/kg. Additionally, a review of the adsorption data presented during the equilibrium time experiments reported above indicate DCP adsorptive capacities approaching 10 mg/g, which is approximately an order of magnitude lower than the loadings reported using activated carbon (Dobbs and Cohen 1980). Finally, activated carbon adsorbers treating DCP contaminated influents often are changed out on a one to two year frequency, if breakthrough, instead of plugging problems, are the reason for change-out associated with the lower adsorption capacity of kenaf observed thus far may not be prohibitive in terms of technical viability. Albeit the adsorptive capacities are much lower than those reported for activated carbon, the kenaf still does show adsorptive capacity. And since kenaf is two orders of magnitude cheaper than carbon, economic viability is still feasible, since, by weight, bulk adsorbent costs are also two orders of magnitude cheaper than activated carbon. Essentially, operational costs are likely to determine which of the two adsorbents are economically superior.

Another negative aspect of these data in terms of DCP adsorption is that the DCP n values determined during the current project are much higher than those reported by both LaGrega et al. (1994) indicating that kenaf has a much steeper adsorption isotherm for DCP. This indicates that as influent and targeted effluent levels dramatically change, then a much greater impact (potentially adverse if they decrease) on the adsorptive capacity of kenaf than would be observed with using activated carbon as the adsorbent. However, as noted above, some of the isotherm data reviewed indicate that as lower influent adsorbate levels are used, the sorptive loading appears to increase.

Comparison of the K value for TNT to the range of values reported by Zappi (1998) indicates that the K values estimated during the current project is within the same approximate range reported by Zappi (1998) for most TNT contaminated waters. The current study estimates a kenaf adsorptive loading capacity ranging from 0.003 to 6.7 mglg. Zappi (1998) reports a K for TNT in actual wastewaters ranging from 0.1 mglg to 400 mglg depending on the initial TNT concentration. The results for TNT in terms of isotherm slope (n values) are much more positive in terms of the n values than those reported for the DCP data. Zappi (1998) reports a n value of 7.1 using activated carbon, which is near the same range for the n values determined in this current study.

Water Absorption Experiments-The results of this experiment indicated that the dried kenaf core absorbed 10% water by weight within one hour. This absorption rate yielded approximately 70% of the original water content prior to drying. This information is significant in that the kenaf does not appear to be absorbing significantly higher amounts of water than the natural field water content.

Composting of Kenaf Fiber

Objective- The objective of this effort was twofold (i.e. two sub-objectives). The first sub-objective was to develop and construct a bench-scale compost system for use in evaluating the potential of cornposting to degrade kenaf fibers. The second sub-objective was the performance of a series of experiments to evaluate the potential of composting for degradation of kenaf fibers. The bench-scale compost reactors were the heart of this experimental phase because it was used for evaluation of multiple treatments at the same time while providing process conditions similar to actual beds with a high degree of process control.

ExperimentalApproach-The center of the system designed is a 2-liter compost reactor. Since the reactors needed to be capable of withstanding temperatures in excess of 70°C, heat resistive considerations were considered when selecting all building components. Additionally, several external heating techniques were considered since temperature ramping is a key process control within a compost system.

The final compost system design involved the insertion of specially designed 2-liter compost units into a commercial incubator system. The incubator has capability of operating within the 10°C to 80°C temperature range. Initially, a laboratory oven was used for temperature adjustment and control, but the tolerance associated with the unit available within the laboratory was deemed unacceptable.

Several prototype bench units were tested and this design was decided upon as the most flexible within a realistic cost (about $500 each). This unit allows for analysis of reactor headspace gases while providing provisions for irrigation of the reactor without upsetting experimentation. Multiple sample ports were placed within the reactor cap that **is** fastened to the reactor body using a stainless steel pipe clamp. The various ports on the reactor cap can be used for a variety of operations including real-time analysis of headspace gases, collection of ^{14}C radiolabelled carbon dioxide, and/or insertion of thermocouples. A viton gasket is inserted between the cap and the body to provide **loss** of reactor gases during incubation. It was decided not to use microbial temperature feedback temperature ramping due to the complexity of this approach versus perceived minimum benefit. Excavation of the reactor headspace is performed periodically by forcing fresh breathing air or oxygen (both supplied by pressurized bottles) into the reactor headspace. The reactor compost pile within the composter can be periodically mixed via shaking the sealed reactor which will simulate windrow composting. Forced air composting will be tested by forcing oxygen sources up through

the compost pile. The oxygen sources will be aerated through the bottom distribution plate (constructed of Teflon and containing approximately 30-1/8 inch holes). Irrigation will be performed by aspirating nutrient solutions into the compost pile within the reactor.

Periodically, the production of carbon dioxide and utilization of oxygen was monitored using a GasTech multi-gas analyzer. The weep-water exiting the composters was analyzed for pH to ensure that a neutral pH was maintained within the compost piles within the units. Another set of simple bench-scale compost units was constructed using one gallon plastic sample jars. These units were used for performing mesophilic (i.e. incubation temperatures less than 35°C); therefore, a much simpler (and cheaper) design was acceptable. The use of two compost systems allowed for the direct comparison of therrnophilic versus mesophilic composting.

