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OZONE UPTAKE RATES AND SECONDARY PRODUCT EMISSIONS OF GREEN BUILDING MATERIALS

by

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A THESIS

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Approved by

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ABSTRACT

Building materials considered “green” were tested for their ability to remove ozone and their potential to generate undesirable byproducts such as aldehydes. Three types of ceiling tile were tested, along with seven flooring materials and eight wall materials. These materials were selected based on “green” criteria. For several this means they were recycled or produced from renewable resources. Others were designed to be low emitting, or due to their composition were likely to be low emitting. Ozone deposition velocities ranged from 0.25 m h^{-1} for a type of resilient linoleum type flooring to 8.23 m h^{-1} for a clay based paint. Summed aldehyde yields ranged from 0.0 for a clay wall plaster to 0.67 for a recycled rubber tile. We find that ‘green’ carpet is a very good ozone sink, with a reaction probability of 3.69×10^{-5}, but aldehyde yields are large (>0.3). The clay wall plaster has a reaction probability higher than carpet at 5.63×10^{-5}, and aldehyde yields are very low. This promising material can reduce ozone concentrations in a typical building by 65% if applied to walls as an alternative to paint. Results showed overall that materials that were fleecy or porous had higher ozone reactivity then materials that were smooth or non-porous. Coatings and finishes on the material also reduced ozone reactivity.

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NOMENCLATURE

Symbol	Description
A	Surface Area of Material
A_c	Surface Area of Chamber Not Covered by Material
A_i	Surface Area of Material i
AER	Air Exchange Rates
ASHRAE	American Society of Heating, Refrigeration and Air-conditioning Engineers
ASTM	American Society of Testing and Methods (?)
CAAA	Clean Air Act Amendments
C_e	Exhaust Concentration of Ozone
C_{in}	Inlet Concentration of Ozone
C_O	Byproduct Concentration with Ozone Exposure
C_{PES}	Byproduct Concentration before Ozone Exposure, Primary Emission Sample
CMFR	Completely Mixed Flow Reactor
DNPH	Dinitro Phenyl Hydrazine
EPA	Environmental Protection Agency
ER	Emission Rate
ER_t	Emission Rate at time period t
ER_{PES}	Emission Rate from primary emission sample
GC/FID	Gas Chromatograph/Flame Ion Detector
HPLC	High Performance Liquid Chromatograph
IAQ	Indoor Air Quality
IEQ	Indoor Environmental Quality
I/O	Indoor to outdoor ozone concentrations
IOU	Integrated Ozone Uptake
KI	Potassium Iodide
LEED	Leadership in Energy and Environmental Design
LOD	Limit of Detection
O_3	Ozone

ppb	Parts per billion
$NaSiO_4$	Sodium Silicate
PES	Primary Emission Samples
Q	Volumetric Flow Rate
SER	Secondary Emission Reactions
TD	Thermal Desorber
T_a	Ambient Chamber Temperature (298 K)
T_0	Flow Meter Calibration Temperature (273 K)
USGBC	United States Green Building Council
UT	Univerisyt of Texas at Austin
VOCs	Volatile Organic Compounds
v_d	Deposition Velocity
$v_{d,i}$	Deposition Velocity of Surface i
v_t	Transport Limited Deposition Velocity
V	Volume
λ	Air Exchange Rate
WHO	World Health Organization
γ	Reaction Probability

1. INTRODUCTION

1.1. BACKGROUND

Ozone (O_3) is a recognized pollutant by the United States Environmental Protection Agency (EPA). The majority of ozone in buildings comes from infiltration of photochemical smog, even though some indoor appliances emit ozone. Combined with the fact that 90% of a person's time is spent in buildings (Jenkins, et al., 1992), indoor exposure to O_3 is a serious health hazard. Studies have shown that 43% to 76% of our ozone exposure comes from our time spent indoors (Weschler, 2006); (Leet, et al., 2004); (Sarnat, et al., 2005). In addition to the direct health impacts, O_3 also reacts with material surfaces to produce secondary byproducts. These reactions remove O_3 from the air, simultaneously producing volatile products that may be more or less harmful than the ozone removed. The major method of reducing indoor exposure to air pollutants, such as ozone, is to actively (e.g. mechanical systems) filter the air. These methods add to the capital and operating (energy) costs of a building. A reduction in ozone levels though will also result in a reduction in the secondary byproducts, reducing the filtration requirement for all compounds. Ozone has been targeted for this study because previous research (Weschler, et al., 1992)(Reiss et al., 1995)(Wang and Morrison 2006)(Wang 2010)(Hoang 2010) has shown that various building materials and surfaces, have the ability to passively reduce indoor O_3 concentrations. As stated, this reduction in O_3 is often accompanied by an increase in byproduct formation, and this byproduct formation could possibly be as harmful, or worse, than the O_3 that is removed. Thus, the ozone removal capabilities of materials must be considered alongside any reaction products.

1.2. SOURCES OF OZONE

Ground level ozone (or tropospheric ozone) is a product of photochemistry which involves sunlight, vapor phase organic compounds, and nitrogen oxides (Seinfeld and Pandis, 2006). Ground level ozone is a problem in densely populated urban areas where correlations have been observed between morbidity and mortality and ambient ozone concentrations. The high population density causes an increase in the concentrations of the organic compounds, nitrogen oxides, and ozone levels. Urban areas are not alone in being affected by high outdoor ozone concentrations; rural background outdoor ozone concentration levels have increased, with signs indicating they shall continue to rise(Seinfeld and Pandis, 2006); (Lelieveld and Dentener, 2000). The majority of ozone present inside our constructed environments is primarily a product of ozone from the outside gaining entry inside, via infiltration or other transport methods (Weschler, 2000). There are several indoor sources of ozone, such as copiers and commercial air purifiers which are designed to remove contaminants, but instead actually produce ozone (Waring, et al., 2008) (Britigan, et al., 2006). Several companies even market commercial ozone generators advertising the health effects of ozone. Common unintentional sources of indoor ozone are printers, copiers, electronic air filters, and electronic devices in general (Destaillats, et al., 2008) (Lee, et al., 2001). Some indoor sources can generate ozone at rates comparable to or even greater than that due to infiltration of smog.

1.3. REGULATION OF OZONE

For ambient (outdoor) air there are regulations in place via the Clean Air Act and the National Ambient Air Quality Standards (1997). The Enviromental Protection Agency (EPA) has recently promulgated an 8 hour ozone standard of 0.075 ppm (June 2007). While the EPA regulates outdoor ozone concentrations there is no Federal and little state regulation to control indoor ozone levels, nor is there regular monitoring to determine if the indoor levels are within the attainments levels of outdoor ozone. Some guidelines do exist, both US (21 CFR801.415) and international (World Health Organization – WHO) that provide recommended levels and methods of control, though none are currently mandatory nationwide. The Food and Drug Administration (FDA) has created a 50 ppb limit for ozone levels due to devices that generate indoors while within an enclosed space (21 CFR801.415). The level designated by the FDA does not go lower because toxicity studies do not clearly support a lower limit (Shaugnessy et al. 2006). One of the few regulations concerning indoor ozone comes from California. The California Air Resources Board (ARB) limits indoor air cleaning devices to emissions of ozone such that the concentration 2” from the exhaust is no greater than 50 ppb (ARB, 2007). Both of these regulations specifically target indoor sources of ozone, but do not truly address the issue of outdoor and indoor sources of ozone working together to create high levels of exposure. In Canada, Health Canada has begun work on an 8 h limit of exposure proposal (Health Canada, 2010). This limit would create an average exposure level that would need to be attained for indoor environments, much as the 8 h ozone exposure level set, for ambient air, by the EPA does in the United States. All of these regulations, proposals, and guidelines may initiate future indoor ozone regulation, but currently they are not as expansive as those found for outdoor exposure.

1.4. OZONE IN INDOOR ENVIRONMENTS

Indoor ozone levels are highly dependent on air exchange rates, indoor sources, active air filtration, the rate of ozone reactions with other species in air and the rate at which ozone is removed by indoor sources. This research if focused on this fourth mechanism. Indoor ozone concentrations can be estimated by using a traditional mass-balance model that includes sources and sinks. Nazaroff and Cass (1986) proposed such a model. If a building is assumed to be a completely mixed flow reactor (CMFR) operating at steady state, the concentration of indoor contaminants may be estimated. Figure 1.1 shows the C_{in} and C_e for a building, which is a function of the air exchange rate (λ), total volume (V) and the sum of the deposition velocities of materials present indoors ($v_{d,i}$) and the surface areas of those materials (A_i).

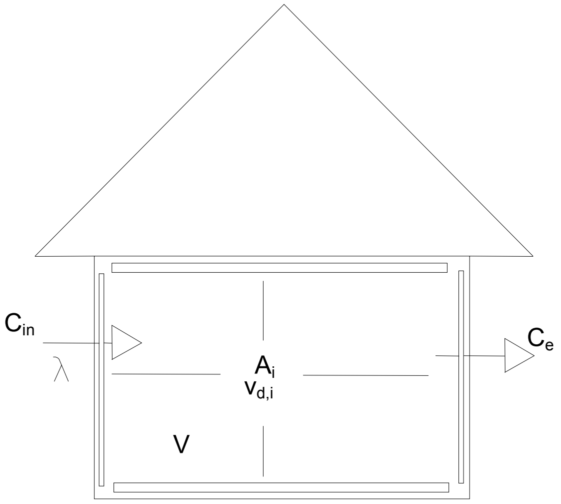


Figure 1.1: Steady State CMFR

Assuming a room is a completely mixed flow reactor (CMFR), operated at steady state, that no homogeneous reactions occur and that there are no removal mechanisms other than ventilation and deposition, it is easy to model how selection of materials can benefit human exposure. The ratio of the exhaust to the inlet ozone concentration can be estimated using equation 1.

$$\frac{C_e}{C_{in}} = \frac{1}{1+\frac{1}{\lambda V}\{\sum_i v_{d,i} A_i\}} \tag{1}$$

Using average values of deposition velocity for paint and carpeting (0.44 and 0.54 m h^{-1}) ($v_{d,i}$)(Grontoft 2004), a typical air exchange rate of 0.5 h^{-1} (λ), a total interior surface area of 150 m^2 (A_i) and total volume of 45 m^3 (V) an ozone reduction of 45% (C_e/C_{in}) can be achieved, when these values are applied to equation 1. This is without attempts to select materials specifically for their ozone reducing potential. If materials with high ozone reduction abilities are specifically chosen, the amount of ozone available to cause damage and produce byproducts can be drastically reduced. Minimizing C_e/C_{in} requires maximizing the deposition velocities and surface areas. For example, replacing a painted ceiling with highly reactive ceiling tiles may significantly reduce ozone and byproduct concentrations and occupant exposure.

1.5. BYPRODUCTS FROM MATERIALS

Primary emissions are defined as those emissions that are released directly from activities, household products and materials. An example of this is the release of formaldehyde, α-pinene and hexanal, which are all slowly emitted from plywood flooring into buildings (Hodgson et al. 2000). Part of these primary emissions are inherent within the building materials themselves, and can only be affected by modifications in the manufacturing, and possibly installation processes. Other primary emissions could be influenced by the habits of the people residing in and using the building. Choices in the products they use in cooking and cleaning or the materials they bring inside are ways that habits will affect primary emissions.

Secondary emissions of volatile organic compounds (VOCs) are defined as emissions resulting from chemical transformations, sometimes initiated by the interaction of a building material with a gaseous reactant (Weschler et al., 1992; Reiss et al., 1995; Morrison et al., 1998; Morrison et al., 2002). For example, secondary emissions have been found to emit from carpet, in the form of aldehydes, when exposed to ozone (Weschler et al 1992). These secondary emissions can come in the form of carcinogens (formaldehyde), irritants (carbonyls, dicarbonyls, acids), free radicals, and other oxidation products (Weschler 2004). These secondary emissions may contribute to morbidity and mortality correlations previously associated with ozone (Weschler et al. 2006)(Bell et all. 2006). Ozone, in the form of smog, is one of the key oxidizing agents in the initiation of secondary emissions from indoor surfaces. If the ozone concentrations can be reduced, this would in turn reduce secondary emissions and thus exposure to both ozone and secondary emissions.

When ozone reacts with materials, VOCs in the form of aldehydes, ketones and carboxylic acids are frequently formed (Weschler et al., 1992);(Weshler 2007);(Pandrangi and Morrison 2008);(Waring et al., 2008). VOCs are defined as natural or synthetic organic compounds in the boiling point range of 50 ^{o}C to 260 ^{o}C (WHO,1989) excluding pesticides. 80% of primary sources of VOC levels in our environment come from motor vehicles, transport and storage of VOCS, and solvent usage (National Air Quality and Emissions Trends Report, 1997). Many VOC pollutants that are found in outdoor air can also be found in indoor air, and in higher concentrations, due to indoor sources such as manufactured products and cleaning products. Indoor VOC concentrations will ultimately be influenced by infiltration from the outdoor environment, ventilation and dilution and emissions from indoor sources, with the dominant source depending on the purpose of the building, construction quality, and people using the building.

1.6. HEALTH EFFECTS OF OZONE AND BYPRODUCTS

The World Health Organization (WHO 2003) ozone has been shown to harm lung function and irritate the respiratory system. Epidemiological studies of exposure at high ambient concentrations show correlations with cough, lower and upper respiratory symptoms, shortness of breath along with a host of other issues associated with breathing (Galizia and Kinney, 1999). Studies have shown an association with ozone and morbidity in the form of respiratory and asthma related medical conditions being elevated (Hubbell et al., 2005). VOCs (such as carbonyls and carcinogens) have been shown to be toxic and carcinogenic reducing the overall health of building occupants. O_3, in the form of smog, has been shown to increase mortality (Bell et al. 2004). Even small increases in ambient ozone levels have a measurable impact on increases in mortality (Bell et al. 2005)(Bell et al. 2006)(Weshler et al. 2006). The effects of these pollutants depends on the exposure of an individual to the air contaminant, which is defined as the concentration of a pollutant an individual is in contact with, multiplied by the exposure time interval (Sparks et al. 1993). Recent research suggests the possibility that the peak exposure concentration or integrated exposure may also be important in determining what effects someone should anticipate due to exposure (Bell et al. 2006);(Weshler 2006). Research has also shown that it may be that no one type of pollutant may directly cause the health effects, but instead a mixture of ozone, carcinogens, toxins, and irritants may work together to create lasting health problems (Anderson et al. 2010). This creates the opportunity to reduce indoor ozone exposure and exposure to other pollutants, for the mentioned risk groups and the population at large, with the selection of the building materials given the quantified knowledge.

1.7. CAN BUILDINGS REDUCE OZONE EXPOSURE?

Indoor air quality (IAQ) in the form of pollutants is affected by the emissions of compounds from the building materials (primary emissions), sorption and desorption processes between the pollutants and the surfaces, the removal of pollutants via ventilation and deposition on the surfaces, chemical reactions at the surfaces, and finally the reaction at the material's surface with the air pollutants all serve to affect the emissions of secondary byproducts and the airborne concentrations of both the byproducts and ozone (Nazaroff 1986); (Morrison, et al., 1998);(Morrison 2006). This research will focus primarily on ozone uptake and byproduct emission rates for green building materials. The unique characteristics of our constructed environments have an effect on increasing the frequency of reactions between surfaces and airborne pollutants, in this case ozone. With 90% of our time spent indoors (Jenkins, 1992) the reality is that people can reduce their exposure with smart material choices. Related to the time people spend indoors is the current push for greater energy efficiency in building designs. To improve energy efficiency, buildings are designed or “weatherized” to reduce Air Exchange Rates (AER). Lower air exchange decreases ozone infiltration rates, but also increases the amount of time that O_3 has to react with indoor environment, and reduces dilution of secondary emissions. It has also been shown that a building’s interior surface can be used as a passive air cleaning mechanism (Kunkel et al 2009). Because there is such a higher surface area to volume ratio found in indoor environments, than that available from other mechanisms, the relative influence of these surfaces increases to the point of exceeding that of the other removal mechanisms, of sorption/desorption, deposition, and chemical reactions (Nazaroff et al 2003). The concentrations of the pollutants will be strongly influenced by the air exchange rate (AER), the number of times the total volume of air within a space is totally replaced by fresh air, of the indoor environment and the surfaces ability to react with O_3. This air cleaning will be achieved by the ambient mixing found within an indoor environment, the mass transfer of O_3 to the buildings surfaces, and the chemical reactions of O_3 with those surfaces. From this stated high surface area to volume ratio, even for those materials with relatively low reactivity with ozone the sheer amount of available reactive surfaces will cause these surface reactions to become the dominate mechanism of removal, over even active control mechanisms.

There is an opportunity to identify building materials with good ozone reduction ability and low secondary byproduct emissions and promote them via the LEED certification system. These “good” building materials will be identified by an as yet to be determine threshold O_3 reaction probability and an upper limit total byproduct yield. Among the most well-known and active materials commonly found in our indoor environments are carpet, which are thought to be responsible for nearly half of the ozone removal in a carpeted building (Morrison, et al., 2002). Carpet due to its composition and the deposition of reactive material, has relatively regular ozone reduction ability and secondary emissions. Carpet is also responsible for high levels of secondary emissions. What other materials exist that might have carpets reduction ability, but coupled with low secondary byproducts? In a home or indoor environment where cooking is ongoing many surfaces get coated with various ozone reactive contaminants, and in all cases of indoor environments cleaning products and other commonly used human products increase the reactivity of materials with ozone. This deposition of a new reactive coating could come to dominate over the material used, though the human activities will be performed no matter what materials are used. Under the assumption that the overall contribution of indoor sources of ozone are at levels that can be considered negligible, the ratio of indoor to outdoor ozone concentrations (I/O) can be within the range of 0.2 to 0.5 (Avol et al. 1998; Romieu et al. 1998). This ratio signifies an important impact on human exposure to ozone concentrations while inside a built environment. By choosing materials that have a greater impact on ozone reduction, the I/O ratio could be further reduced reducing human exposure to the ozone.

1.8. USING MATERIALS TO REDUCE OZONE EXPOSURE

Surfaces with sufficient reactivity (or ability to consume ozone) will dominate the removal of O_3 by the air exchange. This rate of O_3 transfer is dependent primarily upon the transport of O_3 to the surface and the rate of the surface reaction. While ozone reactions with a building material's surface can decrease a building occupants' exposure to ozone, the reaction byproducts formed by the ozone reacting with the material may lead to a net degradation of the indoor air quality. Given limited toxicological guidance, it is difficult to determine the exact threshold requirements for many of the byproducts formed. A maximum "yield" could be specified above which the byproduct emissions are considered unacceptably high. Given typical air exchange rates and comparing that to replacing surfaces with building materials, with high enough deposition velocities, effective filtration rates several times higher than what a typical air exchange rate may be obtained. Taking a high deposition velocity (5 m h^{-1}) and an indoor surface area (800 m^2) an effective air filtration rate ($v_d \times A$) of 4000 m^3 h^{-1} can be achieved. This is 25 times a typical infiltration rate ($V \times \lambda$) of 150 m^3 h^{-1} (Morrison et al. 1998). This is with no added active energy costs needed to obtain this improvement in air quality. Surfaces that make up a high percentage of indoor surfaces should be targeted. These would be the ceiling, floorings, and wall materials. The share of total surface area that these materials cover makes these surfaces ideal candidates. Certain types, such as carpeting and painted drywall will be obvious. Others will have to be researched to take into account differing tastes and the wide range of materials available. Commercial, residential, and dual use materials will all be studied. For this project, all of the materials studied will be in some way “green,” based on LEED criteria. Either in their manufacture, composition, or some additional criteria, they must be considered ‘green’. Furniture and cabinet materials will not be examined because of the low level of total surface area of each material, the total impact on ozone, and byproducts would be moderate to low.

