Biodegradation and Feasibility of Three Pleurotus Species on Cigarette Filters

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BIODEGRADATION AND FEASIBILITY OF THREE *PLEUROTUS* SPECIES ON CIGARETTE FILTERS

by

Raymond A. Updyke

A Thesis Submitted in Partial Fulfillment of the Requirements for a Degree with Honors (Accounting)

The Honors College

University of Maine

May 2014

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Abstract

This study was designed to evaluate the biodegradation and feasibility of growing three oyster mushroom species - *Pleurotus ostreatus*, *Pleurotus citrinopileatus*, and *Pleurotus djamor* - on three different cigarette filter waste substrates: intact cigarette filters, blended cigarette filters, and smoked, intact cigarette filters. Cigarette filters are a common waste and are made primarily of cellulose acetate. Oyster mushrooms (*Pleurotus spp.*) have been shown to degrade synthetic polymers similar to cellulose acetate. In the experiment, the substrates were inoculated with mushroom spawn and placed in a growth chamber maintained at 24°C. After a six-week period, mycelium surface area colonization, observed quality, and biodegradation by weight was calculated.

All species had accelerated biodegradation compared to an estimated natural biodegradation of 25% over six weeks. *P. djamor* had the highest quality mushrooms and the blended cigarette filter substrate had the highest colonization percentage. The costs associated with the procurement of cigarette filters may rapidly increase break-even metrics and may cause an enterprise to be nonviable commercially. Direct investment or government sustainability grants would be required to successfully maintain a small growing operation. Countries with a low HDI (Human Development Index) would benefit greatly benefit from these methods. The safety of the mushrooms for consumption should be investigated in further studies. Overall, *P. djamor* should be further investigated as a mushroom with possible economic value to degrade cigarette filter waste.
Acknowledgement

This research is a recipient of the 2013 Charlie Slavin Research Fund. I would like to thank the Honors College for their unwavering support for my research. I would also like to thank my advisor, Dr. Marianne Sarrantonio, on her guidance, suggestions, and time on this research.
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**List of Definitions**

Biological efficiency (BE): Fresh mushroom weight divided by total dry weight of all substrates multiplied by 100; a practical scientific and business statistic used to estimate mushroom yields (Chang & Miles, 2004).

Break-even: The value that sets revenue equal to total costs. In this case, it is either USP or BE.

Degree of substitution (DS): The average number of substituent groups attached to a base group (Encyclopedia of Polymer Science and Technology, 2011). In this case, it is the number of acetyl groups substituting hydroxyl groups in a d-glucose unit of a cellulose acetate molecule (0-3).

Process improvement: Synonymous with business efficiency. Calculated as the new rate minus the old rate divided by the old rate times 100. Expressed as a percentage. A positive value represents an increase in efficiency; a negative value indicates a loss in efficiency.

Spawning rate: The amount of spawn substrate by weight. Expressed as a percentage of total substrate weight.

USP: Unit selling price. In this case, the price the mushrooms sell for.
**Introduction**

Cigarette filters are an environmental and social negative externality from tobacco smoking that cause an economic loss to society. Over 5.6 trillion cigarettes are smoked annually worldwide; about 4.5 trillion of them become litter (Novotny et al., 2009). Additionally, cigarette filters are a major source of ocean pollution accounting for about 30% of all shoreline wastes (Slaughter et al., 2011). The remnants of smoked cigarettes (tobacco and filter) include a variety of pesticides, carcinogens, and heavy metals (Slaughter et al., 2011, Talio et al., 2012) including cadmium and lead (Ashraf, 2012). Toxic leachates from cigarette filters do not biodegrade readily and present a major environmental issue (Slaughter et al., 2011). The environmental and social costs of cigarette filter waste have an economic cost such as the cost of cleanup for aesthetics. Cigarette filter waste presents a number of problems from toxic leachates to general pollution with an associated social and environmental cost, which has an economic value.