The success of a compost effort was gauged based on total volume reduction achieved within a specific incubation period. Additionally, during incubation, headspace gas analyses (using the GasTech analyzer) were used to evaluate progress during composting.

Two incubation runs were performed. The first focused on mesophilic composting. The first had a compost amendment formulation (by weight) of 10% potatoes, 10% apples, 10% lettuce, 30% seasoned compost (kenaf based), and 30% fresh kenaf.

The second run compared thermophilic composting to mesophilic composting. This experiment was performed using single replicate reactors. Compost formulations fro the thermophilic incubations were 35% equal proportioned amounts of potatoes, apples, and lettuce, 15% old compost, and fresh 50% kenaf. The formulations for the mesophilic incubations were 20% equal proportions of the vegetables, 10% old compost, and 70% fresh kenaf. The compost was aerated via natural air inversions into the vessel, with only volume reduction being monitored. This experiment also utilized duplicate reactors. Forced aeration was used to provide oxygen to the compost piles. Aeration was performed on an every other day schedule.

Results- The first experiment indicated that mesophilic composting was capable of achieving approximately 30% reduction of total compost pile volume within a 14 week period. This yields a daily degradation rate of approximately 0.3% per day. Conversely, the amount of volume reduction observed during the second series of composting experiments within the thermophilic compost was about 13% over the 20 days of incubation. This equates to a volume reduction rate of approximately 0.7% per day. This is about twice the rate observed with the mesophilic compost during the first experiment over three times the incubation period. Unlike the first mesophilic compost experiment, little volume reduction was observed with the second mesophilic compost experiment for the 20 days of testing performed during the second test. Clearly, thermophilic composting will provide a more rapid and thorough compost step. But, more importantly, the most stable component of kenaf appears to be amenable to composting providing a strong basis for the proposed process in terms of adsorbent disposal. Note that significant reductions in oxygen headspace were noted. Typically less than 10 ppm prior to air-recharge within the therophilic composters; however, the mesophilic units showed much less oxygen utilization. Carbon dioxide production levels did match the oxygen utilization trends. Also, the pH of the compost leachates were all found to be neutral.

CONCLUSIONS

This study yielded surprising results in that the stability of a packed kenaf bed was quite high. These positive results provide a potential framework for designing kenaf packing columns using designs similar to those used with activated carbon adsorption systems.

The experiments already performed indicate that there is some potential for using kenaf as a commercial adsorbent. The results were found to be mixed. In terms of the more soluble and ionic organic adsorbate, DCP, the observed adsorptive levels were about two orders of magnitude lower when compared to the values reported in literature for activated carbon. Conversely, the TNT adsorptive data generated did indicate that kenaf has adsorptive capacities (measured as K) similar to those reported in literature for

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commercial activated carbon.

Composting experiments indicate that kenaf is amenable to composting as a means of fiber reduction. Thermophilic composting was found to be much more rapid in terms of rate of volume reductions achievable.

FUTURE RESEARCH EFFORTS

Further experimentation will be initiated in future efforts to:

1. Evaluate the performance of kenaf versus activated carbon using influents of much lower adsorbate strengths. The observed leveling off of the isotherms at lower concentrations may show a higher potential for using kenaf for DCP than the recent results generated.

2. Evaluate the use of fiber modification as a means of increasing adsorptive capacity. Candidate techniques include ozonation and acidification which may chemically convert the surface of the fibers into degradation products with higher adsorptive capacities.

3. Evaluate other candidate natural materials that are also amenable to composting. Examples include hay, peat, and peanut hulls.

4. Evaluate the use performance of the best natural adsorbents for use with other adsorbates, such as pentachlorophenol (PCP) and methyltetrylbutylether (MTBE).

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Table 1. Data Set for the Equilibrium Time Experiments

Agitation Time (hr)	Kenaf Dose (g)	DCP Aqueous Phase Initial	Concentration (mg/l) Final
0.5	0.5	0	0
0.5	0.5	0	0
			AVG: 0
0.5	0	10	8.7
0.5	0	10	9.9
			AVG: 9.3
0.5	0.5	10	4.4
0.5	0.5	10	4.9
			AVG: 4.7
1	0.5	10	3.4
1	0.5	10	3.5
			AVG: 3.5
1.5	0.5	10	3.8
1.5	0.5	10	3.9
			AVG: 3.9
2	0.5	10	4.0
2	0.5	10	3.6
			AVG: 3.8
2.5	0.5	10	4.5
2.5	0.5	10	3.9
			AVG: 4.2

Table 2. Summary of Calculated Freundlich Coefficients

Adsorbate ([ ]$_o$)	K (mg/g)	n
	Kenaf Core	
DCP (100 ppm)	0.520	3.23
DCP (175 ppm)	0.191	1.23
TNT (10 ppm)	0.033	0.284
TNT (20 ppm)	0.043	0.582
TNT (40 ppm)	0.030	0.860
TNT (50 ppm)	0.500	1.64
TNT (110 ppm)	6.70	4.20