1.9. PURPOSE OF RESEARCH

Research was proposed to the United States Green Building Council (USGBC) which runs the Leadership in Energy and Environmental Design (LEED), to create a new grading criteria for the LEED grading system, based on the quantified O_3 removal capability and the byproducts of various building materials. This will provide building designers (architects, engineers, owners) with information on which materials will improve a building’s health and reduce occupant exposure via a passive, low energy means of ozone reduction. Through this research guidelines for a testing standard, to be used by third party testers, hired by material manufacturers, will be set up along the ASTM testing format for the improvement of indoor air quality. At present there is no grading method for materials as used by the USGBC. This research specifically fulfills the needs of ASHRAE standard 189.1 and item 4.1 of the *Indoor Environmental Quality (IEQ): Pollutants and stressors*, as described in the USGBCs research committee’s A National Green Building Research Agenda. The two stated general research topics of the committee’s findings are 1) “Clarify the chemistry, biology, and mechanics of indoor environmental quality (IEQ) to inform improvement strategies,” and 2) “Develop metrics and tools to quantify indoor conditions and simplify the processes of understanding, assessing and improving IEQ.” It specifically addresses the priority topic 3) to “Develop more effective standards and protocols for product emissions testing.”

2. GOALS AND OBJECTIVES

Common building materials and furnishings remove ozone but also generate undesirable byproducts (Weschler, et al., 1992) (Weschler, 2006) (Weschler, et al., 2007) (Wang, et al., 2005) (Morrison, et al., 2006). These phenomena significantly influence the indoor concentrations of ozone, carbonyls, aerosols, irritants, and other problematic pollutants. Contemporary interest in "green buildings" has driven an explosion in new and re-labeled building materials that are recycled, sustainable, low-emitting, and/or otherwise "green" by various definitions. Many of these are natural materials such as wood and other biomass products, which are themselves composed of ozone-reactive organics such as terpenoids and unsaturated oils. Recent research has reported on the ozone uptake capabilities of some green building materials, but emission rates of oxidation products were not reported (Hoang, et al., 2009). The goal of this research is to evaluate ozone uptake and product emission rates/yields for multiple classes of green building materials and identify those materials that may passively reduce ozone concentrations within buildings without generating unhealthy byproducts.

To accomplish this goal, specific objectives were established. The objectives of the current study are as follows:

2.1. OBJECTIVE 1: THE OZONE REMOVAL CAPABILITIES OF GREEN BUILDING MATERIALS SHALL BE QUANTIFIED

Deposition velocities, reaction probabilities, and the integrated ozone uptake of ozone with green building materials will be quantified.

Hypothesis: Some green building materials exhibit sufficiently large ozone deposition velocities (and other parameters) such that reduction of indoor levels of ozone can be achieved through the appropriate use of these materials in buildings.

2.2. OBJECTIVE 2: MEASURE BYPRODUCT EMISSION RATES ASSOCIATED WITH GREEN BUILDING MATERIALS

The rate of the oxidation byproduct emissions in the form of the C1-C12 aldehydes, plus acetone, will be quantified. The measurements will be reported as secondary emission rates and product yields, which can be used in indoor air quality models to estimate the impact on indoor concentrations of products.

Hypothesis: Due to the wide range of material composition (biomass, inorganic, synthetic, etc.) ozone reduction capabilities of green building materials do not correlate with product emission rates or yields, i.e., some materials may be good ozone sinks without generating substantial amounts of reaction byproducts, while others WILL exhibit high product emission rates.

2.3. OBJECTIVE 3: ESTABILISH THE EFFECTS OF PARAMETER VARIATIONS ON SPECIFIC MATERIALS

A subset of the materials tested in this research will be studied to observe the influence of variable environmental conditions that would be expected indoors. Parameters varied include temperature, humidity, ozone concentration, and exposure duration.

Hypothesis: Changes in temperature, humidity, ozone concentration, and exposure duration will have measurable and significant effects on the ozone uptake rates and byproduct emission rates and/or yields.

2.4. OBJECT 4: COMPARE RESULTS TO THOSE OBTAINED IN INDEPENDENT EXPERIMENTS AT THE UNIVERSITY OF TEXAS AT AUSTIN

For a subset of materials, results obtained at the S&T laboratory will be compared against results of experiments at the University of Texas at Austin. Tests performed at UT Austin take place in different size chambers and under different conditions, such as the “loading ratio” of the material in the chamber.

Hypothesis: Differences in testing apparatus (operated under the same environmental conditions) will not significantly influence reported ozone reaction probabilities and byproduct yields; these parameters are thought to be independent of the fluid mechanical conditions inside a chamber or the geometry of the chamber or material.

3. MATERIALS AND METHODS

3.1. MATERIALS

Nineteen ‘green’ building materials were chosen for testing. The building materials were chosen based on multiple “green” criteria. Some were low emitting (such as some paints) while others were made from recycled materials (such as rubber tiling) and a few were made from renewable resources (such as bamboo flooring). Shown in Table 3.1 is a list of the materials tested at Missouri S&T along with their manufacturer, internal project ID, composition, green attributes, intended usage, and whether the University of Texas at Austin (UT) also tested the materials.

Table 3.1. Tested Materials and Attributes

ID	MANUFACTUER	SURFACE	COMPOSITION	GREEN ATTRIBUTE*	INTENDED USAGE	UTA TESTED
FLOORING						
FC-1	Interface flooring	recycled backing carpet	nylon, glasbac backing	recycled, CHPSLEM	commercial	yes
FC-2	Shaw	fabric backed carpet	nylon, softbac platinum backing	recycled, CHPSLEM	commercial	no
FRf-1	Forbo	Marmoleum resilient tile	linoleum substitute	renewable, CHPSLEM	commercial	no
FRf-2	Rubber Products	puzzle-locking tiles	recycled rubber	recycled	commercial	no
FRf-3	Armstrong	bio-based resilient tieles	no information	renewable, CHPSLEM	commercial	no
FCf-1	American Olean	porcelain clay tile	sealed porcelain clay	likely low emitting	commercial	no
FWf-1	EcoTimber	finished hardwood flooring	hardwood composite	renewable	dual	no
FWf-2	Smith & Fong	finished bamboo flooring	bamboo composite	renewable	dual	no
WALLING						
WC-1	unknown (Portugal)	cork wall tiles	cork	renewable	commercial	no
WC-2	Golterman & Sabo	fabric acoustical wall panel	fiberglass, fabric	renewable	commercial	no
WC-3	Carnegie Fabrics	fabric wall covering	xorel fabric, paper	renewable	commercial	no
WP-1	Benjamin Moore	latex paint & primer	acrylic latex	low VOC, Greenguard	dual	yes
WP-2	Bioshield	clay based paint	clay, pigments, cellulose, binders	likely low emitting	dual	no
WP-3	EcotTrend	collagen based paint	amino acrylic resin with collagen binder	low VOC, Greenguard	dual	no
WCP-1	American Clay	clay plaster wall coating	clay, pigment	likely low emitting	dual	yes
WD-1	USG	drywall	gypsum	recycled	dual	no
CEILING						
CP-1	Armstrong	mineral fiber ceiling tile	mineral fiber, binders	CHPSLEM	residential	no
CP-2	Chicago Metallic	perlite ceiling tile	perlite	likely low emitting	commercial	yes
CP-3	Certainteed	fiberglass ceiling tile	fiberglass, binders	CHPSLEM	commercial	no

*(CHPSLEM) Collaborative for High Performance Schools Low Emitting Materials

3.2. EXPERIMENTAL METHODS

3.2.1. Overview. To meet objectives 1 and 2, deposition velocity, reaction probability and aldehyde yield values are required for each material. Flow through laboratory chambers have been used successfully to measure these values based on a material/mass balance model of a well mixed chamber (Morrison, et al., 2002) (Wang, et al., 2006) (Poppendieck, et al., 2007). Briefly, humidified air containing ozone flows into a chamber containing a building material. Ozone removal through the chamber can be related to mass transfer coefficients and surface reaction rate parameters. Products formed on the surface are measured using well established analytical techniques by concentrating chamber outlet gases. Results are reported as deposition velocity, reaction probability, and product yield. These values can be used to predict how the building materials may impact indoor air quality in buildings (Morrison et al., 2006; Kunkel et al., 2009).

3.2.2. Chamber Apparatus Description and Diagram. Figure 3.1 is a schematic of the experimental system. The primary component of the system is a ten-liter stainless steel cylindrical container that was electro-polished by the manufacturer (Eagle Stainless). The container has a lid with three compression locks and a palladium-cured silicone gasket to seal the lid to the main body. Two ¼" ports (inlet and outlet) are located on top of the lid to allow gas to access the chamber. The gas passing through the system is a mixture composed of purified compressed building air, tank oxygen, ozone and water (relative humidity). The air is purified using an oil trap and an activated carbon trap (organic vapor specific). The ozone was generated by passing the oxygen through an ozone generator constructed in-house, applying the principal of arc-discharge formation of ozone from dry oxygen. The water was generated by passing half of the purified air stream through a water "bubbler" (Ace Glass) before returning both flows to mix together and mixing the air with the ozone saturated oxygen. The flows were controlled by three mass flow controllers (MKS, inc). Exhaust gas samples were collected by drawing the flow through sample tubes (measured by a mass flow meter and a mass flow controller), while the ozone concentration was measured using an ozone analyzer (1008-PC Dasibi). Prior to the beginning of the project the ozone analyzer was calibrated using an ozone calibration source (model 306, 2B Technologies). Eight electromechanical solenoid valves were used to control the direction of the gas streams and the timing of the sampling. Three of the valves allowed for the exposure of the material to the gas stream and bypass to allow quantification of the inlet ozone concentration. Tubing was stainless steel (both ¼ and 1/8 inch) with two lengths of Teflon tubing connecting the ozone generator the system and connecting the “bubbler” to the water trap. The entire system was set inside a walk-in temperature controlled chamber, operated at 25 ^{o}C for the entire experimental period, except for times when parameter variations required adjustment. Data was acquired and valve timing was all controlled by an in-house data acquisition system (LabView). Figure 3.2a and 3.2b are photographs of the experimental system, showing the setup from two different angles.

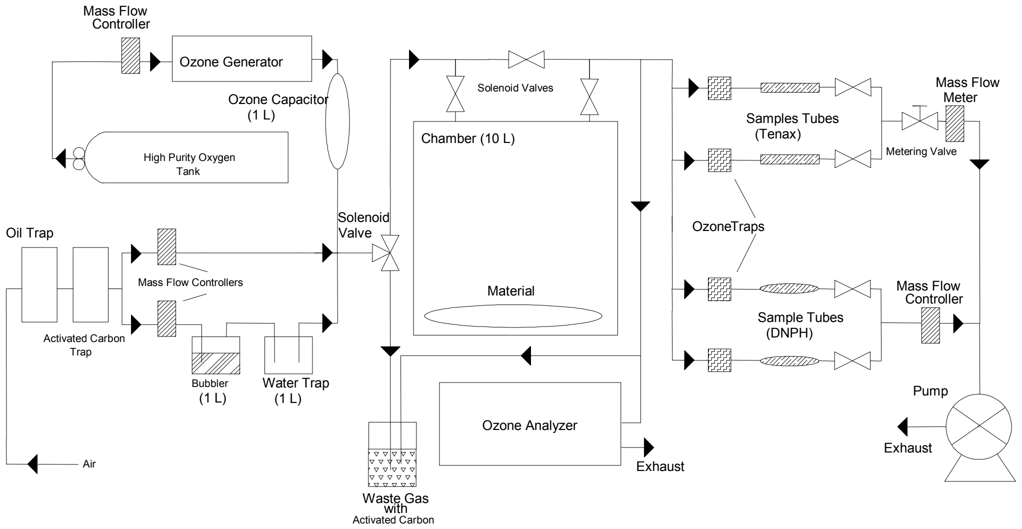


Figure 3.1 System Diagram

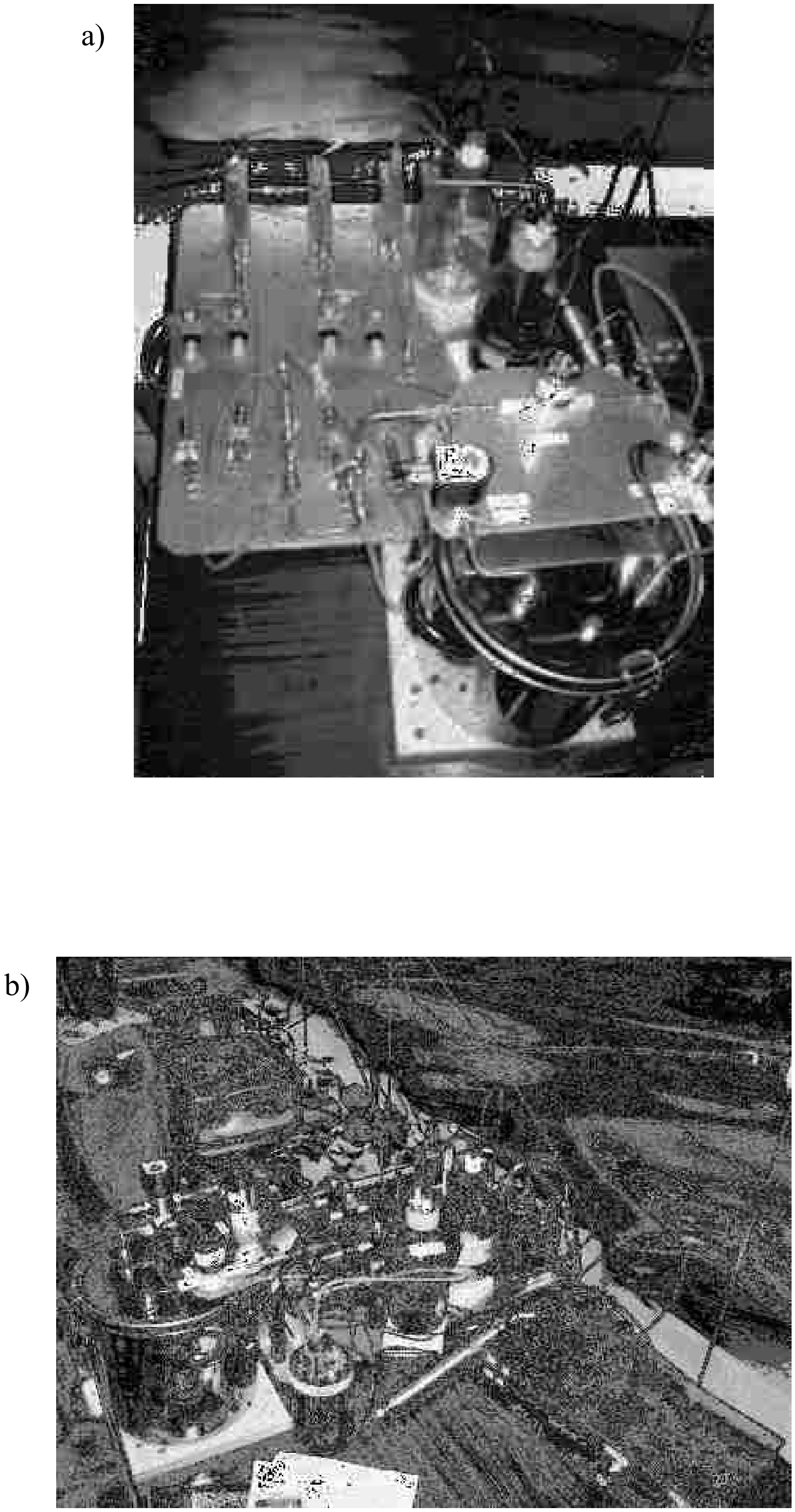


Figure 3.2 a) System Photographs b) System Photographs

3.2.3. Experimental Procedure: Exposure of Materials. For each experiment the chamber was cleaned by rinsing once with methanol. The chamber was then exposed to ozone at concentrations >1000 ppb for two hours to quench any reactive sites remaining on the chamber inner surface. Then the chamber was flushed with ozone-free air for one hour. The chamber was then opened and the piece of a material to be tested was placed inside the chamber.

A total of 2.050 standard L min^{-1} (0 ^{o}C) flowed through the system during an experiment. At the experimental temperature of 25 ^{o}C the total flow rate was 2.238 L min^{-1}. The streams consisted of two streams of dry air and a stream of oxygen. The first stream of air was set at 1000 sccm (standard cubic centimeters per minute) . The second stream was also set at 1000 sccm, and passed through the water trap and the "bubbler"to generate a stream at 100% relative humidity (or wet air). The wet and dry air were then mixed together to generate a stream at 50% relative humidity. This resulted in a total air flow stream of 2 L min^{-1} (2000 sccm). These flow rates were modified for parameter variations, though the total air flow rate never dropped below 2 L min^{-1}. Relative humidity was confirmed once every two weeks using a pen-sized humidity sensor (Fischer Thermo-Hygro) that was placed inside the chamber and allowed to come to equilibrium with the air flow for one hour. The third stream of high purity oxygen was set at 50 sccm flowed through the ozone generator.

The total flow rate was determined by the requirements of the ozone analyzer and sampling tubes. The ozone analyzer required at least 1 L min^{-1} of gas flow to be able to reliably measure the ozone concentration, while minimum volumes were required to be collected on both the DNPH and Tenax tubes. Although higher flow-rates through the sample tubes may have improved the protocol's limit of detection, they would also have created a very high flow rate through the chamber reducing the residence time and thereby reducing the sensitivity of ozone uptake measurements.

The ozone generator was operated so that there was a constant inlet concentration of ozone in the range of 150 to 200 ppb. This concentration was changed for parameter variations and chamber cleaning. This ozone/oxygen stream was mixed with the air stream before being introduced to the chamber and sampling system. The air/oxygen/ozone stream (exposure stream) could be directed into the chamber for normal experimentation, while a bypass valve allowed the exposure flow to be directed away from the chamber and into an activated carbon trap during shut down periods and preparation to prevent the chamber from over pressurizing. Three solenoid valves were used to direct the exposure stream either through the chamber to expose the sample material to the gas, or through bypass to quantify the inlet ozone concentration. The exposure stream, either from the chamber or bypass, was continuously sampled via ozone analyzer while it was also sampled via DNPH and Tenax tubes in the sampling train at three sampling times.

3.2.4. Experimental Procedure: Sample Timing and Volumes. A standard chamber protocol lasted for 31.5 hours as show in Figure 3.3. During the standard protocol there were three sampling periods. At each of these sampling periods there were two sets of 1 h samples collected on both DNPH and Tenax tubes. During the sampling period flowrates of 500 sccm and 30 sccm, respectively, were passed through the DNPH and Tenax tubes, resulting in a total volume of 30 L and 1.8 L respectively. These flows were confirmed using a mass flow meter (MKS, int.) coupled with a needle valve for the Tenax. At the beginning of each sampling protocol the flow through the flow meter was confirmed and modified as needed. A mass flow controller (MKS, int) was used to control the flow through the DNPH tubes.

“Primary emission samples” (PES) were collected in replicate during the first three hours of the protocol, and the two secondary emission samples (2 hour and 24 hour) were collected in replicate after ozone exposure of the material commenced. At time zero and for three hours after that the material was exposed to ozone free, 50% relative humidity air, with a one hour sample performed at the one hour (1 h) period and a second one hour sample performed at the 2 h period. These two samples were used to quantify the primary emission rates of analytes. Each sample period was consisted of a DNPH and a Tenax tube collected in parallel, at the same time, from the same gas stream. The second or replicate sample was collected in the hour immediately following (t = 2 h) the initial first pair of samples. After the replicate sample was collected the ozone generator was activated and the gas stream (t = 3 h) was directed to bypass the chamber. This bypass was performed for two hours to allow the ozone generator to warm up, and thus allow the inlet ozone concentration to reach steady state. After the steady state period (t = 5 h) the flow was directed into the chamber exposing the material for 12 hours to the ozone/oxygen/air mixture. After the 12 hours of exposure (t = 17 h) the flow was bypassed once again for 0.5 h to measure the inlet ozone concentration. Once the 0.5 h time period had passed (t = 17.5 h) the gas stream was once again sent to the reactor until the end of the 24 hours of ozone exposure (t = 31 h) when the flow was once again bypassed to confirm the inlet ozone concentration for 0.5 h. The 2 hour ozone exposure samples and 24 hour ozone exposure samples were collected at the 7-9 h and 29-31 h periods. These samples represent the secondary emission sample rates along with the emission rates at those time period with ozone exposure. For 28 hours the material was continuously exposed to gas flow with or without ozone. The reaction chamber ozone concentration was continuously measured, with the inlet ozone concentration measured at the beginning, middle, and end of the ozone exposure period of the protocol.