Cigarette filters are made of a plastic called cellulose acetate (CA, also called tow), which is cellulose wood pulp that has been plasticized (esterified) to create structure, prevent combustion, and prevent fungal or bacterial spoilage (Fischer et al., 2008, Talio et al., 2012). CA was once regarded as non-biodegradable, but further research has concluded that, depending on the degree of substitution (DS) of the CA, CA is biodegradable within four to nine months in soil environments (Northrop & Rowe, 1987) and cigarette filters with a DS of 2.45 have been shown to anaerobically degrade (Zenjian et. al., 2003). Cigarette filters are litter in the environment, but research has concluded that the main fiber of cigarette filters, CA, is biodegradable.
Significant research has shown that different microorganisms can break down CA. Gu, Coulter, Eberiel, McCarthy, & Gross (1993a) found that microorganisms can break down CA with a DS of 1.7 into methane byproducts within 30 days in an anaerobic bioreactor, yet Gu et al. (1993b) also found that CA biodegradation is dependent upon water content. Certain gram-negative Pseudomonas species have been shown to degrade CA (Nelson, McCarthy, & Gross, 1992). Additional bacteria that have been shown to degrade CA up to DS 2.3 include the gram-negative Neisseria sicca bacteria and the water-borne, gram-negative Alcaligenes xylosoxidans bacteria (Sakai, Yamauchi, Nakasu, & Ohe, 1996). Multiple microorganisms have been shown to degrade CA.

Oyster mushrooms (Pleurotus spp.) are one of the most adaptable, cultivated mushrooms in the world and can readily break down certain wastes. In 2002, over 2,590,000 MT of oyster mushrooms were produced in China alone (Chang & Miles, 2004). Oyster mushrooms grow on numerous substrates including: sawdust, grain straw, cottonseed, other agricultural waste, coffee pulp, cardboard, and pulp and paper sludge (Chang & Miles, 2004). Oyster mushrooms prefer cellulose to hemicellulose and lignin and grow readily with almost 100% colonization on cellulose products (Chang & Miles, 2004). Oyster mushrooms are gourmet mushrooms that can create economic value while being able to biodegrade certain wastes.

This study was conducted to determine the biodegradation and feasibility of using three Pleurotus species: grey oyster mushrooms (Pleurotus ostreatus), yellow oyster mushrooms (Pleurotus citrinopileatus), and pink oyster mushrooms (Pleurotus djamor) to grow on different cigarette filter substrates. One substrate included unsmoked cigarette filters with the surrounding filter paper intact, the second substrate included unsmoked
cigarette filters and the surrounding filter paper that have been meshed and blended together, and the final substrate included burnt cigarettes with a smoked cigarette filter and residual tobacco. The estimated colonization of the mycelium on the substrate and the post–experiment dry weight of the substrates was determined to evaluate and estimate the biodegradation and the feasibility of mushroom growers sustainably utilizing cigarette filters to mitigate the societal and environmental externalities of cigarette litter. The purpose of this study is to evaluate the biodegradation via weight loss and the profitability of three *Pleurotus* species to grow on cigarette filters.

**Literature Review**

Studies suggest that oyster mushrooms break down industrial wastes that are similar to cigarette filter waste. Several studies evaluated the process in which the mushrooms can break down industrial wastes and other studies evaluated the biological efficiency (BE) and the nutritional components of the resulting mushroom crop. Oyster mushrooms are a white-rot fungus (Stamets, 2005). White-rot fungi have been shown to break down multiple industrial wastes such as textile effluent dyes, synthetic polymers, wood preservatives, and lignin-like pesticides due to white-rot’s ability to break down both cellulose and lignin and lignin-like compounds (Pointing, 2001). Another study showed that grey oyster mushrooms (*Pleurotus ostreatus*) have the ability to degrade disposable diapers contaminated with urine (Espinosa-Valdemar, Turpin, Delfín, & Vázquez-Morillas, 2011). These studies suggest that *Pleurotus* species have the capability to degrade CA cigarette filter waste and that there is a BE associated with their degradation of CA materials.
The industrial wastes mentioned above are similar to complex lignin and can be broken down by white-rot fungi. White-rot fungi have three specific enzymes that can break down these industrial wastes: lignin peroxidase, manganese-dependent peroxidase, and laccase. These enzymes carry out various oxidation reactions to generate free radicals, which carry out further reactions that biodegrade industrial wastes. The creation of free radicals from white-rot fungi allows the mushrooms to destroy lignin-like synthetic polymers like CA. Oyster mushrooms are a white-rot fungus and carry out free-radical producing enzymatic reactions, which can possibly degrade the synthetic polymer CA found in cigarette filters.