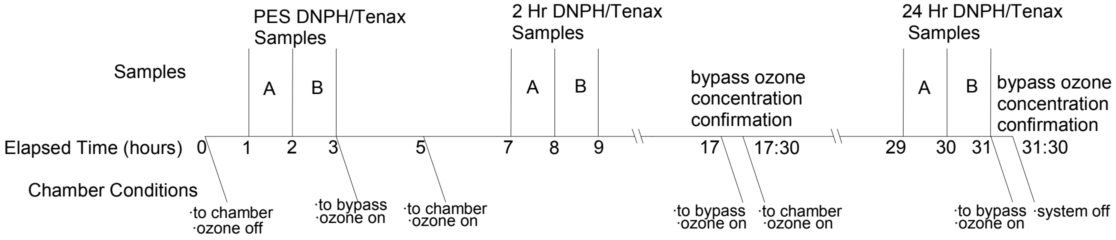


Figure 3.3 Timing Diagram

3.3 METHODS FOR MATERIAL PREPARATION

3.3.1. Sodium Silicate Method. All materials were coated with sodium silicate ($NaSiO_4$) on the back and sides. Sodium silicate is nonreactive with ozone, sealing the materials from reaction with ozone. This is to force only the surface of the materials that would normally be exposed in a business or home to react during testing. The sodium silicate was applied using a fresh clean piece of foam dipped in the sodium silicate solution and applied to the material after preparation and drying. The sodium silicate coated material was then placed face down in a clean box and allowed to dry for 24 hours.

3.3.2. Potassium Iodide Method. Six of the materials were chosen to be coated with potassium iodide (KI) to allow the calculation of the transport limited deposition velocities of the materials. KI was used because it is thought to be a near "perfect" sink for ozone (Brown, et al., 2008) and was simple to apply to the surface once dissolved into solution. The deposition velocity values determined for these six materials were used to determine the reaction probability for all the other materials. Materials were matched based on the visual and tactile surface characteristics of the material. The KI was applied via foam dipped in saturated KI solution and then applied to the surface of a previously prepared sample of building material. These pieces were then allowed to dry for 24 hours before testing. The KI solution used was saturated and consisted of 20 mL of Milli-Q xxx filtered water and 28 g of KI solid, the solution was created prior to each application.

3.3.3. Interface Carpet. Interface carpet was cut into a 9 inch circle using a pair of office scissors cleaned with methanol prior to cutting. $NaSiO_4$ was then applied per method described earlier.

3.3.4. Shaw Carpet. Shaw carpet was cut into a 9 inch circle using a pair of office scissors cleaned with methanol prior to cutting. $NaSiO_4$ was then applied per method described earlier.

3.3.5. Forbo Resilient Flooring. Forbo resilient flooring was cut into a 9 inch circle using a pair of office scissors cleaned with methanol prior to cutting. $NaSiO_4$ was then applied per method described earlier.

3.3.6. Rubber Products Tiling. Rubber products interlocking rubber floor tile was cut into a 9 inch circle using a standard wood keyhole saw cleaned with methanol prior to cutting. Shaping after cutting was performed using a box cutter knife. Excess rubber dust was blown off using compressed building air. $NaSiO_4$ was then applied per method described earlier.

3.3.7. Armstrong Floor Tiling. Armstrong floor tile was considered too brittle to cut to shape via scissor or saw. Instead scoring was performed on the material, within a circle traced onto the back of the material with pencil, with a standard box cutter (cleaned with methanol), along a straight line. The excess material was then snapped off using a pair of pliers. This created a roughly circular shape of slightly lesser dimensions than the standard nine inch template. $NaSiO_4$ was then applied per method described earlier.

3.3.8. American Olean Porcelain Tile. Due to the difficulty in cutting the porcelain tile and the likelihood of contamination from machine oils if cut via machine, the porcelain tile was left as is and sealed via the $NaSiO_4$ method. The calculations took this reduced surface area into account.

3.3.9. Ecotimbers Wood Flooring. Ecotimber wood flooring was cut in two pieces both roughly triangular in shape. The total dimensions were less than the standard nine inch diameter of normal testing pieces. This reduced dimensional size was taken into account in ozone reactivity and byproduct calculations. Excess wood dust was blown off using compressed building air. $NaSiO_4$ was then applied per method described earlier. For testing both pieces were fit together and placed within the reaction chamber.

3.3.10. Smith and Fong Plyboo Flooring. Plyboo bamboo flooring was cut in two pieces both trapezoidal in shape. The total dimensions were less than the standard nine inch diameter of normal testing pieces. This reduced dimensional size was taken into account in ozone reactivity and byproduct calculations. Excess wood dust was blown off using compressed building air. $NaSiO_4$ was then applied per method described earlier.

3.3.11. Cork Wallboard. Cork sheeting was cut into a nine inch diameter circle using a pair of office scissors cleaned with methanol prior to cutting. The sheeting was than adhered to a piece of USG drywall, cut to shape, using cork manufacturer supplied adhesive and roller. Each piece was allowed to dry for 24 hours sitting face up in a clean box, at which time the drywall and cork wallboard were trimmed to matching shape. The $NaSiO_4$ was then applied as per method described.

3.3.12. Acoustic Wall Panel. Acoustic wall panels were received manufactured to 8.5 inch diameters by the manufacturer for testing. Samples were manufactured to shape per contract with Missouri S&T. $NaSiO_4$ was then applied per method described earlier.

3.3.13. Xorel Wall Covering. The Xorel wall covering was cut into a 9 inch circle using a pair of office scissors cleaned with methanol prior to cutting. The covering was then adhered to pre cut drywall using standard wall covering adhesive (type). After the material was adhered and allowed to dry for 24 hours the material and drywall were then trimmed to matching shape for testing. $NaSiO_4$ was then applied per method described earlier.

3.3.14. Benjamin Moore Ecospec Latex Paint. Sheets of USG Drywall pre-coated in Ecospec paint were received from UT Austin, these sheets were cut into a 9 inch diameter circle, using a standard wood keyhole saw, and cleaned with methanol prior to cutting. Shaping after cutting was performed using a box cutter knife. Excess drywall dust was blown off with compressed building air in first case, and wiped clean using a Kimwipe, delicate task wipe (Kimtech Science) moistened with Millipore filtered water (MillQ Water Systems) in the second sample. $NaSiO_4$ was then applied per method described earlier.

3.3.15. Bioshield Clay Paint. Bioshield clay based paint was applied to precut USG drywall samples cut into the standard nine inch diameter circles. One sample was applied using a paint brush and the other with a roller to take into account the different textures found in application. Textures were assumed to be more variable than normal paints because of the high viscosity, based on tactile experience, of the clay based paint. Product did not call for primer, but discussions with company representative recommended use of a primer because it extends the amount of surface area that can be covered, therefore reducing the amount needed to be used and cost, which is assumed what most consumers would choose to do. Thus a standard primer (Valspar) was applied using a paint roller and allowed to dry for 24 hours before coating of Bioshield paint was applied and allowed to dry for 24 hours sitting face up in a clean box before $NaSiO_4$ application.

3.3.16. Ecotrend Collagen Paint. Ecotrend paint was applied to precut USG drywall pieces after standard primer (Valspar) was applied and allowed to dry for 24 hours. Application was performed using a paint roller as recommended by manufacturer. Pieces were then allowed to dry for 24 hours face up in a clean box before $NaSiO_4$ application.

3.3.17. American Clay Wall Plaster.

3.3.17.1 Mixing method. American Clay wall plaster was mixed in a five gallon stainless steel bucket using a standard clay mixing paddle, cleaned with deionized water prior to mixing, driven by a standard power drill. The composition of the mixture consisted of ten pounds of clay, one gallon of tap water, and a fifth a pint of pigment. This is the standard mixing method recommended by American clay, divided by five to account for the smaller amount of clay needed to be used in application on samples.

3.3.17.2 Application method. The application of the American clay plaster was performed as per the manufacturer's instructions, which can be summarized as follows. First by using a paint roller the sand and glue based primer was applied to a piece of pre-cut USG drywall. This piece was then allowed to dry for 24 hours face up in a clean box. After drying, a steel trowel was used to apply the American clay mixture to the surface of the primed drywall, creating an even layer on the surface. The clay was allowed to dry for several hours before the clay surface was wetted again using a spray bottle filled with tap water. The trowel was then used to smooth the surface. The piece was then allowed to dry face up in a clean box. After drying, a box cutter was use to trim the piece to shape for testing and compressed building air was used to blow excess dust from the piece. $NaSiO_4$ was then applied by the standard method.

3.3.18. USG Drywall. USG Drywall was cut using a standard wood keyhole saw cleaned with methanol prior to cutting. The material was cut into a nine inch circle traced onto the back of the product using a pencil. Shaping after cutting was performed using a box cutter knife. Excess dust was blown off using compressed building air. For material testing samples of only USG drywall $NaSiO_4$ was then applied per method described earlier. For those material samples that were using the USG drywall as a base the $NaSiO_4$ was not applied until the application of the additional materials.

3.3.19. Armstrong Ceiling Tile. Armstrong ceiling tile was cut using a standard wood keyhole saw cleaned with methanol prior to cutting. The material was cut into a nine inch circle traced onto the back of the product using a pencil. Shaping after initial cutting was performed using a box cutter knife. Excess dust was blown off using compressed building air. $NaSiO_4$ was then applied per method described earlier.

3.3.20 Chicago Metallic Ceiling Tile. Chicago Metallic or Eurostone ceiling tile was cut using a standard wood keyhole saw cleaned with methanol prior to cutting. The material was cut into a nine inch circle traced onto the back of the product using a pencil. Shaping after intial cutting was performed using a keyhole saw. Excess dust was blown off using compressed building air. $NaSiO_4$ was then applied per earlier method.

3.3.21. Certainteed Ceiling Tile. Certainteed ceiling tile was cut using a standard wood key hole saw cleaned with methanol prior to cutting. The material was cut into a nine inch circle traced onto the back of the product using a pencil. Shaping after initial cutting was performed using the key-hole saw. Excess dust was blown off using compressed building air. $NaSiO_4$ was then applied per method described earlier.

3.4. ANALYTICAL METHODS

3.4.1. Determination of C1 - C5 Aldehydes and Acetone. Gas samples for the analysis of C1 – C5 aldehydes and acetone were collected on glass tubes containing dintrophenylhrydrazine (DNPH) (Aldrich/Supelco) coated silica gel crystals. The reaction between the DNPH and the carbonyl compounds collected form conjugate hydrazones, which are more easily detected using UV spectroscopic methods. The sample gas was collected for 1 hour at 500 sccm. After sampling was performed all cartridges were stored in a laboratory refrigerator until analyzed. To create sampling solutions the tubes were broken to remove the silica gel and were extracted in 4 mL of acetonitrile. This solution was placed in a sonicator for 5 min to ensure complete extraction and then withdrawn and forced through a 0.45 µm syringe filter (EasyDisc) to remove any large solids that can clog the Waters High Performance Liquid Chromatograph (HPLC). The filtered solution was divided between a 1 mL HPLC sample vial, and a 7 mL storage vial. C1 thru C5 aldehydes and acetone were specifically quantified with this method. The HPLC method is based on EPA TO-11A (U.S.E.P.A., 1999) and can be found in Appendix C.

Concentration calibration equations were created for each of the six carbonyls targeted by creating diluted stock solutions. Identical volumes of the stock solutions were injected, with at least two sets of injections for each concentration point. Five different concentrations were injected, along with a zero concentration injection to create the calibration equation. The concentrations ranged from the lowest of 2.5 ng with the highest being 300 ng.

3.4.2. Determination of C5 - C12 Aldehydes. Gas samples for the analysis of individual aldehydes, from C6 through C12 aldehydes, were collected on TENAX-TA thermal desorption tubes (Markes Intl.) at a flowrate of 30 sccm for one hour per tube. These were analyzed by thermal desorption (Markes, Intl.) into a gas chromatography/flame ionization detector (GC/FID) (Agilent), using the cyclooctane standard explained in section 3.5.1. All tubes were processed using an aldehyde method developed that is similar to that used by the EPA (U.S.E.P.A., 1999) shortened to conserve both time and carrier gas. See appendix C for details on the method conditions. To calibrate the thermal desorption tube method, a sequence of increasing volumes of stock solutions containing C6-C12 aldehydes were injected onto Tenax tubes and analyzed. Stock solutions were created for each of the eight upper aldehydes (C5-C12) that were being quantified. Initial solutions of each of the individual pure solutions (Sigma-Aldrich) were created using 25 mL vials, in each case 50 µL of the pure solution was added to 25 mL of methanol. From the initial stock solutions, combined stock solutions with all eight aldehydes were created. Four total combined stock solutions were created, with 10 µL and 5 µL being injected into 25 mL vials to create the new solutions. These resulted in a combined stock solution with an average concentration of 7.8 ng µL-1 and a second solution with a concentration of 0.78 ng μL^{-1}. Volumes of 5 µL, 10 µL, 25 µL, 50 µL, 100 µL and 250 µL were injected to create a mass calibration curve up to 150 ng. After the stock solution was injected onto the tube, the tubes were placed in line with a nitrogen stream flowing at 40 sccm for 2 min, to purge methanol from the Tenax. After purging, the internal standard was injected as described in section 3.5.1. Once the calibration Tenax tubes were prepared they were processed using the same TD/GC/FID method used to quantify the emissions and yields from the material samples. A calibration curve was generated based on the known mass of the aldehyde injected and the resulting peak areas; each of the calibration curves had R^2 values of 0.98 or higher.

3.4.3. Limit of Detection. Instrumental limit of detection was estimated using the lowest reproducible mass injected (which was then multiplied by 3). This resulted in the following limits of detection (instrumental (ng) and gas concentration (ppb)). Analysis of laboratory blanks, inlet and empty chamber exhaust samples indicated that a background level of carbonyl compounds was present and could not be reduced further via practical and efficient methods. These values are presented in Table 3.2.

Table 3.2. Limit of Detection

	LOD (ng)	LOD (ppb)
C1	15.6	1.3
C2	63.2	3.5
C3	102.6	4.3
C4	75.7	2.6
C5	101.8	2.9
C6	12.5	5.1
C7	11.2	4
C8	4.9	1.6
C9	7.9	2.3
C10	6	1.6
C11	11.1	2.6
C12	5.6	1.2
Acetone	97.4	4.1

3.5. EXPERIMENTAL METHODS

3.5.1. Internal Standard Method. An internal standard was created using a Dynacalibrator. Cyclooctane was chosen as the internal standard because it is stable, separate from the target aldehydes, has a retention time similar to that of the targeted aldehydes, and no targeted aldehydes appeared at that same retention time. It also is not found naturally in abundance. The internal standard is used to confirm that the analysis of the Tenax tubes was not compromised and to normalize the peaks for consistency amongst samples. A sample of cyclooctane was placed inside a diffusion tube, the total mass of the diffusion tube and cyclooctane was then found using a digital balance. The diffusion tube was then placed inside the heating chamber (40 ^{o}C) of the Dynacalibrator. The sample was allowed to sit for more than a week before samples were taken for internal standard use, to allow the system to reach steady state. To take a sample for the internal standard the exhaust for the dynacalibrator was capped. The flow rate out of the sample tube was then tested via a digital mass flow meter (Aalborg USA), the flow was set around 80 sccm, to ensure enough of a sample was taken to be used as an internal standard. Applying a gas tight syringe to the end of the sample tube, draw a 10 mL sample over the course of a 30 second time interval, to ensure the draw was slow enough to gather a quality internal standard sample. The sample was then injected over a 10 second time period onto the Tenax tube while the tube was purged with a 40 sccm stream of dry nitrogen.

3.5.2. Ozone Trap Cleaning Method. Ozone traps (LpDNPH, Aldrich/Supelco) were used during gas sampling for both the DNPH and Tenax tubes. These traps were placed upstream of the tubes to remove the ozone, because ozone has been shown to react with the collected samples reducing overall recovery (Calogirou, et al., 1996). The ozone traps can accumulate carbonyls, which would later contaminate later samples. Because of this after each experiment the traps were cleaned. The traps were mounted inside a drying oven (60 ^{o}C), and were each purged with 40 sccm of pure nitrogen flow for 24 hours. The method used was based on a method develop by UT (Poppendieck, et al., 2007).

3.5.3. Transport Limited Deposition Velocity. Materials with varying surface textures were chosen to be coated with potassium iodide (KI) to find the transport limited deposition velocity (v_t) based on the specific surface area of the materials. KI is considered to be a near perfect sink for ozone (Brown, et al., 2008); thus, the ozone reaction rate at the surface is so fast that boundary layer mass-transfer resistance dominates and determines the maximum ozone flux to the surface. The KI protocol was only performed for three hours, with 1 h set aside for the ozone concentration to reach steady state and 2 h of the material being exposed to the exposure stream.

3.5.4. GC/FID Method. An aldehyde method used is similar to that used by the EPA but the GC run-time was shortened to conserve both time and gas. See Appendix C for the Methods. The internal standard injected as a gas phase on each of the Tenax tubes. The tubes were tested in their experimental batches. Using stock solutions the retention times of each of the upper aldehydes, C5 through C12 were found. Standard solutions of were created to produce peak-area versus concentration plots. The analytes on the Tenax tubes were desorbed with a thermal desorber (TD), then separated and analyzed using a gas chromatograph with a flame ion detector (GC/FID).

3.5.5. HPLC Method. The DNPH vials, before being assayed by the HPLC, had to be processed to create a liquid solution to test. The tubes were scored, snapped in half, and all materials within the tubes (silicon wool and DNPH crystals) were placed in a 7 ml vial. Four ml of acetonitrile were then added to the 7 ml vial. These vials were then placed in an ultrasonic water bath (Bransen 2210) and left for 5 minutes to ensure thorough mixing. Using filter and syringes the fluid and solids were separated, with the majority of the fluid going in 4 ml vials for storage and 0.5 ml being placed in a HPLC sampling vial. These vials along with standard solutions (to confirm continuation of HPLC reliability) were all tested in their experimental batches. The analytes quantified using HPLC were C1 thru C5 aldehydes and acetone. The HPLC method can be found in Appendix C after the GC/FID method.

3.5.6. Final Processing Method. An assumption was made that the chamber was a completely mixed flow reactor (CMFR) and that at the time the samples were taken it had reached steady state to allow for the calculation of the ozone mass transfer rate and the byproduct yield. While the aldehydes are undoubtedly not the only pollutants emitted by the various green building materials, they can be used as surrogates to denote which other pollutants exist (Morrison, et al., 2003).

3.6. DETERMINATION OF OZONE DEPOSITION VELOCITY AND REACTION PROBABILITY

The deposition velocity, reaction probability, integrated ozone uptake, and aldehyde byproduct yields were measured for all materials. The transport limited deposition velocity was determined by coating the surface of select materials, the materials that were the most representative of the types of surfaces being tested, with potassium iodide, considered a perfect ozone sink.

3.6.1. Ozone Concentration. The ozone concentration was measured at the exhaust (the concentration the material was constantly being exposed to or exhaust concentration, C_e) and from the bypass (the concentration at the inlet to the reactor, C_{in}) with the timing described previously in section 3.2.3. Deposition velocity (v_d), reaction probability (γ) and integrated ozone uptake (IOU) were calculated based on average bypass or inlet concentrations from C_{in} (4-5 h, 17:15-17:30 h, 31:14-31:30 h) and from the average chamber or exhaust concentrations (6-7 h, {16-17 h or 17:30-18:30 h}, 30-31 h), with the resulting values corresponding to 2 h, 24 h and average values for each experiment. Uncertainty for these the calculations was based on error propagation of 2 times the standard deviation of the concentrations measured during those periods, which was always higher than the manufacturers 1 ppb ozone analyzer uncertainty. Figure 3.4. shows an example of dynamic ozone concentration. High values show periods where ozone is sampled from the inlet; low values are sampled from the outlet.

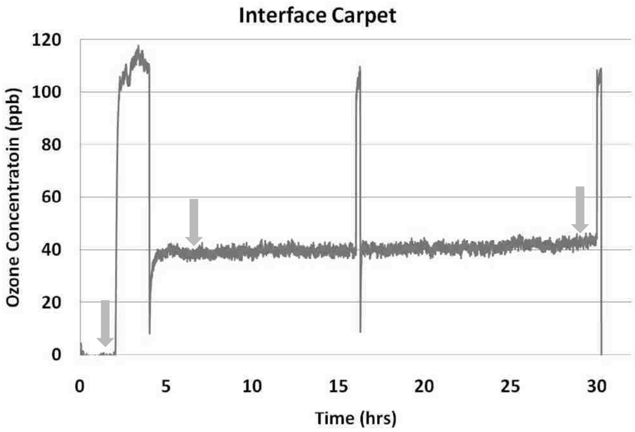


Figure 3.4 Example of dynamic ozone concentration.

3.6.2. Deposition Velocity. The deposition velocity specific to the building materials tested could only be calculated if the deposition velocity for the chamber walls and lid were taken into account. The equation used to find the deposition velocity to the chamber (v_c) is as follows, though in this case v_c and A_c were set to 0, and A was set to the chambers internal surface area,

$$v_d = \frac{Q\frac{T_a}{T_0}\left(\frac{C_{in}}{C_e}-1\right)-v_c A_c}{A} \tag{2}$$

Where Q is the volumetric flow rate (m^3 min^{-1}), A_c is the inner surface area of the chamber not covered by the material (m^2). This equation is the equation that was used to calculate the deposition velocity of all the materials tested. This means that when the material is placed in the chamber a fraction of the inner surface of chamber is still exposed, so when calculating the ozone deposition velocity for the material itself, v_d, the reduction due to the exposed chamber surfaces has to be taken into account. v_c is the deposition velocity of the stainless steel chamber (m h^{-1}), C_{in} (ppb) is the inlet O_3 concentration, C_e (ppb) is the exhaust O_3 concentration, T_a is the ambient temperature (K) within the chamber, T_0 is the calibration temperature (K) for the mass flow controllers and A is the projected area of a sample material (m^2).

3.6.3. Reaction Probability. Calculation of reaction probability, γ, is based on the resistance uptake theory. The deposition velocity is a function of a "transport limited" deposition velocity, v_t, and the reaction probability. Rearranging the equation gives equation 3 (Cano-Ruiz 1998),

$$\gamma = \frac{4}{(v_b)}\left(\frac{1}{v_d} - \frac{1}{v_t}\right)^{-1} \tag{3}$$

The transport-limited deposition velocity was determined utilizing the method described in section 3.5.3. The transport-limited deposition velocity was also calculated using equation 3.

3.6.4. Integrated Ozone Uptake. The integrated ozone uptake (IOU) of materials was calculated using equation 4. In this research the IOU of building materials was defined as the moles of ozone reacted divided by the surface area of the material tested. This calculation provided the quantification of the total molar consumption of ozone by the building materials over the 24 hours of the experimental protocol, by time-integrating the difference between the inlet and outlet concentrations over the course of the building material ozone exposure period. The ozone uptake was normalized by the surface area of the materials tested. The resulting units were moles m^{-2}. The effects of the chamber surfaces on the total IOU was negligible.

$$IOU = \frac{Q}{A}\int_0^t (C_i - C_e)\,dt \tag{4}$$

Where Q is the volumetric flow rate (m^3 min^{-1}), A is the surface area of the material (m^2), C_i is the molar concentration of ozone at the chamber inlet (moles L^{-1}), C_e

is the molar concentration of the ozone at the exhaust, and *t* is the duration of the experiment (min).

3.6.5. Ozone Reaction Product Yield. Reaction product yields are defined as the moles of product generated for every mole consumed by the material surface. Yields were calculated as the molar difference between the ozone exposed emitted byproducts and the pre-ozone exposure byproducts divided by the molar difference between the inlet and chamber ozone concentrations.

$$Yield = \frac{C_O - C_{PES}}{C_{in} - C_e} \tag{5}$$

Where C_O is the concentration of the byproducts with ozone exposure (ppb), C_{PES} is the concentration of the byproducts before ozone exposure (ppb), C_{in} is the concentration of ozone at the inlet (ppb) and C_e is the concentration of ozone at the chamber exhaust (ppb).

3.6.6. Carbonyl Primary and Secondary Emission Rates. Emission rates were determined based on the mass of each carbonyl collected. Analysis of laboratory blanks, inlet and empty chamber exhaust samples indicated that a background level of carbonyl compounds was detectable, at significant levels, relative to both the primary and secondary emission rates of several of the building materials. Inlet air was tested, both with ozone traps and without, and found to be clean. Therefore, the chamber gasket was likely to be a source of the targeted carbonyls, which was emitted at a level unaffected by ozone. To account for background levels, the primary emission rate for species *k*, $e_{k,s}$, was calculated as in equation 6,

$$e_{k,s} = \frac{vV}{A_s}\left(C_{k,e} - C_{k,b}\right) \tag{6}$$

V is the volume of the chamber, v_d is the deposition velocity, and A_s is the material surface area, $C_{k,e}$ is the measured exhaust concentration of species *k* and $C_{k,b}$ is the background concentration of species *k*. This is the emission rates in the presence of ozone, so these emissions would be what individual occupants would be exposed to if they wish to benefit from the ozone reduction capabilities of the building materials.

An assumption, that the chamber was a completely mixed flow reactor (CMFR) and that at the time the samples were taken it had reached stead state, was made to allow for the calculation of the ozone mass transfer rate and the byproduct yield. While the aldehydes are undoubtedly not the only pollutants emitted by the various green building materials, they can be used as surrogates to denote what other pollutants are also likely to exist (Morrison, et al., 2006).

$$ER = \frac{C_O Q}{A} \tag{7}$$

$$Secondary\ Emission\ Rates = ER_t - ER_{PES} \tag{8}$$

3.7. PROTOCOL VARIATIONS

To test the effects of varying conditions caused by both the atmosphere and personal human comfort choices various, conditions were tested. High/Low (35/15 ^{o}C) temperature conditions, high/low (75/25%) relative humidity and high/low (300/50 ppb) ozone concentration conditions were all tested. Except for the condition being modified all other conditions were kept standard, 25 ^{o}C, 50% RH and 150-200 ppb O_3.

3.7.1. Empty Chamber. Protocol variations were performed on the chamber to investigate the effect of temperature, humidity, and ozone concentration on the deposition velocity and IOU of the empty chamber. No aldehyde samples were collected since ozone-initiated emissions were found to be negligible. For the empty chamber protocol variations only the two hour deposition velocity and integrated ozone uptake were quantified.

3.7.2. Interface Carpet. Full 24 hour protocols were performed when testing the carpet samples for the effects of protocol variation. Aldehyde samples were collected as per standard protocol requirements. Six variations on the standard protocol were performed using Interface Carpet. They were high/low temperature (31/14 ^{o}C), high/low relative humidity (75/25 %RH) and high/low ozone (>300/<50 ppb). Each protocol variation utilized a different piece of Interface Carpet.

3.7.3. American Clay Wall Plaster. Repeated short two hour protocols were performed with a single piece of American Clay wall plaster coated drywall. No aldehydes were collected from this sample because of the low yields from standard protocol experiments. Seven variations of the two hour protocol were performed on American Clay. They were high/low temperature (31/14 ^{o}C), high/low relative humidity (75/25 %RH), high/low ozone (>300/<50 ppb) and long term (7 days). The long term experiment was performed before the other six parameter variations, and because of relative stability in the ozone reactivity for that single piece, an additional piece of American Clay was used throughout all further parameter variations.

4. RESULTS

4.1. COMPILED RESULTS

Below are the compiled results for all of the building materials. Figure 4.1 shows the deposition velocities of the materials in the same order as shown in Table 3.1. Side by side are the replicate experiments for each material at standard conditions. Deposition velocities range from 0.17 for FC-2 to 8.23 m h^{-1} for WP-2, which are consistent with the range of values reported for the compilation of materials by Grontoft and Raychaudhuri (2004). The highest values (>2 m h^{-1}) are observed for carpet (FC-1, FC-2), ceiling tiles (CP-1, CP-2, CP-3), clay wall plaster (WCP-1), a clay based paint (WP-2), an acoustical wall tile (WC-2) and an unpainted drywall (WD-1). The lowest values (< 0.5 m h^{-1}) are observed for a sealed porcelain tile (FCf-1), two resilient floor tiles (FRf-1, FRf-3) and finished bamboo flooring (FWf-2). In general, fleecy and porous materials exhibited higher deposition velocities than smooth, sealed surfaces. As expected from previous research carpeting (FC-1 and FC-2) and drywall (WD-1) have high deposition velocities. The clay based paint (WP-2) and the clay wall plaster (WCP-1) also have high deposition velocities. The acoustic wall tile has a high deposition velocity as well, which may stem from its composition being similar to that of carpet. Two of the ceiling tiles (CP-1 and CP-3) also have high deposition velocities, possibly due to their composition and morphology.

Shown in Figure 4.2 are the average reaction probabilities of all of the materials tested. The reaction probabilities follow the same trends as the deposition velocities for the materials. The reaction probabilities range from 8.3×10^{-7} for FRf-2 up to 1.0×10^{-4} for WC-2. These values fall within the ranges estimated by Cano-Ruiz et al. (1993) for materials including Teflon and glass (low) to muslin and brick (high). The results for the latex based paint and the collagen-based paint (WP-1: 2.7×10^{-6} and WP-3: 3.2×10^{-6}, respectively) are very similar to those reported for fresh latex paint (Reiss et al. 1995). As with deposition velocity, fleecy and porous materials exhibit higher reaction probabilities, while smooth nonporous surfaces have lower reaction probabilities. The fabric acoustical panel, WC-2, has the highest reaction probability, and this was over 100 times that of the cork wall tiles and resilient flooring.

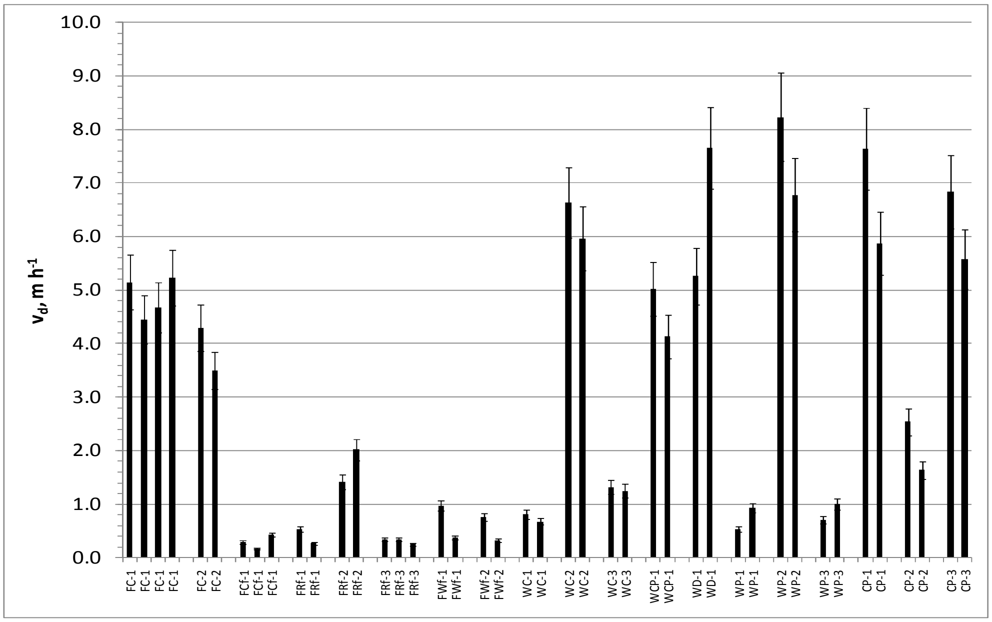


Figure 4.1. Deposition velocities for all materials, including replicates.

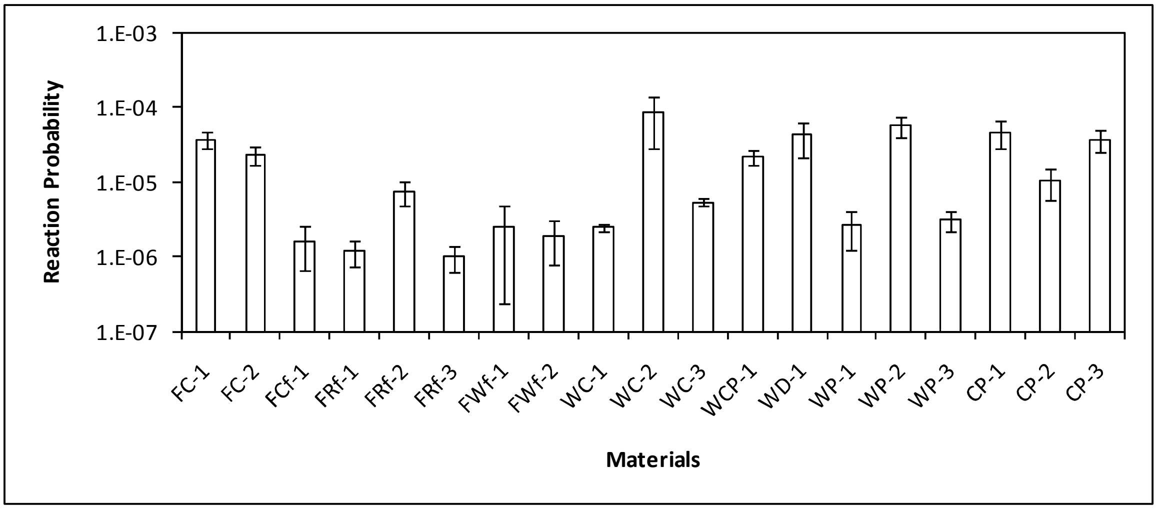


Figure 4.2. Average reaction probabilities for all materials.

Figure 4.3 shows the average integration ozone uptake for the various materials tested. It follows the same general distribution as the deposition velocities.

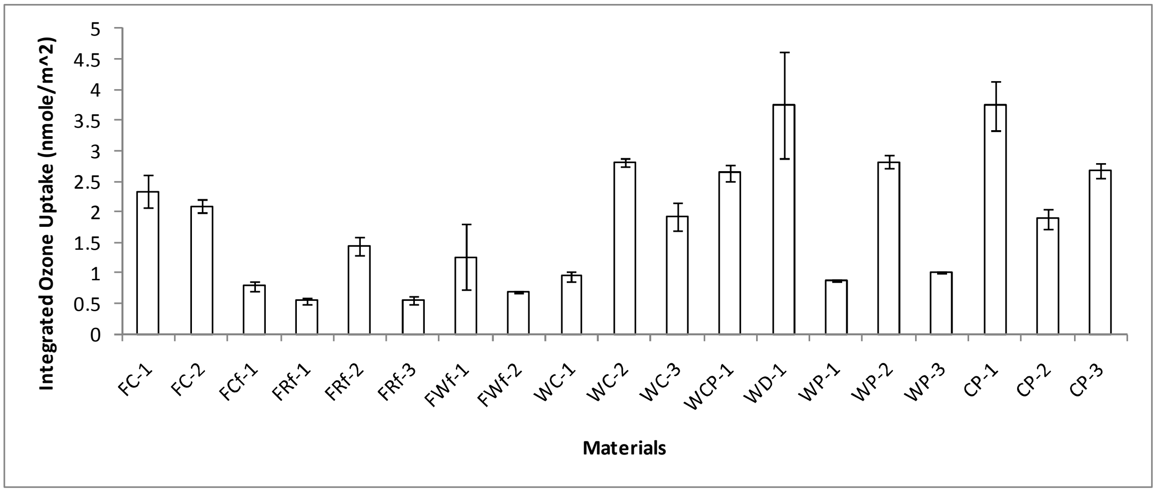


Figure 4.3. Average integrated ozone uptake for all materials.

Figure 4.4 shows the average total yields found for the various materials. The 2 hour yields range from less than the detection limit (CP-1 and WCP-1) to 0.90 for the acoustic wall paneling (WC-2) and up to 1.5 for the 24 hour yields for finished hardwood flooring (FWf-1). Wood flooring (FWf-1) exhibited high yields, possibly due to organic reactants in the finish. In contrast, the bamboo flooring (FWf-2) has a very low yield, indicating a low surface concentration of unsaturated organics. Production of secondary organic aerosols from untreated wood is high, (Toftum, Freund et al. 2008), though all but one of these materials tested previously are untreated board, in the form of bare wood that has not been coated with a finish or paint, the single treated wood was painted.

Table 4.1 shows the compound-specific yields for the nine materials that exhibited high 2 hour yields and Table 4.2 shows yields for the same materials at 24 hours. The carpet FC-1 has yields dominated by C9, which is consistent with previous research (Weschler, Hodgson et al. 1992; Morrison and Nazaroff 2002). Nonanal, C9 is a major contributor but C8 and C10 are also observed in both cases. After 24 hours, C6 is emitted at a high rate. The resilient porcelain flooring, FCf-1, has significant yields of both C1 and acetone in the 2 hour exposure period, with much lower yields after 24 hours of exposure. Similarly FRf-1, a type of renewable flooring tile, has a 2 hour total yield of >0.4 of C9 and C10, but negligible yield after 24 hours of exposure. FRf-3, a renewable flooring tile has significant yields of C9 and C10 in both the 2 hour and 24 hour sample periods, with an addition of C8 after 24 hours of exposure, indicating a more sustainable source of reaction products. In contrast to these materials, the renewable wood flooring, FWf-1, has negligible yields after 2 hours of ozone exposure, but significant yields after 24 hours of C6, C7, C9 and C10. The acoustic fabric wall paneling, WC-2, exhibits significant yields for both 2 hour and 24 hour. For the 2 hour exposure period C1, C8, C9 and acetone are all emitted at relatively high rates, with lower rates for C10. While for the 24 hour exposure period C1, C8, C9 and acetone are all emitted, though at significantly lower rates. WP-2, the clay based paint, has low yields of C6 and C9. CP-3, the fiberglass ceiling tile, exhibits high yields of formaldehyde, C1, during the 2 hour exposure period, and much small yields of C9 and C10. The formaldehyde yield reduces considerably after 24 hours.

Figure 4.5 shows the average total secondary emission rates for the materials. While yield and secondary emission rates are not identical parameters, they are related, and the secondary emission rates follow a trend similar to the average total yields from Figure 4.4. Emissions ranged from negligible (WP-3) to 100 μg m^{-2} h^{-1} (WC-2).