Oyster mushrooms have been shown to degrade industrial wastes that include CA. A study found that *Pleurotus ostreatus* could grow on urine-contaminated disposable diapers, which are mostly cellulose and comprise a substantial portion of landfill waste (Espinosa-Valdemar et al., 2011). Disposable diapers additionally include a small amount of CA and the oyster mushrooms were able to colonize on the diapers. The overall BE of the study was very low though, with a range of 0% – 34% BE compared to an average BE of *P. ostreatus* on hay of 60%- 80%. This study shows that *P. ostreatus* can degrade products with CA in them, but at a low efficiency, which may be caused to other factors such as a lack of nutrients.

Oyster mushrooms have the capacity to breakdown lignin-like materials such as synthetic polymers. Cigarette filter waste contains CA and remnant tobacco, which may include toxic leachates such as nicotine and arsenic (Moriwaki, Kitajima, & Katahira, 2009). Oyster mushrooms may have the capacity to break down the two main components of cigarette filter waste – CA and remnant tobacco – into a substrate that is
economically viable for mushroom growth. This study will attempt to determine the efficacy of the biodegradation process via the measurement of weight loss and the economic efficiency and feasibility of growing mushrooms as it relates to mycelium colonization, a precursor to mushroom growth and BE.

**Methodology**

Cartons of 100 count cigarette filter tube boxes were purchased from the Main Smoke Shop in Old Town, ME. A package of 20 count Hi-Val brand class A regular king cigarettes were purchased from Tim’s Little Big Store in Old Town, ME. Medium gusseted polyurethane bags were obtained from Spores101.com. Grey, yellow, and pink oyster mushroom grain spawn at 100% germination was imported from mushroombox.co.uk at 200g per species.

The trial was a 3 x 3 factorial of three *Pleurotus* species on three substrates - unsmoked, intact cigarette filters, blended unsmoked cigarette filters, and smoked, intact filters and remnant tobacco. Each species and substrate combination was replicated three times resulting in 27 test bags. All substrates were air-dried and weighed. The spawning rate was set at 40% of the total air-dried weight of the substrate. The total weight of both the substrate and the spawn together was calculated for each sample. All substrates, except the spawn, were pasteurized at 120° C in a pressure cooker to kill most potential competitors with the mushroom mycelium. All substrates were wetted to 60-65% moisture content. The individual substrates were then placed into individual polyurethane bags. The substrates were then inoculated with the spawn and the bags were tied with a rubber band with four 2 cm slits at the top of the bag to improve gas exchange. The samples were then incubated in a growth chamber at a constant 24° C, at a relative
humidity of 75-90% for six weeks, and with a 4cm gap between the inner and outer growth chamber doors for gas exchange.

After six weeks, the samples were taken out of the growth chamber. The quality of the samples were ranked on a scale from 0 - 3, 0 indicating no mycelium growth, 1 indicating significant mycelium growth, 2 indicating hyphae presence, and three indicating mushroom fruiting body presence. Mycelium colonization of the total substrates was estimated as a percentage of surface area. The samples were then air-dried for a week. After one week of drying, the total substrate was weighed to record and calculate biodegradation via weight loss.

Results

![Colonization (%) & Biodegradation (%) Correlation](Fig. 1 Colonization (%) & Biodegradation (%) Correlation)
Little correlation was found between the observed surface mycelium percentages versus the amount of biodegradation (calculated percentage of weight loss). The $R^2$ value was 0.2289, which shows little to no correlation between surface mycelium influencing biodegradation of the substrate material (*Fig. 1*).

![Average Colonization of Substrates (%)](chart)

*Fig. 2 Average Colonization of Substrates (%)*

Cigarette filters that were blended together had a higher average colonization (90%) compared to cigarette filters alone (69.44%) or burnt cigarette filters with remnant tobacco (40%) (*Fig. 2*).
Grey oyster mushrooms had a higher average surface mycelium colonization (87.78%) compared to yellow (54.44%) or pink (57.22%) oyster mushrooms (Fig. 3).