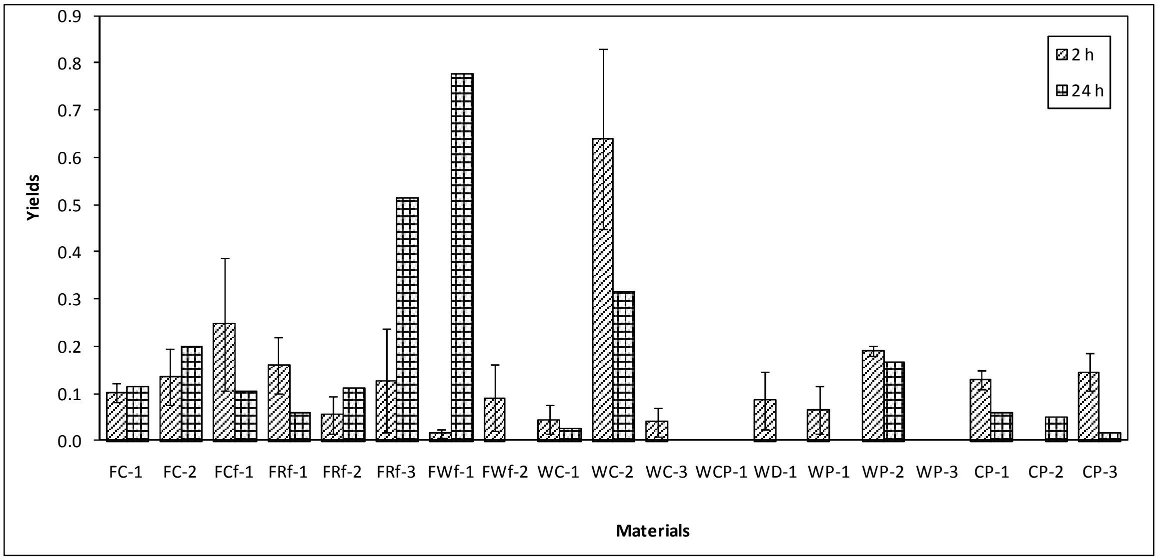


Figure 4.4. Average total yields for all materials.

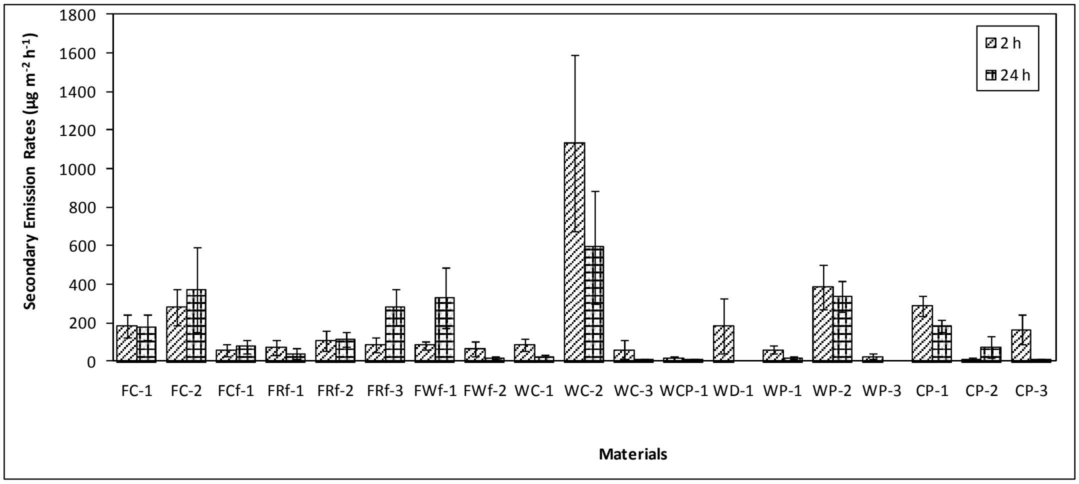


Figure 4.5. The average total secondary emission rates for all materials.

Table 4.1. 2 Hour yields for nine materials.

	C1	C6	C8	C9	C10	Acetone
FC-1	0	0	0	0.137	0	0
FC-2	0	0	0.021	0.101	0.039	0.054
FCf-1	0.385	0	0	0	0	0.160
FRf-1	0	0	0	0.120	0.095	0
FRf-3	0	0	0	0.151	0.226	0
FWf-1	0	0	0	0	0	0
WC-2	0.064	0	0.554	0.154	0.015	0.111
WP-2	0	0.126	0	0.058	0.016	0
CP-3	0.141	0	0	0.040	0.019	0

Table 4.2. 24 Hour yields for nine materials.

	C1	C6	C7	C8	C9	C10	C12	Acetone
FC-1	0	0	0	0	0.120	0	0	0.000
FC-2	0	0.091	0	0.033	0.181	0.074	0.021	0
FCf-1	0.098	0	0	0	0	0	0	0.160
FRf-1	0	0	0	0	0	0	0	0
FRf-3	0	0	0	0.129	0.365	0.278	0	0
FWf-1	0	0.565	0.246	0.122	0.224	0.398	0	0
WC-2	0.035	0.000	0	0.328	0.104	0.000	0	0.055
WP-2	0	0.139	0	0	0.102	0	0	0
CP-3	0.035	0.000	0	0	0	0	0	0

4.2. TRANSPORT LIMITED DEPOSITION VELOCITY

Figure 4.6 shows the calculated results found from the materials when potassium iodide (KI) is applied to the surface of the material to find the transport limited deposition velocity (v_t). The paint exhibits the lowest v_t, while the clay based wall plaster has the highest. It is surprising that the rubber tile has a low v_t, based on the presumed reactivity and surface roughness. Corkboard has a high v_t in the same range as the clay based wall plaster, while the porcelain clay tile, which is not much rougher in surface texture than the paint, has a v_t twice that of the paint. Carpet has a relatively high v_t.

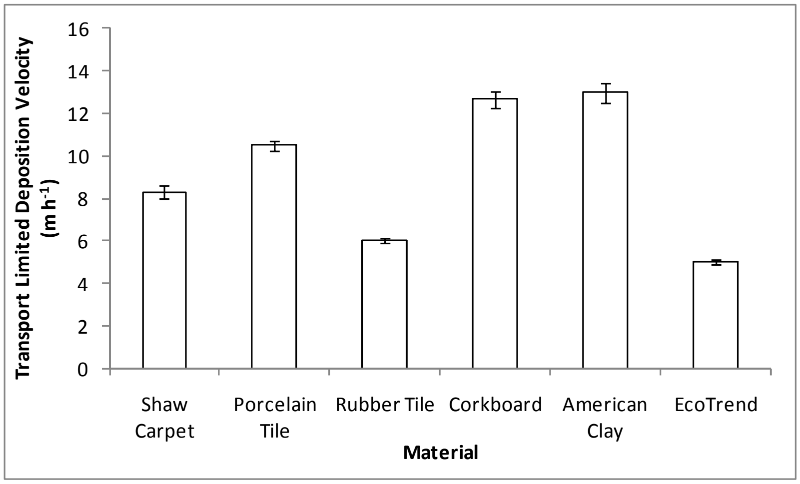


Figure 4.6. Transport limited deposition velocities.

4.3. MATERIAL SPECIFIC RESULTS

The following section has the results by material. Replicates are reported for each calculation as *result 1, result 2, ± typical uncertainty* for each individual experiment. The figures after each set of reported replicate values show the average primary and secondary emissions and the yields for each material. Yields and secondary emissions are calculated by subtracting the primary emissions. Both the yields and the secondary emission rates can produce negative results for individual compounds. This negative result is due in part to the inherent "noise" from the emission rates of the various compounds and in part due to the reduction of primary emission rates over time for the compounds as they are off-gassed by the material.

For the deposition velocity, reaction probability and integrated ozone uptake the uncertainties are shown directly as the greatest uncertainty for each material for each type of calculation. Uncertainties are not shown on the emission figures due to the difficulty in clearly displaying the uncertainties on stacked bar charts. Please refer to Appendix B for the individual experiment level information regarding results and uncertainties.

4.3.1. Blank Chamber.

Number of replicates:	3
Average Deposition Velocity:	0.05, 0.08, 0.06 ± 0.01 m h^{-1}
Integrated Ozone Uptake:	3.3, 4.1, 3.7 $\times 10^{-9} \pm 0.3 \times 10^{-9}$ moles cm^{-2}

While the building materials tested in the 10 liter chamber are likely to dominate the ozone reactivity, the stainless steel walls of the chamber can affect the observed reduction of ozone and the emission of byproducts. To that end the ozone reactivity and byproduct formation rate of the blank chamber were measured. Only deposition velocity and integrated ozone uptake were measured. While three replicates were performed using only an empty chamber, byproduct samples have only been collected for two of the experiments under the assumption that there would be negligible yield from the cleaned and ozone treated steel chamber. Byproducts results are heavily dependent on the extent to which the chamber was cleaned prior to use. If a large amount of methanol (500 mL) was used to rinse the chamber, followed by high levels (>1 ppm) of ozone treatment, the byproduct emission rates are lower, compared with using less methanol. There is no direct relationship between the ozone concentration and the emission rates. Another possible source of chamber emissions is the sealing gasket, between the chamber and the lid, which may absorb and off-gas byproducts over the course of previous experiments and then emit the absorbed aldehydes during the primary emission phase. Figure 4.7 has the yield and emission rate results of the blank chamber.

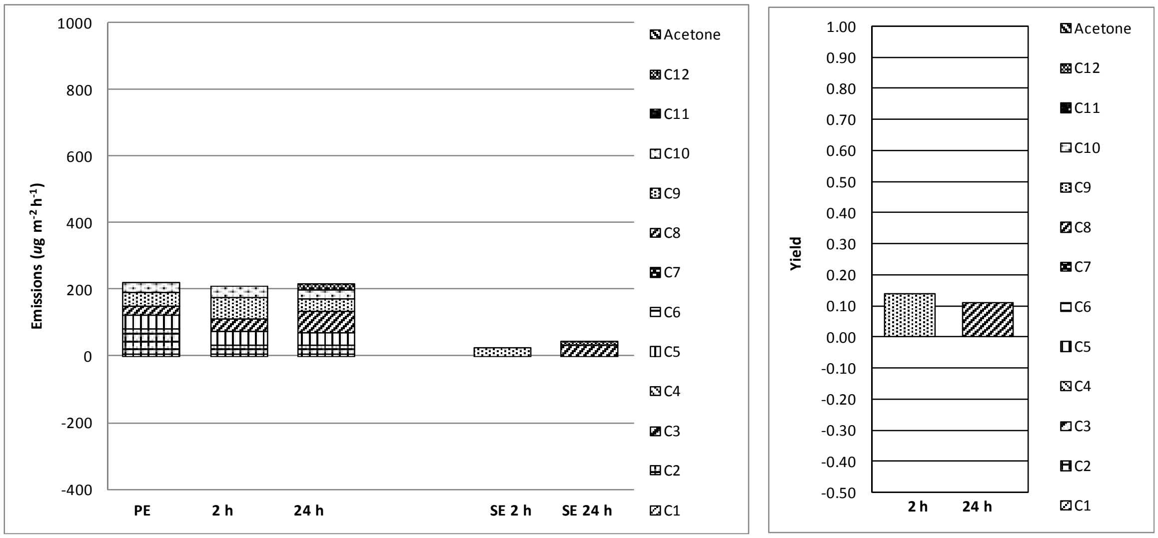


Figure 4.7. Yields and emission rates for blank chamber experiments.

4.3.2. Interface Carpet.

Number of replicates: 4
Average Deposition Velocity: 4.5, 4.7, 5.2, 5.2 ± 0.4 m h^{-1}
Integrated Ozone Uptake: 25, 15, 25, $\times 10^{-9} \pm 3\times 10^{-9}$ moles cm^{-2}
Average Reaction Probability: 42, 30, 33, 43 $\times 10^{-6} \pm 14\times 10^{-6}$

The green carpeting material, FC-1, exhibits consistent and high ozone deposition velocities, reaction probabilities, integrated ozone uptake and yields. The yields from this material have a net positive value, which is most evident for C9, as would be expected, for carpet (Morrison and Nazaroff 2002). The deposition values calculated for FC-1 are in the mid-range relative to those measured in small chambers (1.4 – 6.1 m h^{-1}; (Morrison and Nazaroff 2000)) a FLEC device (1.2 m h^{-1}; Kleno, 2001) and field studies (1.4 – 12.8 m h^{-1}); (Wang and Morrison 2006)(Wang 2010). Over the course of the experiments the deposition velocity decreases by more than 30 percent, which is consistent with aging phenomena observed (Morrison et al. 2000). Figure 4.8 shows the yield results for carpet with C_9 dominating the emissions and the yield values, consistent with previous research (Morrison and Nazaroff 2002).

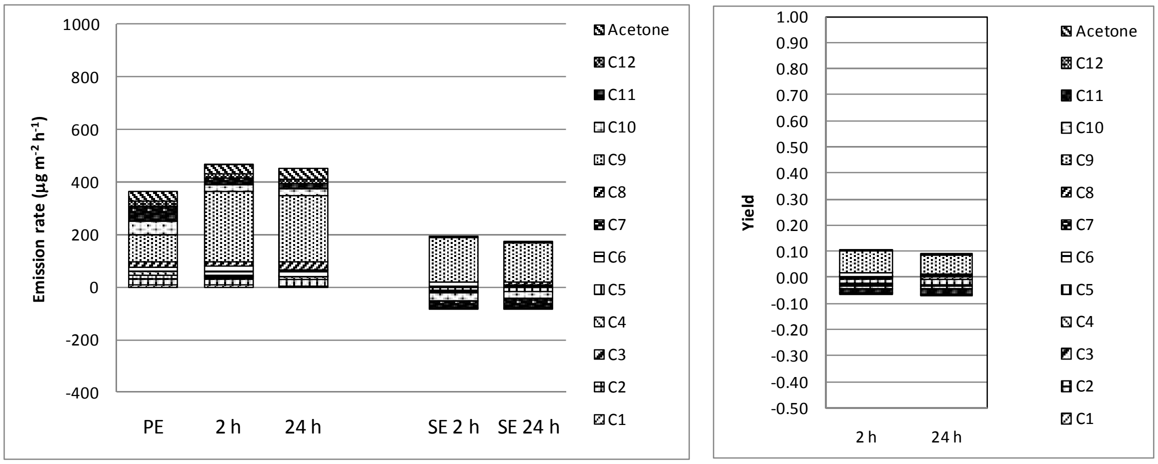


Figure 4.8. Yield and emission rate results for FC-1.

4.3.3. Shaw Carpet.

Number of replicates: 2
Average Deposition Velocity: 4.3, 3.5 ± 0.3 m h^{-1}
Integrated Ozone Uptake: 19, 22 $\times 10^{-9} \pm 1 \times 10^{-9}$ moles cm^{-2}
Average Reaction Probability: 27, 19 $\times 10^{-6} \pm 5 \times 10^{-6}$

The fabric backed carpeting, FC-2, has, as expected for carpeting (Morrison and Nazroff 2002), high ozone deposition velocities, reactions probabilities, integrated ozone uptake and yields. Figure 4.9 shows the compiled average yield and emission rate results. C2 has a significant negative yield, due to its significant primary emission rate. With that major exception the yields are mostly positive. When the plastic packaging containing the rolled carpet was initially opened a strong odor was observed from the material, which was less noticeable over time. This off-gassing effect should not be discounted in the effects on the yields. Research would have to be performed to find the length of time needed to allow the initial ozone independent off-gassing to become negligible. Over the course of the experiment the deposition velocity decreases by more than 35 percent, which is expected from experiments performed with carpets (Morrison et al. 2000).

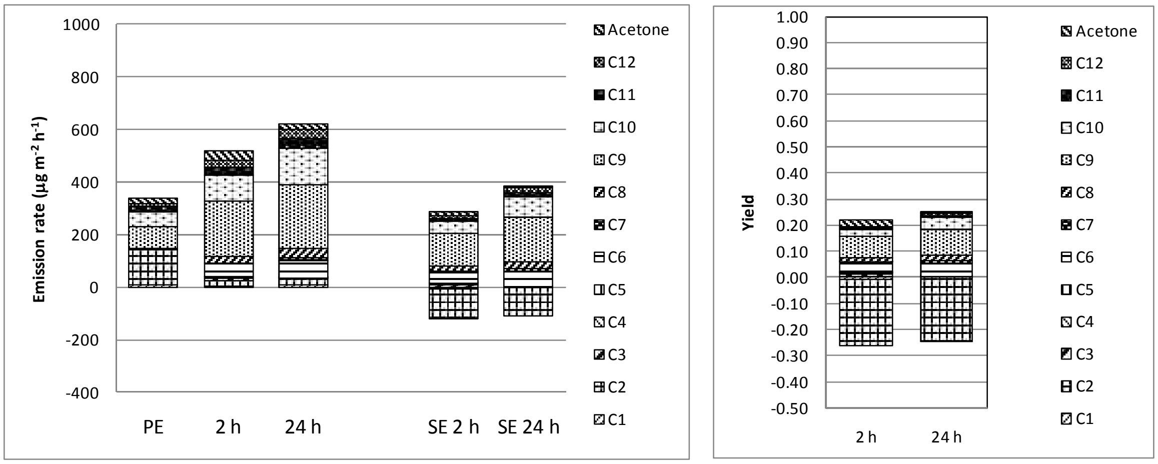


Figure 4.9. Yield and emission rate results for FC-2.

4.3.4. Forbo Resilient Floor Tile.

Number of replicates:	2
Average Deposition Velocity:	0.44, 0.27 ± 0.06 m h^{-1}
Integrated Ozone Uptake:	6.15, 4.78 $\times 10^{-9} \pm 0.48 \times 10^{-9}$ moles cm^{-2}
Average Reaction Probability:	1.50, 0.88 $\times 10^{-6} \pm 0.40 \times 10^{-6}$

The linoleum-style resilient flooring, FRf-1, exhibits low deposition velocities, integrated ozone uptake and reaction probabilities. Figure 4.10 shows the average yield and emission rate results for FRf-1. The 2 hour yield has a net positive value while the 24 hour yield has a significant and completely negative yield. Typical linoleum style flooring frequently includes "drying oils" that retain ozone-reactive double-bonds post-manufacture, which frequently leads to secondary emissions (Poppendieck et al. 2007). FRf-1 did not generate measurable amounts of secondary aldehydes after 24 hours of exposure, indicating that reactive compounds deplete prior to the 24 hour point. The deposition velocity decreases by 80 percent, which is consistent with the aging phenomena observed for several materials (Sabersky et al. 1973; Reiss et al. 1994)

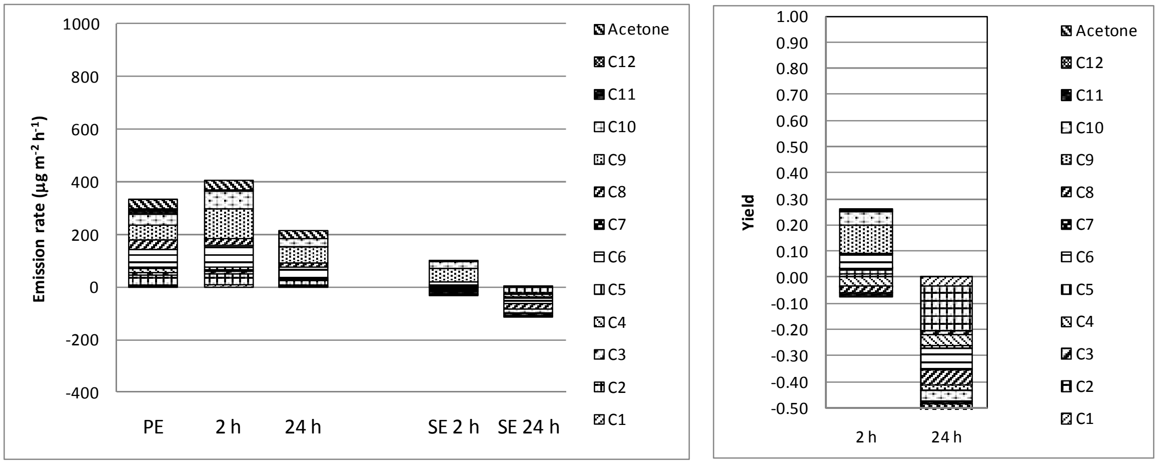


Figure 4.10. Yield and emission rate results for FRf-1.

4.3.5. Rubber Products Tile.

Number of replicates:	2
Average Deposition Velocity:	1.42, 2.02 ± 0.21 m h^{-1}
Integrated Ozone Uptake:	12.5, 16.4 $\times 10^{-9} \pm 0.8 \times 10^{-9}$ moles cm^{-2}
Average Reaction Probability:	5.70, 9.33 $\times 10^{-6} \pm 1.28 \times 10^{-6}$

The resilient flooring composed of rubber tile with puzzle-locking edging, FRf-2, has relatively moderate deposition velocities, integrated ozone uptake and reaction probabilities. Relatively high emission rates are consistently seen throughout testing, including primary emissions, which have an impact on the certainty in secondary emission rates and yields. From Figure 4.11 the yields are in the majority positive with C9 having a high 24 hour yield. A distinct rubber odor is detected before and after testing, which may testify to the high primary emissions inherent in the material.

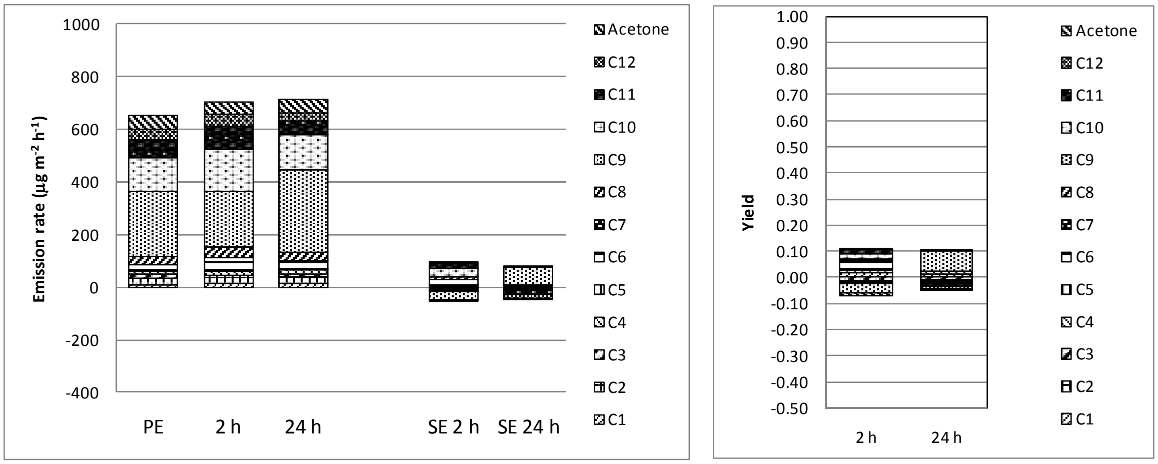


Figure 4.11. Yield and emission rate results for FRf-2.

4.3.6. Armstrong Floor Tile.

Number of replicates: 3
Average Deposition Velocity: 0.34, 0.34, 0.25 ± 0.03 m h^{-1}
Integrated Ozone Uptake: 5.84, 6.78, 3.99 $\times 10^{-9} \pm 0.25 \times 10^{-9}$ moles cm^{-2}
Average Reaction Probability: 1.11, 1.13, 0.83 $\times 10^{-6} \pm 0.39 \times 10^{-6}$

The bio-based resilient floor tiling, FRf-3, has low ozone reactivity, with relatively low deposition velocities, integrated ozone uptake and reaction probabilities. This is balanced with the low emission rates of the material, from Figure 4.12, when compared against other tested materials. Significantly, the 24 hour yields are large, with significant positive and negative yields. With the 24 emission rates being dominate over both the primary and the 2 hour emission rates. The primary contributors to the high negative yields are C3 and C5 aldehydes, with high primary emissions, and negligible secondary emissions for both 2 hour and 24 hour. This may be due to the material still off gassing from production. The positive yields are dominated by C8-C12 aldehydes, which may indicate reactions with the composition of the tiles, perhaps the fatty acids included in the bio-based composition.

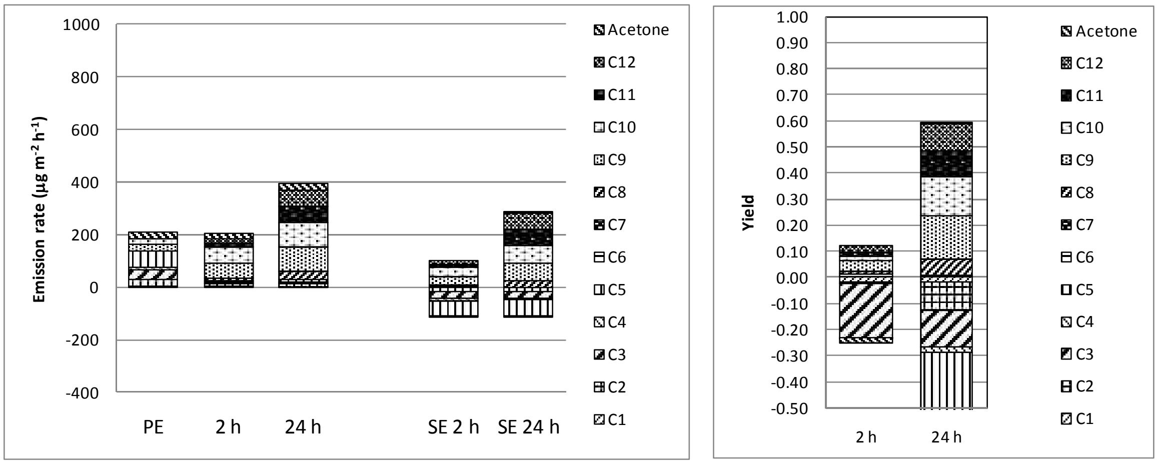


Figure 4.12. Yield and emission rate results for FRf-3.

4.3.7. American Olean Porcelain Tile.

Number of replicates:	3
Average Deposition Velocity:	0.29, 0.17, 0.43 ± 0.07 m h^{-1}
Integrated Ozone Uptake:	7.56, 6.39, 9.65 $\times 10^{-9} \pm 0.83 \times 10^{-9}$ moles cm^{-2}
Average Reaction Probability:	1.11, 1.13, 0.83 $\times 10^{-6} \pm 0.39 \times 10^{-6}$

The porcelain floor tile, FCf-1, has consistently low ozone deposition velocities, integrated ozone uptake and reaction probabilities. The yields are low enough that they are negligible or negative, as can be seen from Figure 4.13. The primary emissions are higher than both the 2 hour and 24 hour secondary emissions, with only acetone having significant secondary emissions. The tiles come from the manufacturer with small amounts of glue adhered to the exposed outer surface. This was scraped off prior to testing, but residual may account for the high primary emissions and the consistently high 2 hour and 24 hour emissions. The tile is also glazed at production, which is the most likely reason for the low ozone reactivity. The deposition velocity decreased, with the maximum being 80 percent during the course of an experiment. This is consistent with the aging phenomena seen with a variety of building materials (Sabersky et al 1973; Reiss et al. 1994).

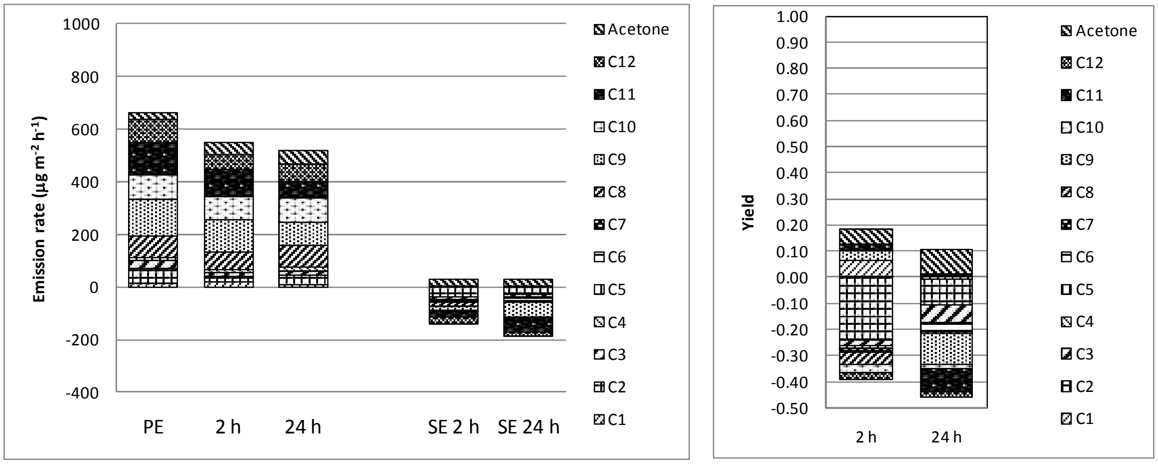


Figure 4.13. Yield and emission rate results for FCf-1.

4.3.8. Ecotimbers Wood Flooring.

Number of replicates:	2
Average Deposition Velocity:	0.97, 0.38 ± 0.21 m h^{-1}
Integrated Ozone Uptake:	20.1, 5.1 $\times 10^{-9} \pm 5.3 \times 10^{-9}$ moles cm^{-2}
Average Reaction Probability:	3.70, 1.26 $\times 10^{-6} \pm 2.24 \times 10^{-6}$

The renewable wood flooring, FWf-1, has moderate ozone reactions, though with poor reproducibility between the replicates. The yields are moderate for the 2 hour sample, while for the 24 hour sample are significantly high with only C3 being of much abundance in the negative yield as can be seen in Figure 4.14. In the 24 hour yield of particular abundance are the C6, C7, C9 and C10 aldehydes. Wood based flooring material, with polymer-based finishes, are expected to have both high yields and high ozone reactivity. While the yields are consistent for 24 hours, the ozone reactivity is not. The dominant yields of C6 and C10 aldehydes, which are commonly found in human skin oils, suggest human contact. The aldehydes may also be from the wood oils present in the product or from machine oils during manufacture. Standard protocol has fresh pairs of latex gloves to be used at all stages in the wood handling process; the oils may have come from handling during manufacture or shipping.

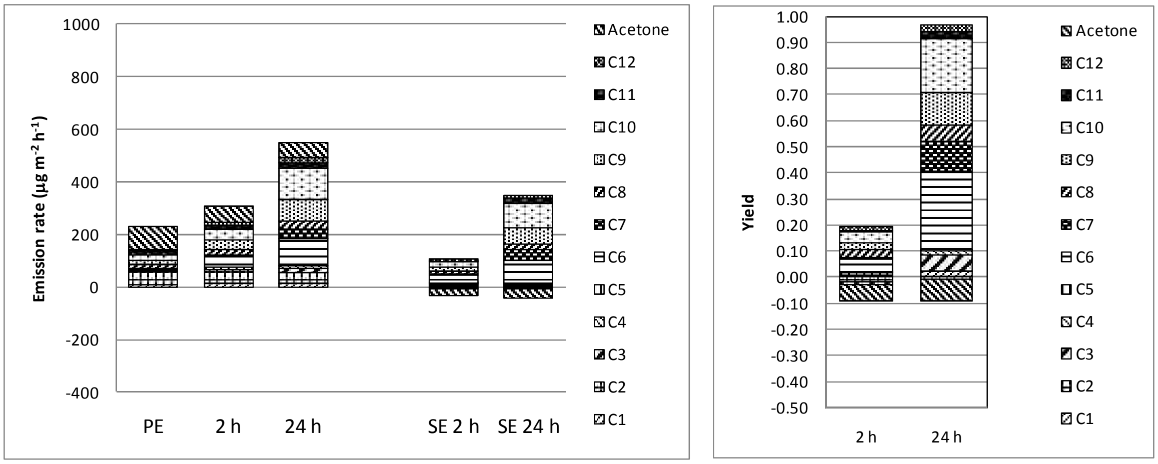


Figure 4.14. Yield and emission rate results for FWf-1.

4.3.9. Smith And Fong Plyboo Flooring.

Number of replicates: 2
Average Deposition Velocity: 0.33, 0.76 ± 0.15 m h^{-1}
Integrated Ozone Uptake: 7.05, 6.84 $\times 10^{-9} \pm 0.09 \times 10^{-9}$ moles cm^{-2}
Average Reaction Probability: 2.8, 1.1 $\times 10^{-6} \pm 0.6 \times 10^{-6}$

The finished bamboo flooring, FWf-2, has low ozone reactivity, with exhibited low deposition velocities, reaction probabilities and yields. Looking at Figure 4.15 the total secondary emissions can be seen as negative for the flooring, indicating the that reduction in primary emission rates dominates and increase in secondary emissions from the formation of the carbonyls in the presence of ozone. The positive yields are nearly indistinguishable from zero as to be considered negligible. Smooth-finished wood flooring, is expected to have a low reactivity with ozone. There is an observed decrease in the deposition velocity of 60 percent during the course of the experiment. This is consistent with the aging phenomena observed for a variety of materials (Sabersky et al. 1973; Reiss 1994).

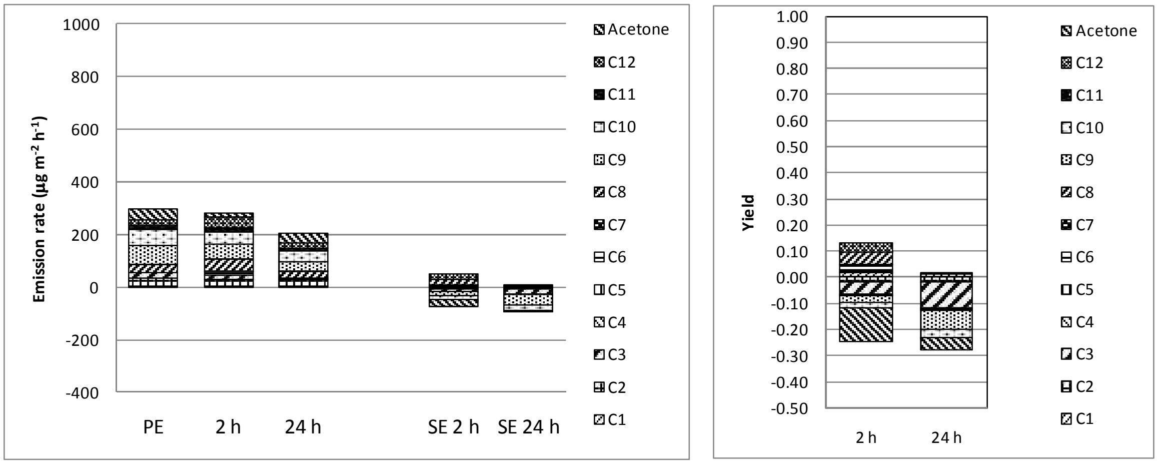


Figure 4.15. Yield and emission rate results for FWf-2.

4.3.10. Cork Wall Board.

Number of replicates:	2
Average Deposition Velocity:	0.81, 0.68 ± 0.05 m h^{-1}
Integrated Ozone Uptake:	10.7, 8.3 $\times 10^{-9} \pm 0.8 \times 10^{-9}$ moles cm^{-2}
Average Reaction Probability:	2.7, 2.2 $\times 10^{-6} \pm 0.2 \times 10^{-6}$

A cork wall tile, WC-1, has relatively low ozone reactivity, with low deposition velocities and very low reaction probabilities. Figure 4.16 shows the 2 hour yields of C8-C12 aldehydes are positive, while 24 hour yields are so close to zero as to be considered negligible. The primary emissions are relatively low for the cork wall tile, suggesting that the 2 hour secondary emissions reflect true results for the examined compounds. Due to the nature of the cork composition and adhesive used to place the cork on drywall, the yields are much lower than what would be expected.

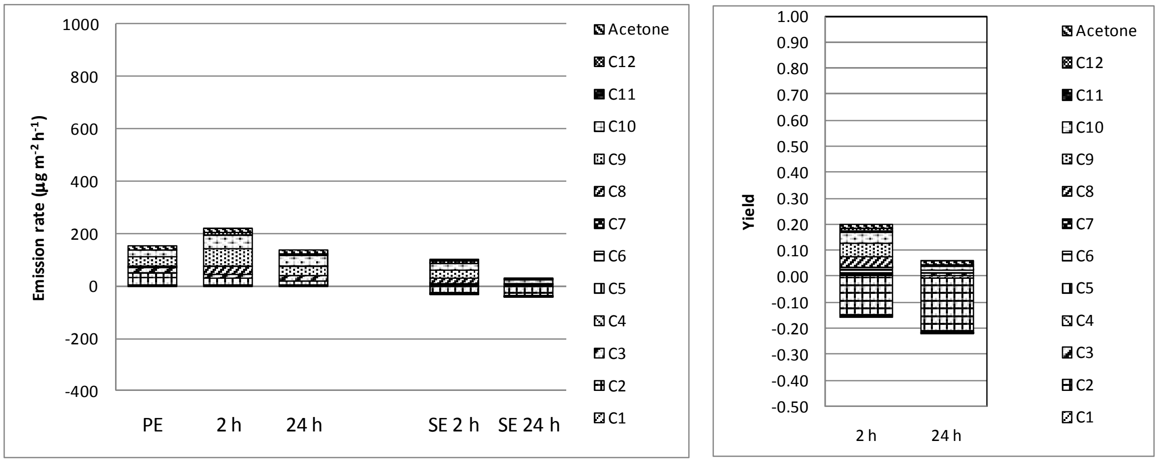


Figure 4.16. Yield and emission rate results for WC-1.

4.3.11. Acoustic Wall Paneling.

Number of replicates:	2
Average Deposition Velocity:	6.6, 6.0 ± 0.24 m h^{-1}
Integrated Ozone Uptake:	29, 27 $\times 10^{-9} \pm 2 \times 10^{-9}$ moles cm^{-2}
Average Reaction Probability:	101, 65 $\times 10^{-6} \pm 55 \times 10^{-6}$

The pre-formed acoustical wall panels, WC-2, exhibit very high ozone reactivity, in the form of deposition velocities, integrated ozone uptake and average reaction probabilities along with very high primary and secondary emission rates. As a fleecy textile product, WC-2 also exhibits a very high deposition velocity. The emissions and 2 hour yields are higher than any other tested material as can be seen in Figure 4.17. The 2 hour yields are dominated with C8, C9 and acetone. The 24 hour yields are not as high as the 2 hour yields, but evident. The acoustic wall panel is a textile and so as to be expected C9 is produced in large quantities.

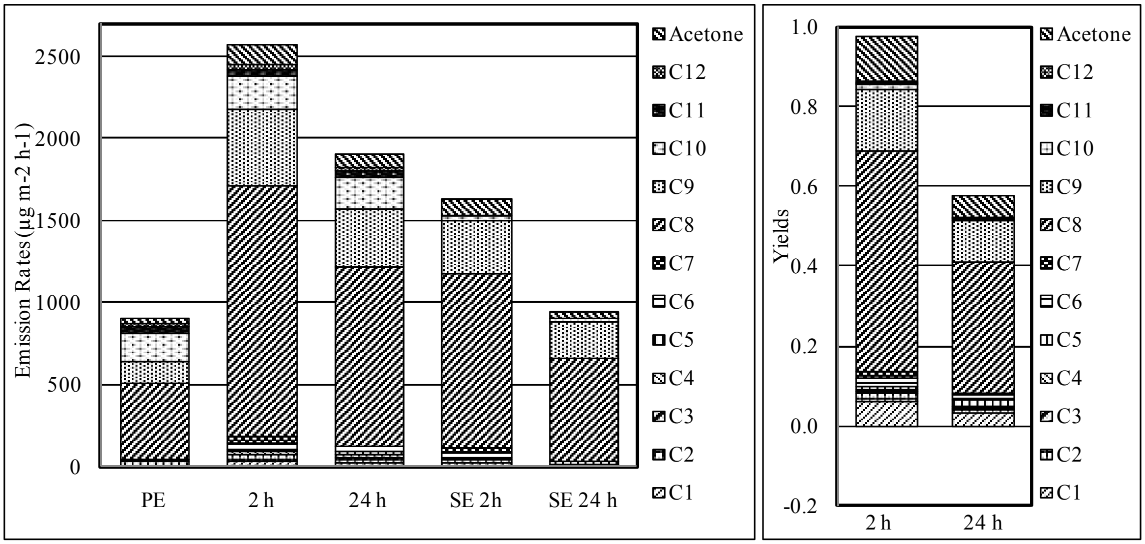


Figure 4.17. Yield and emission rate results for WC-2.