Fig. 3 Average Colonization on all Substrates by Pleurotus Species (%)

Fig. 4 Average Biodegradation by Pleurotus Species (%)
Smoked filters with remnant tobacco had a higher average biodegradation (45.65%) compared to intact filters (32.66%) or blended filters (33.64%) (Fig. 4).

![Average Quality by Species (0-3)](image)

*Fig. 5 Average Quality by Pleurotus Species (0-3)*

Quality was defined on a scale of 0 - 3. A rating of zero indicated no or little observable mycelium growth, a rating of one indicated significant surface mycelium colonization, a rating of two indicated hyphae presence, and a rating of three indicated fruiting body growth. Pink oyster mushrooms had a higher average observed quality (1.56) compared to grey (1.11) or yellow (0.78) mushrooms (Fig. 5 & 6).

*Table 1 Summary of Key Experiment Statistics for Pleurotus Species*

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiment Length (Days)</td>
<td>42</td>
</tr>
<tr>
<td>Average Colonization</td>
<td>66.48%</td>
</tr>
<tr>
<td>Average Quality</td>
<td>1.148</td>
</tr>
<tr>
<td>Average Biodegradation (%)</td>
<td>37.32%</td>
</tr>
<tr>
<td>Correlation between Biodegradation &amp; Quality</td>
<td>0.1357</td>
</tr>
<tr>
<td>Correlation between Biodegradation &amp; Colonization</td>
<td>0.4785</td>
</tr>
<tr>
<td>Estimated Average Weekly Biodegradation</td>
<td>6.22%</td>
</tr>
<tr>
<td>Estimated Days till Biodegradation (&gt;66%)</td>
<td>74</td>
</tr>
<tr>
<td>Estimated Weeks till Biodegradation (&gt;66%)</td>
<td>11</td>
</tr>
<tr>
<td>Estimated Months till Biodegradation (&gt;66%)</td>
<td>3</td>
</tr>
<tr>
<td>Minimum Recorded Days for Natural Biodegradation</td>
<td>90</td>
</tr>
<tr>
<td>Estimated Process Improvement (Days)</td>
<td>16</td>
</tr>
<tr>
<td>Estimated Process Improvement (%)</td>
<td>17.46%</td>
</tr>
</tbody>
</table>
A summary table of key statistics was created (Table 1). Typical estimates of the minimum number of days till biodegradation range from three to nine months (Puls, Wilson, & Holter, 2011). Biodegradation occurs when more than 66% of the initial weight has been lost (Puls, Wilson, & Holter, 2011).

Discussion

The accelerated biodegradation compared to the estimated natural biodegradation of the cigarette filters is interesting to note. Biodegradation did occur beyond the study metrics of observed quality and observed surface area colonization by mycelium. The observed quality of mycelium, hyphae, or fruiting body growth had extremely low correlation ($r = 0.1357$) with biodegradation. The subjective aspect of quality may have caused this low correlation. The observed surface mycelium colonization had low correlation with biodegradation as well ($r = 0.4785$), but higher than the observed quality

*Figure 6 P. djamor mushroom fruiting body growth out of an intact cigarette filter post drying*
metric. Surface mycelium may be responsible for biodegradation of the filter paper coating and grain spawn. Microscopic mycelium may be responsible for slowly degrading the CA material of the filters. The estimated average weekly biodegradation percent (6.22%) leads to a process improvement (17.46%) over the generally accepted three-month to nine-month window for the degradation of cigarette filters (Table 1). Exponentially over time, the production of free radicals by the mycelium may be cleaving off the hydroxyl groups of the CA molecule, which would make the cellulose more accessible to the mycelium. Substrate loss was not due to water loss because only air-dried weight was used thus eliminating water weight. There was little correlation between biodegradation and quality or surface mycelium percentages, yet biodegradation did occur at a greater rate than other microbes documented possibly due to the mycelium’s ability to produce free radicals.