4.3.12. Xorel Rayon Wall Covering.

Number of replicates: 2
Average Deposition Velocity: 1.32, 1.25 ± 0.05 m h^{-1}
Integrated Ozone Uptake: 22, 16 $\times 10^{-9} \pm 2 \times 10^{-9}$ moles cm^{-2}
Average Reaction Probability: 5.5, 5.1 $\times 10^{-6} \pm 0.6 \times 10^{-6}$

The fabric wall covering, WC-3, has moderate deposition velocities, with low reaction probabilities. The yields and secondary emissions are close to zero, to the point of being negligible. The emission rates remain relatively constant during the experiment, indicating very little emissions due to ozone reactions. The wall covering may be designated as a fabric, which would lead one to assume high reactivity and emissions, though in this case the material seems to be coated with a glossy substance that may be inhibiting the reactivity between the ozone and the composition of the fibers. A decrease in the deposition velocity is observed during the course of the experiment of 30 percent, which is consistent with the aging phenomena observed for materials (Sabersky et al. 1973; Reiss 1994). Seen in Figure 4.18, the yields and secondary emissions are relatively low, indicating that ozone reactions will not cause a significant degradation of air quality from these secondary emissions.

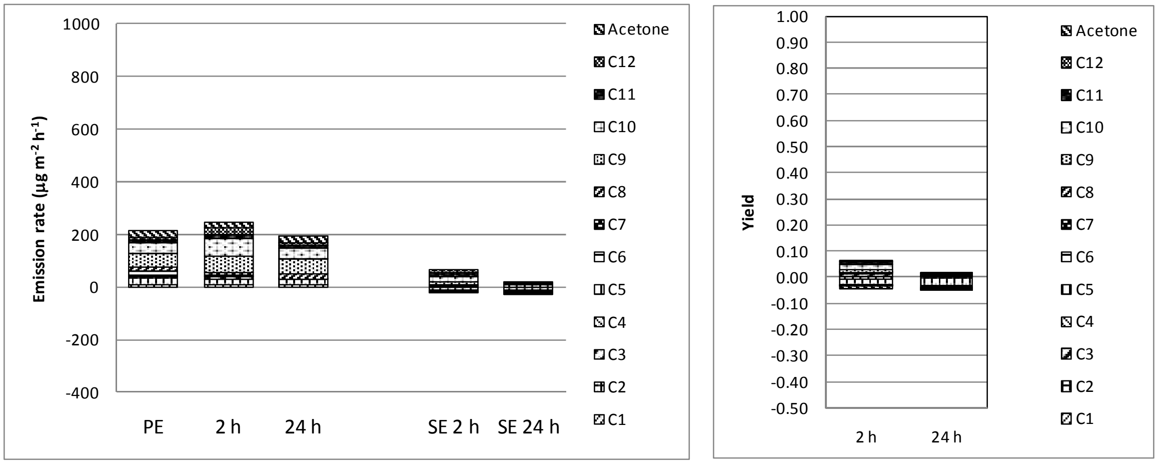


Figure 4.18. Yield and emission rate results for WC-3.

4.3.13. Ecospec Latex Paint.

Number of replicates: 2
Average Deposition Velocity: 0.54, 0.93 ± 0.14 m h^{-1}
Integrated Ozone Uptake: 8.9, 8.5 $\times 10^{-9} \pm 0.8 \times 10^{-9}$ moles cm^{-2}
Average Reaction Probability: 1.9, 3.5 $\times 10^{-6} \pm 1.5 \times 10^{-6}$

The latex based paint and primer, WP-1, has low ozone deposition velocities and modest to low yields. The reaction probability is similar to that reported for relatively fresh latex paint (Reiss et al. 1995). Though still very low, the difference in the primary and secondary emission rates did produce measurable yields as seen in Figure 4.19. The C2 yield is significant in its size and consistency for both 2 hour and 24 hour yields. This indicates that little to no C2 is emitted after ozone exposure occurred. Either the material has finished off-gassing by that point or the presence of ozone inhibits the production of C2. Yields as a whole are relatively small, with the 2 hour positive yield being reflected by the negative yield and the 24 hour yields being dominated by the negative yield. The low relative primary emission rates are consistent with dried paint material that has had a chance to air out (Reiss 1994); (Kleno 2001); (Hoang 2009).

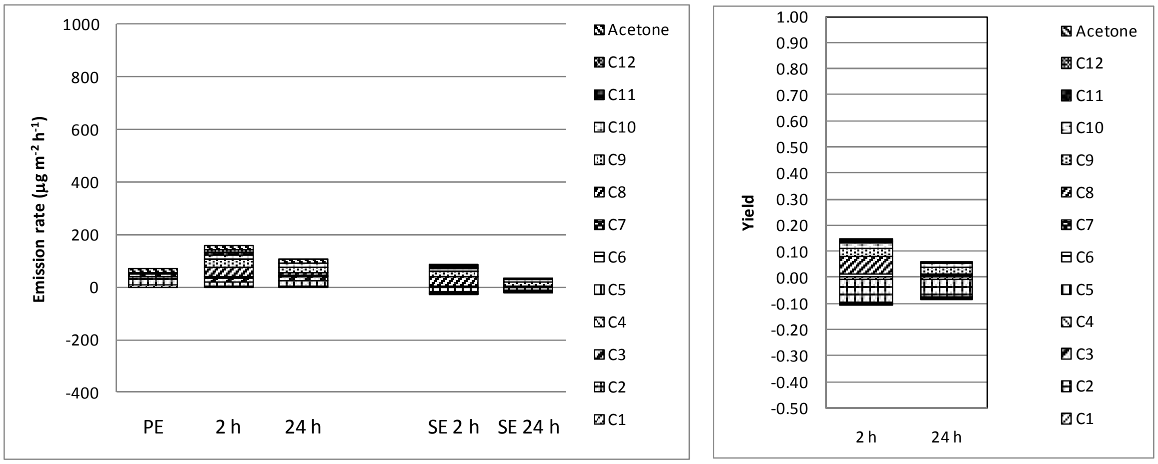


Figure 4.19. Yield and emission rate results for WP-1.

4.3.14. Bioshield Paint.

Number of replicates: 2
Average Deposition Velocity: 8.2, 6.8 ± 0.5 m h^{-1}
Integrated Ozone Uptake: 27, 30 $\times 10^{-9} \pm 3 \times 10^{-9}$ moles cm^{-2}
Average Reaction Probability: 69, 44 $\times 10^{-6} \pm 5 \times 10^{-6}$

The clay based paint, WP-2, has very high ozone reactivity in the form of deposition velocities, reaction probabilities and ozone uptake. The yields are moderate, as seen in Figure 4.20, with the material being dominated by C6 and C9 for the 2 hour yield and C9 for the 24 hour yield. Both the paint binding agent and the composition of the clay could both lead to the high reactivity of the paint and the yields. The high deposition velocity of WP-2 may be due to its iron- or aluminum-catalyzed decomposition of ozone (Usher et al. 2003).

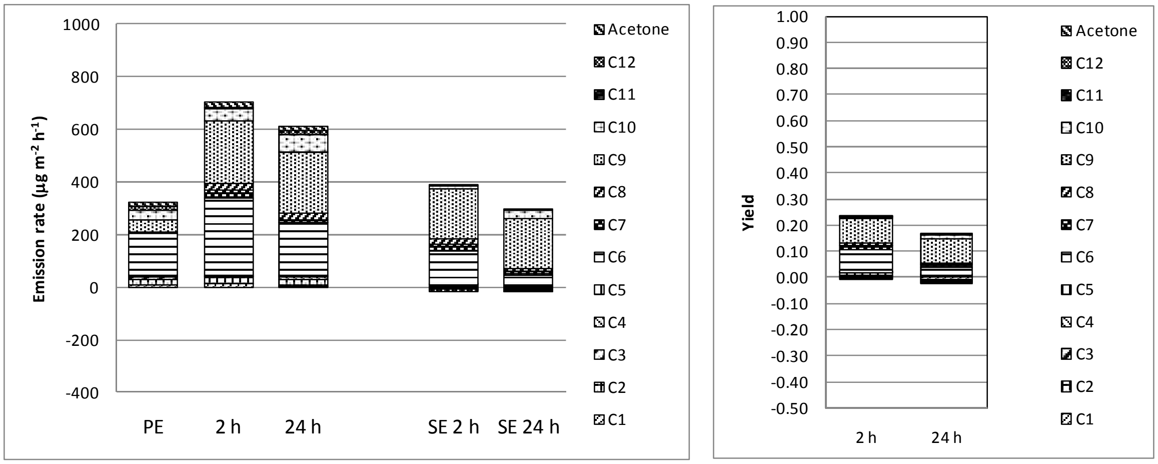


Figure 4.20. Yield and emission rate results for WP-2.

4.3.15. Ecotrend Callogen Paint.

Number of replicates: 2
Average Deposition Velocity: $0.7, 1.0 \pm 0.1$ m h^{-1}
Integrated Ozone Uptake: $10, 10 \times 10^{-9} \pm 1 \times 10^{-9}$ moles cm^{-2}
Average Reaction Probability: $2.5, 3.8 \times 10^{-6} \pm 0.6 \times 10^{-6}$

The collagen based paint, WP-3, has low deposition velocities and reaction probabilities, with moderate ozone uptake. The reaction probabilities are consistent with those values found for fresh latex paint (Reiss et al. 1995). The 2 hour and 24 hour yields, from Figure 4.21, are dominated by negative yields, with C2 being the most dominant compound. Since collagen is a mixture of proteins composed of amino acids, this suggests that the materials composition is not amenable to ozone reactions. WP-3 did exhibit a decrease in the ozone deposition velocity over the course of the experiment of 40 percent. This decrease is consistent with the observed aging phenomena for a variety of materials (Sabersky et al. 1973; Reiss 1994).

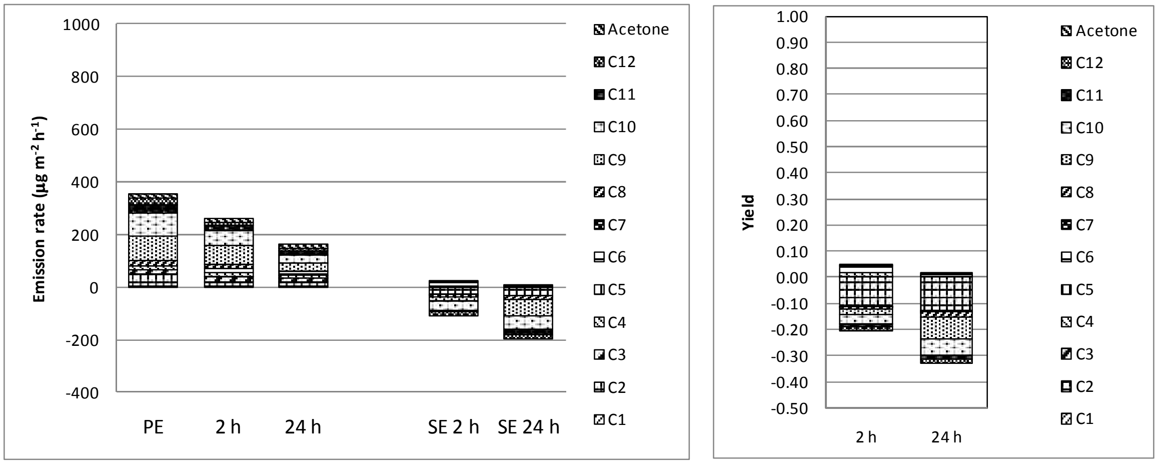


Figure 4.21. Yield and emission rate results for WP-3.

4.3.16. American Clay Wall Plaster.

Number of replicates: 2
Average Deposition Velocity: 5.0, 4.1 ± 0.3 m h^{-1}
Integrated Ozone Uptake: 28, 24 $\times 10^{-9} \pm 2 \times 10^{-9}$ moles cm^{-2}
Average Reaction Probability: 25, 19 $\times 10^{-6} \pm 5 \times 10^{-6}$

The clay based plaster, WCP-1, exhibits very high relative ozone reactivity, in the form of deposition velocities, ozone uptake and reaction probabilities. From Figure 4.22 WCP-1 has yields and secondary emissions so low as to be considered negligible. The emission rates and yields indicate there is little chemical reactivity that creates byproducts due to ozone within the elements of the clay plaster. A possible explanation for the high deposition velocities could be due to the iron- or aluminum-catalyzed decomposition of ozone (Usher et al. 2003).

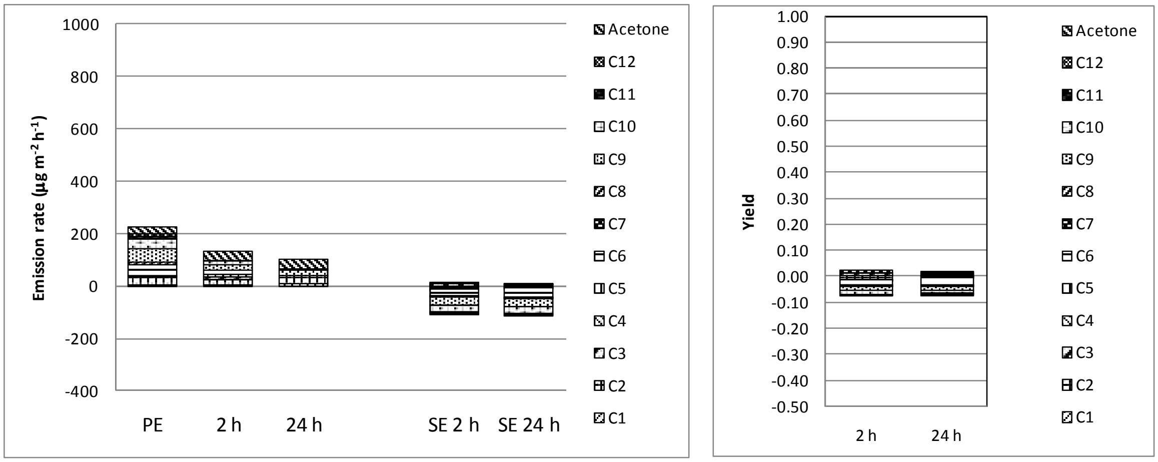


Figure 4.22. Yield and emission rate results for WCP-1.

4.3.17. USG Drywall.

Number of replicates: 2
Average Deposition Velocity: 5.3, 7.7 ± 0.8 m h^{-1}
Integrated Ozone Uptake: 50, 25 $\times 10^{-9} \pm 9 \times 10^{-9}$ moles cm^{-2}
Average Reaction Probability: 27, 58 $\times 10^{-6} \pm 22 \times 10^{-6}$

The drywall, WD-1, has high ozone reactivity, in the form of deposition velocity, integrated ozone uptakes, and reaction probabilities, which is expected from previous drywall research (Kunkel, Corsi et al. 2008). The range of drywall values is similar to that observed in a FLEC cell (4.3 – 5 m h^{-1}) (Clausen et al. 2001); (Grøntoft and Raychaudhuri 2004). Somewhat lower values are observed in a similar small chamber experiment (2.5 m h^{-1})(Nicolas et al., 2007) and in large laboratory chambers by (1.5-3 m h^{-1})(Kunkel et al. 2009). Some compounds exhibit positive 2 hour yields, but 24 hour yields are mostly negative, as seen in Figure 4.23, with what positive yield there is being so low as to be considered negligible. Primary emission rates are much higher than is expected from previous research (Wang 2010), possibly due to contamination from manufacture, shipping, storage or preparation.

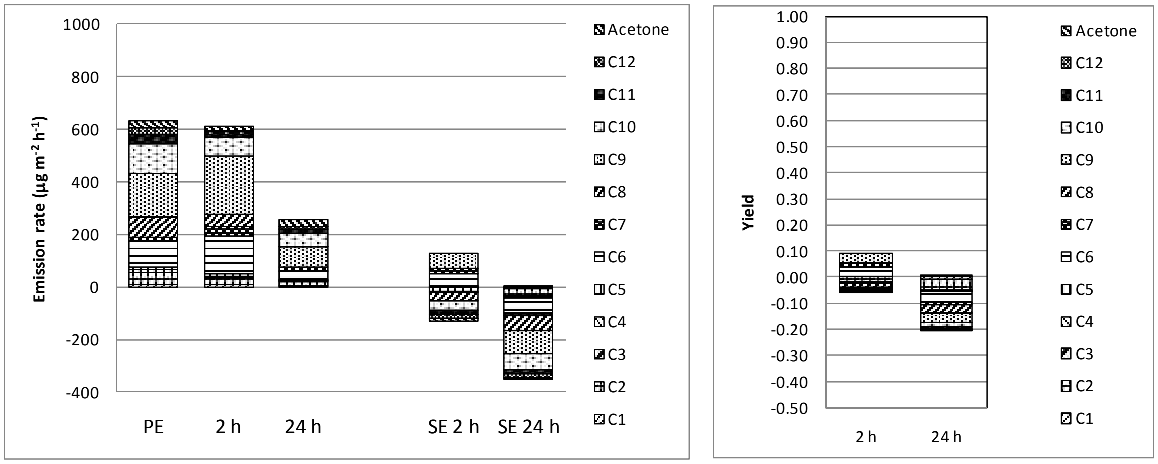


Figure 4.23. Yield and emission rate results for WD-1.

4.3.18. Armstrong Ceiling Tile.

Number of replicates:	2
Average Deposition Velocity:	7.63, 5.87 ± 0.62 m h^{-1}
Integrated Ozone Uptake:	31.8, 43.0 $\times 10^{-9} \pm 4.0 \times 10^{-9}$ moles cm^{-2}
Average Reaction Probability:	59.2, 33.8 $\times 10^{-6} \pm 11.5 \times 10^{-6}$

The ceiling tile, CP-1, exhibits high ozone reactivity in the form of deposition velocity, ozone uptake and reaction probability. This may possibly be due to the porous nature of the coating allowing the ozone to interact with mineral fiber underneath, which composes the bulk of the tile. Secondary emissions and yields are positive for both 2 hour and 24 hour sampling periods, but are very low, and no specific compound dominated (on a molar basis), visible in Figure 4.24. A decrease of 20 percent for the ozone deposition velocity is observed, which is consistent with the aging phenomena observed for a variety of materials (Sabersky et al. 1973); (Reiss 1994).