Pink oyster mushrooms had greater quality compared to grey or yellow mushrooms. Pink oyster mushrooms had an average quality of 1.56, which is a 0.45 (40.54%) increase over grey mushrooms and a 0.78 (100%) increase over yellow mushrooms. Grey oyster mushrooms had more colonization than any other species, but pink oyster mushrooms were the only species that had fruiting body growth. The standard deviation of quality was 1.03, which suggests a large standard of error due to the subjective nature of the ratings. Chiang & Miles suggest that mushroom quality is the most important aspect of future mushroom research and production (2004). This pink oyster fruiting body growth indicates a measurable BE for further studies and identifies pink oyster mushrooms as the best choice for mushroom production on cigarette filters due to their observed qualitative factors that could lead to value-added yields compared
to colonization alone. Russell et al. suggest that tropical fungi can break down complex plastics (2011). Pink oyster mushrooms are pan tropical; that may indicate that more tropical mushroom and fungi are capable of degrading complex plastic and synthetic material. Overall, pink oyster mushroom had the greatest observed quality, which is the most important aspect of mushroom production.

Blended cigarette filters had a higher colonization percentage, yet are less realistically available as compared to burnt cigarette filters with remnant tobacco. Blended cigarette filters had an average surface mycelium colonization of 90.00%, which is a 0.2056 (29.61% process improvement) increase over unsmoked intact cigarette filters and a 0.5 (125% process improvement) increase over burnt, intact cigarette filters. The process improvement is mainly due to the creation of a singular, consistent substrate that is more fixed compared to intact cigarette filters, which can move and have more compaction, which prevents infiltration by the mycelium. The low colonization rate of the burnt cigarette filters with remnant tobaccos suggest that the substrate had a low moisture content or the chemicals in the remnant tobacco prevented mycelium growth. Blended, unsmoked filters are less available than burnt cigarette filters with remnant tobacco because the latter is seen in the environment while the former is a theoretical application of mycelium growth on cigarette filters. A mushroom production operation would have to accept burnt cigarettes from the environment over theoretically clean, intact, unsmoked filters are shown in the experiment and thus the business. Blended cigarette filters have better colonization percentages compared to other substrates, yet are less than ideal compared to abundant smoked cigarette filters in the environment.

The triple bottom line of business is addressed through a P. djamor-based
growing operation on blended, smoked cigarette filters. As mentioned previously, *P. djamor* had the greatest quality compared to grey or yellow oyster mushrooms and blended unsmoked cigarette filters had the highest colonization percentage rates compared to the other two substrates. Using only blended cigarette filters would cause lower colonization and thus lower BE compared to a pure, 100% colonization straw-based operation due to a lack of nutrients from the cigarette filters. Combining blended, smoked cigarette filter waste from the local environment with a regular decomposing straw raw material would provide necessary nutrients to the mushrooms while sustainably degrading the environmental and social costs of cigarette filter wastes (*Fig. 7*). The inclusion of cigarette filter waste would be less efficient than traditional methods, yet the societal and environmental costs may be comparable to the loss in efficiency. *P. djamor* on a mixed straw-cigarette filter waste substrate would be the most efficient way of utilizing cigarette filter waste which is less efficient than current methods, but may be comparable to the social and environmental costs of cigarette filter waste.

Cost analysis can be utilized to estimate the costs of production for utilizing cigarette filter wastes in mushroom production. *Table 2* shows the estimated population required to sustain a daily containment of 5kg of cigarette filter waste substrate assuming an estimated 80% attrition loss and utilizing 2013 smoking trend data from the Centers for Disease Control and Protection (2014). A small-medium sized city is required to sustainably collect enough cigarette filters for 5kg of substrate. A sample *P. ostreatus* growing operation income statement is used as a basis for a *P. djamor* operation with additional capitalization and labor costs associated with obtaining cigarette filter waste (*Table 3*).
Table 2 Estimated Population Required for Cigarette Filter Waste Collection at 5kg

<table>
<thead>
<tr>
<th>Desired Substrate Amount (g)</th>
<th>Average Weight per Cigarette Filter Waste (g)</th>
<th>Cigarettes Needed</th>
<th>Average Number of Cigarettes Smoked per Day (CDC)</th>
<th>Estimated Attrition (Uncontained Loss) (%)</th>
<th>Average Population of Smokers (%) (CDC)</th>
<th>Estimated Population Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>5,000</td>
<td>0.125</td>
<td>40,000</td>
<td>19</td>
<td>80%</td>
<td>18%</td>
<td>58,480</td>
</tr>
</tbody>
</table>

Table 4 shows the additional costs associated with collecting cigarette filter waste. Raw material substitution saving was calculated as the total substrate required (571kg) to yield 400kg of mushrooms divided by the cost of raw materials ($3,090) to yield a substitution amount for utilizing free cigarette filters from the environment over straw.
(Table 5). Direct labor was calculated as $8/hr for four hours to collect and process 5kg of material. Payroll taxes were 13% of direct labor. No additional manufacturing overhead or administrative costs were anticipated. More variable costs are associated with the collection of cigarette filters than the free cost of the filters and there is a fixed capital component to blend the filters.

Table 3 P. ostreatus contribution format income statement for a small growing operation. Adapted from Gurgaon, 2005

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sales</td>
<td>16,000.00</td>
</tr>
<tr>
<td>Less Variable Costs</td>
<td></td>
</tr>
<tr>
<td>Contribution Margin</td>
<td>16,000.00</td>
</tr>
<tr>
<td>Fixed COGS:</td>
<td></td>
</tr>
<tr>
<td>Straw</td>
<td>750.00</td>
</tr>
<tr>
<td>Supplemental Straw</td>
<td>130.00</td>
</tr>
<tr>
<td>Bags</td>
<td>1,200.00</td>
</tr>
<tr>
<td>Spawn</td>
<td>800.00</td>
</tr>
<tr>
<td>Direct Labor</td>
<td>3,200.00</td>
</tr>
<tr>
<td>Total Fixed Costs</td>
<td>6,080.00</td>
</tr>
<tr>
<td>Fixed Overhead:</td>
<td></td>
</tr>
<tr>
<td>Utilities</td>
<td>300.00</td>
</tr>
<tr>
<td>Bavistin (chemical)</td>
<td>100.00</td>
</tr>
<tr>
<td>Formaldehyde (chemical)</td>
<td>110.00</td>
</tr>
<tr>
<td>Total Fixed Overhead</td>
<td>510.00</td>
</tr>
<tr>
<td>Fixed Selling &amp; Admin.</td>
<td>300.00</td>
</tr>
<tr>
<td>Total Fixed Costs</td>
<td>(6,890.00)</td>
</tr>
<tr>
<td>Operating Income</td>
<td>9,110.00</td>
</tr>
<tr>
<td>Less Estimated Depreciation</td>
<td>(1,200.00)</td>
</tr>
<tr>
<td>Less Interest</td>
<td>(1,800.00)</td>
</tr>
<tr>
<td>EBT</td>
<td>6,110.00</td>
</tr>
<tr>
<td>Less Income Taxes</td>
<td>(916.50)</td>
</tr>
<tr>
<td>Net Income</td>
<td>5,193.50</td>
</tr>
</tbody>
</table>

Table 4 Estimated Additional Costs for Cigarette Filter Waste Collection
Table 5 Raw Material Substitution Calculations

<table>
<thead>
<tr>
<th>Raw Material Substitution Calculation:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of Cigarette Filters</td>
<td>-</td>
</tr>
<tr>
<td>Yield (kg)</td>
<td>400.00</td>
</tr>
<tr>
<td>BE (%)</td>
<td>70%</td>
</tr>
<tr>
<td>Basic Substrate Required (Yield/BE) (kg)</td>
<td>571.43</td>
</tr>
<tr>
<td>Cost (Appendix A) ($)</td>
<td>3,090</td>
</tr>
<tr>
<td>Basic Raw Material Cost/kg ($/kg)</td>
<td>0.18</td>
</tr>
<tr>
<td>Savings by Substituting Filters for Basic Substrate ($)</td>
<td>(0.18)</td>
</tr>
</tbody>
</table>

Utilizing the National Horticulture Board’s model for a small growing operation (Gurgaon, 2005), given the additional costs, break-even BE, break-even USP, and the estimated payback period would increase drastically (Table 6). The break-even BE would be 55.58%, the break-even USP would be $33.59, and the payback period would more than double from 11 years to 25 years. The increase in the break-even metrics and the payback period is directly associated with the direct labor cost of collecting and processing the cigarette filters from the environment. The zero-cost aspect of the filters had little impact on the net income compared to the associated large cost of direct labor. A government subsidy or private equity investment of $2,801/yr would need to occur to
reduce the payback period back to 11 years assuming a 70% BE and a USP of $40. A direct labor cost reduction from $10/hr to $5/hr would reduce the payback period to 15 years. Overall, given the additional costs, break-even and payback period metrics increase and private or public investments or direct labor rates must be reduced to sustain optimal net income generation.

<table>
<thead>
<tr>
<th>Initial Investment</th>
<th>49,800.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated Payback Period (years)</td>
<td>11</td>
</tr>
<tr>
<td>Break-Even (BE)</td>
<td>43.27%</td>
</tr>
<tr>
<td>Break-Even USP ($)</td>
<td>$24.73</td>
</tr>
</tbody>
</table>

Metrics with Cigarette Filter Additions:

| Estimated Payback Period (years) | 25 |
| Break-Even (BE) | 55.58% |
| Break-Even USP ($) | $33.59 |

Annual investment required to offset costs | 2,801.00 |

Labor Rate in low HDI country | $5.00 |
New Estimated Payback Period (years) | 15 |

Certain countries can utilize the proposed model of mixed straw and blended cigarette filter waste to evaluate the triple bottom line of business. In general, countries with a low HDI (Human Development Index) would benefit greatly from mixed cigarette filter waste mushroom production. For example: cigarette-smoking rates may be higher in these countries leading to higher available cigarette waste, direct labor costs are also lower due to loose labor laws, and there may be a larger demand for oyster mushrooms than countries with a higher HDI. A country like India may adopt this method and be able to clean the environment of cigarette filter waste by utilizing low labor costs to generate gourmet mushrooms, if there is a market, thus evaluating the environmental, social, and
economic problems with cigarette filter waste.

The safety of the mushrooms may not be satisfactory for human consumption though. Mushrooms are well known from their mycoremediation properties and their ability to absorb heavy metals from the environment (Stamets, 2005). The oyster mushroom may be able to take up the toxic leachates present in the smoked tobacco substrate and may store the chemicals in their fruiting body. Further heavy metal testing should be conducted in future studies to evaluate the heavy metal concentration of oyster mushrooms on cigarette filter waste. The safety of growing oyster mushrooms on cigarette filter waste was not addressed in the experiment, but it is an imperative for future studies to evaluate heavy metal absorption by oyster mushrooms on cigarette filters.

Methodology problems may exist in the collection of the data. One methodology problem was that there was no control degradation group of uninoculated filters over six weeks. The estimate biodegradation may not be realizable and so a control group would have been beneficial in this study. Another methodology problem was the lack of consistent moisture content monitoring. Moisture content should have been regularly established and checked for optimum mushroom growth. Additionally, biodegradation measured per day rather than every six weeks would have helped to explain exponential decay in the samples. A lack of a control group, a lack of moisture control, and a lack of regular degradation sampling created methodology problems that could be addressed in future studies.
Oyster mushrooms have the potential to degrade cigarette filter waste while creating value-added gourmet mushrooms. They have been shown to have an accelerated biodegradation rate compared to an estimated natural biodegradation rate. Pink oyster mushrooms showed the most promising qualitative results while blended cigarettes created a more stable environment for mushroom growth. Forecasting feasibility models were created to estimate the costs and the investments needed to sustainably operate a pink oyster mushroom production facility using a mixed straw-cigarette filter method. The safety of the mushrooms is questionable and needs to be further evaluated. Oyster mushrooms have the opportunity to evaluate the triple bottom line of business by addressing the social and environmental cost of cigarette filter waste by generating economic value through gourmet mushrooms.
References


Author’s Biography

Raymond A. Updyke was born in Indianapolis, Indiana on February 10, 1992. He was raised in East Lyme, Connecticut and graduated from East Lyme High School in 2010. Raymond has a major in accounting and a minor in sustainable agriculture. He is a member of Alpha Tau Omega and Beta Gamma Sigma. He has received the Dean’s scholarship and he is a Charlie Slavin research grant recipient.

Upon graduation, Raymond will be working in the hedge fund administration field.