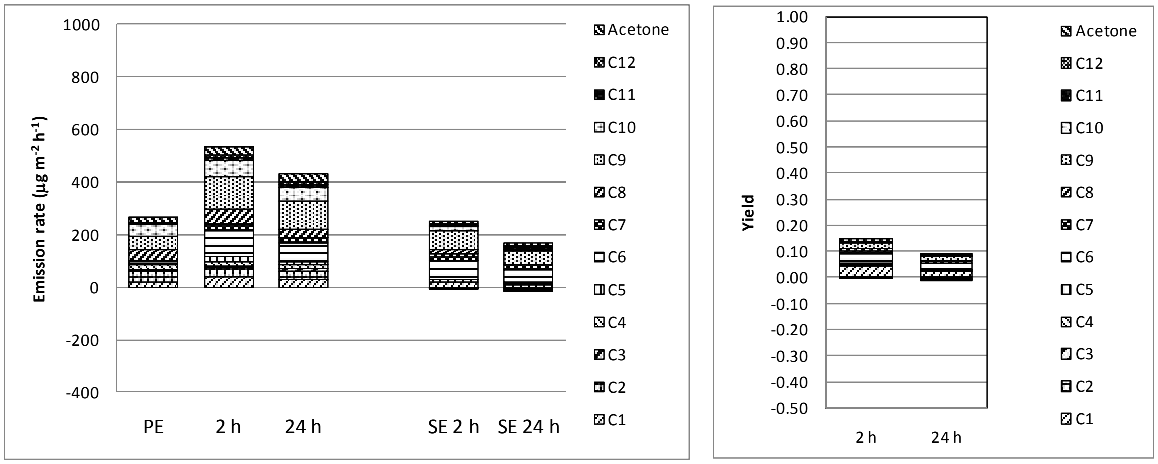


Figure 4.24. Yield and emission rate results for CP-1.

4.3.19. Chicago Metallic Ceiling Tile.

Number of replicates:	2
Deposition Velocity:	1.64,2.54 ± 0.32 m hr^{-1}
Integrated Ozone Uptake:	21.1, 16.7 $\times 10^{-9}$ ± 1.6 $\times 10^{-9}$ moles cm^{-2}
Reaction Probability:	13.5, 6.9 $\times 10^{-6}$ ± 3.9 $\times 10^{-6}$

The mineral based ceiling tile, CP-2, exhibits moderate ozone reactivity in the form of deposition velocity, ozone uptake and reaction probability, while at the same time having negligible yields and secondary emissions. The emission rates also remain relatively constant throughout, Figure 4.25, showing a likelihood of ozone not being the reactive agent to cause secondary byproduct formation for the mineral these tiles were manufactured from. A decrease of 30 percent for the ozone deposition velocity is observed during the course of the experiments, which is consistent with the aging phenomena observed for a variety of materials (Sabersky et al. 1973; Reiss 1994).

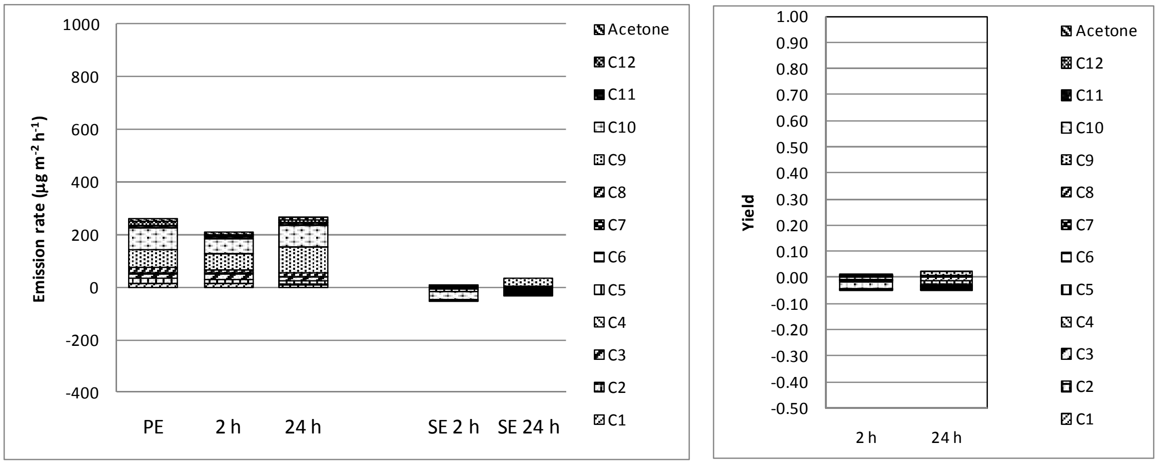


Figure 4.25. Yield and emission rate results for CP-2.

4.3.20. Certainteed Ceiling Tile

Number of replicates:	2
Average Deposition Velocity:	6.84, 5.57 ± 0.45 m h^{-1}
Integrated Ozone Uptake:	28.5, 24.9 $\times 10^{-9} \pm 1.8 \times 10^{-9}$ moles cm^{-2}
Average Reaction Probability:	44.7, 30.1 $\times 10^{-6} \pm 11.7 \times 10^{-6}$

The ceiling tile composed of cardboard-like mineral fiber, CP-3, has high ozone reactivity in the form of deposition velocity, reaction probability and ozone uptake. Found in Figure 4.26, the yields for the 2 hour time period are moderate, being dominated by C8, while those for the 24 hour sample period are negligible. The ozone deposition velocity decreases by 25 percent from the initial point of the experiment until the end, which is consistent with the aging phenomena observed for a variety of materials (Sabersky et al. 1973; Reiss 1994).

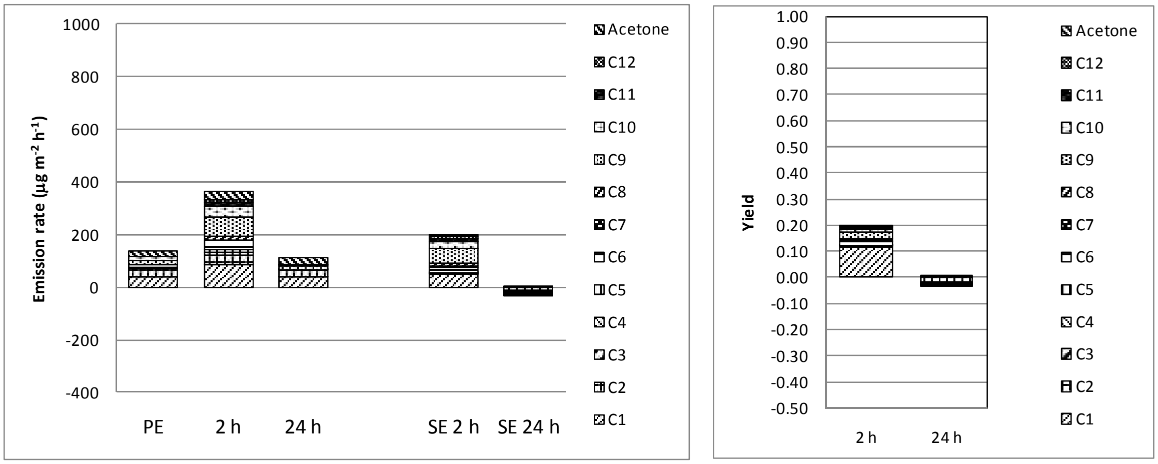


Figure 4.26. Yield and emission rate results for CP-3.

4.4. PARAMETER VARIATIONS

4.4.1. Blank Chamber. For the parameter variations conducted on the chamber without any of the materials present the deposition velocities, and ozone reactivity in general, all fall within a 0.06 m h^{-1} range, with only high ozone concentration and low humidity having a significant impact on the ozone reactivity. These results are taken into account in the calculations performed with the carpet and the clay wall plaster at those conditions. The results from the blank chamber parameter variations can be seen in Figure 4.27. High ozone concentration and high humidity both have the most obvious effect on the deposition velocity within the blank chamber. High humidity conditions result in the highest deposition velocity, while high ozone results in the lowest deposition velocity. All values were taken from when the chamber and ozone generator had reached steady state.

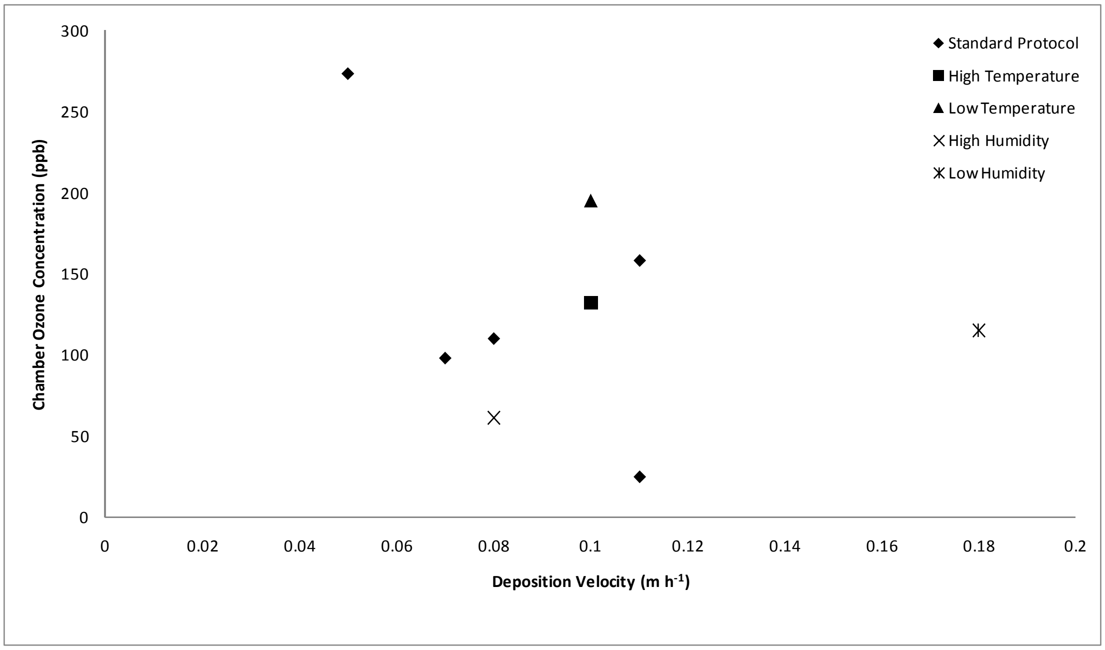


Figure 4.27. Ozone concentrations for blank chamber parameter variations.

4.4.2. Interface Carpet. Interface carpet (or FC-1) shows no significant effect of temperature (15 to 31 ^{o}C) or relative humidity (25 to75%) on the deposition velocity or reaction probability for carpet as shown in Figure 4.28. Shown in Figure 4.29 is a regression analysis for deposition velocity as a function of outlet ozone concentration. At higher ozone concentrations, the measured deposition velocity is lower (statistically significant based on an F value of 11.41 and a P value of 0.05 for 10 samples). A weak line fit was observed with an R2 = 0.57. All of the data points fall within the 95% prediction interval, with several lying outside the 95% confidence interval.

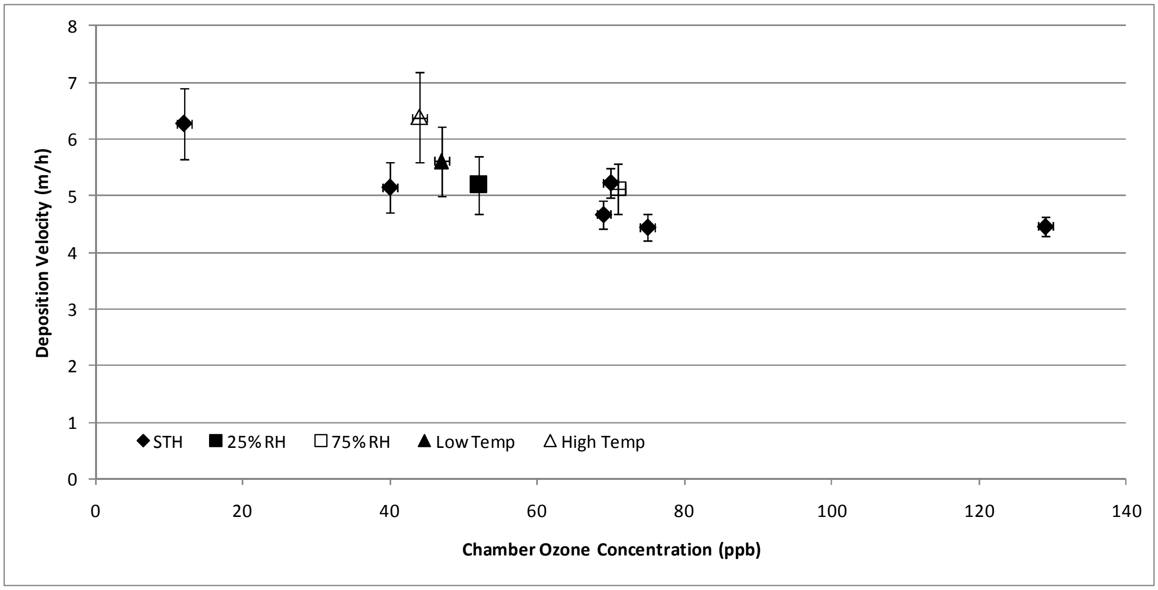
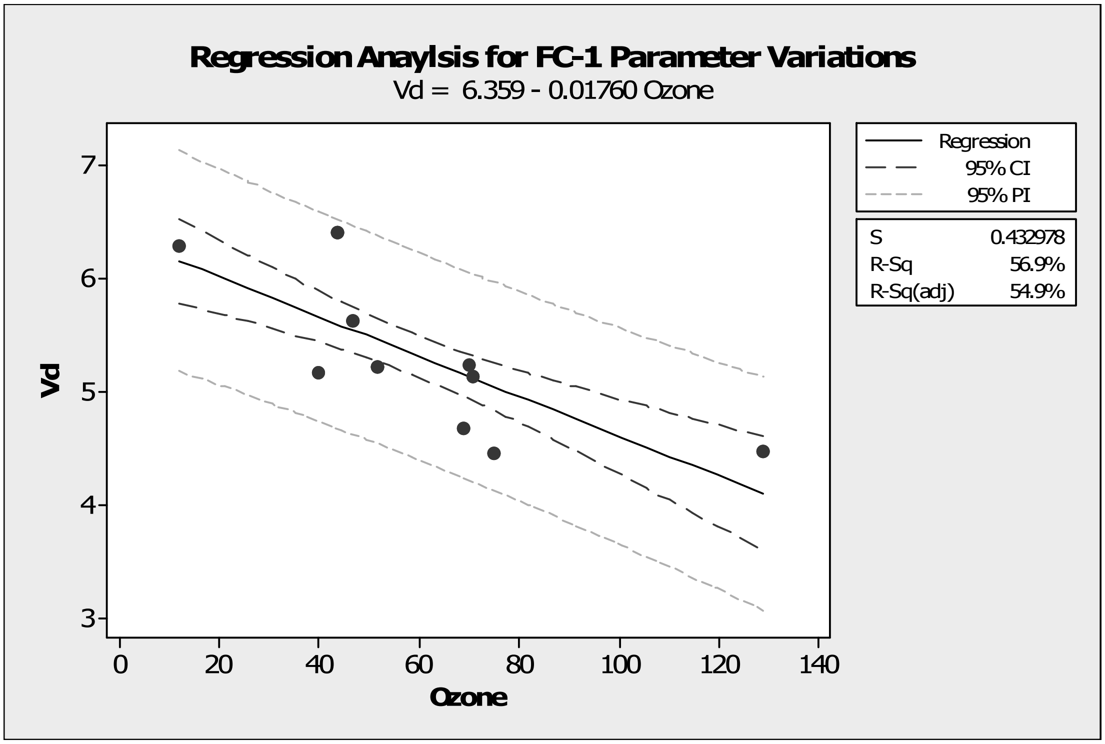


Figure 4.28. Parameter variations for FC-1 with parameters varied



4.29. Regression analysis for FC-1 parameter variations

Figure 4.30 (a, b & c) shows the results for yield as a function of relative humidity, temperature and ozone concentration. Within the experimental uncertainty, there is no observed effect of temperature or relative humidity. However, there may be a reduction in yield with increasing ozone. Unfortunately because there is only one experiment performed at each of the different conditions, and because the variability is large, this cannot be stated with certainty. The regression analysis again shows that the ozone concentration has the most significant effect on deposition velocity, with temperature and humidity having no statistically significant relationship.

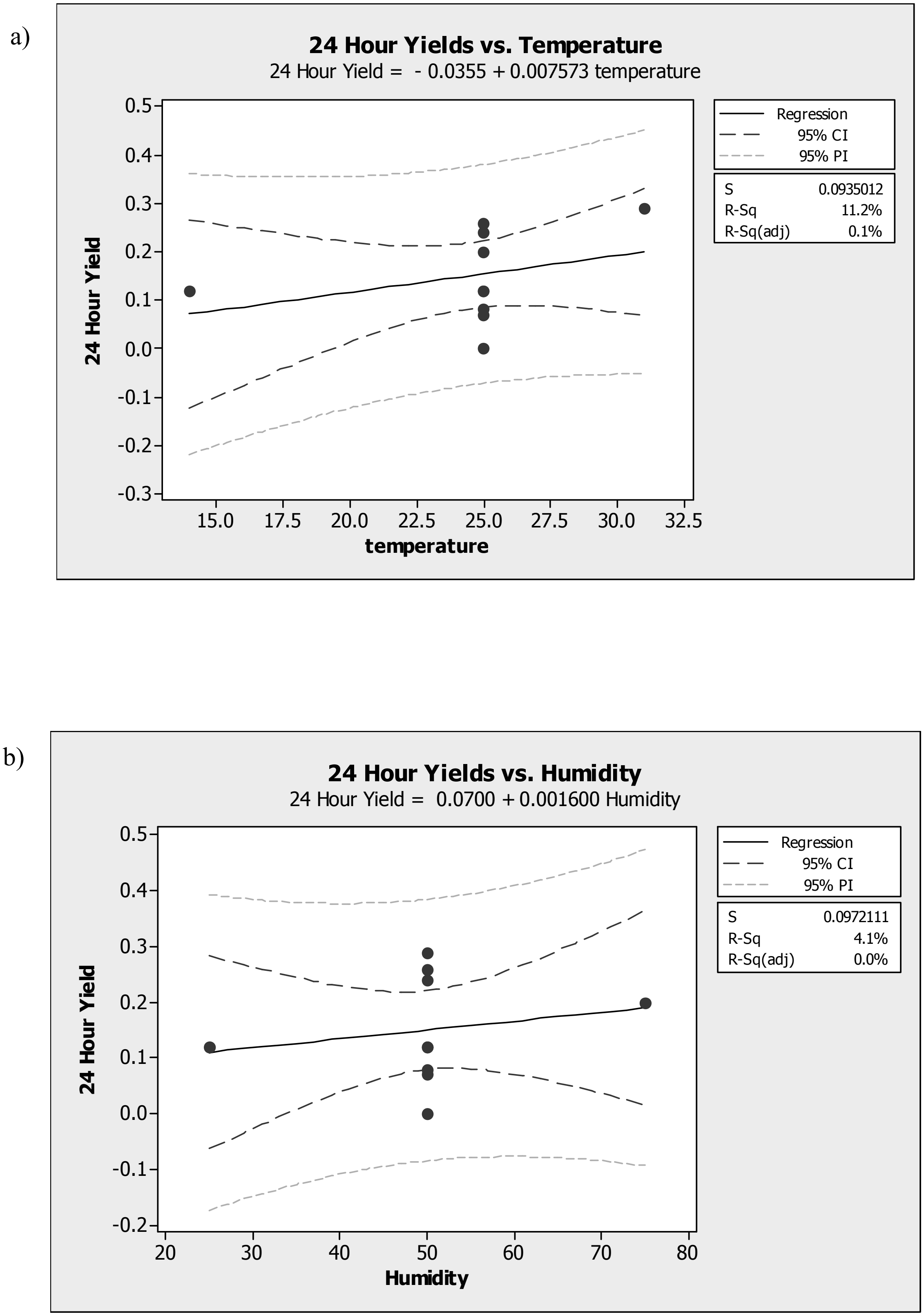


Figure 4.30. a) 24 Hour Yields versus Temperature for FC-1 b) 24 Hour Yields versus Humidity for FC-1 c) 24 Hour Yields versus Ozone Concentration for FC-1

c)

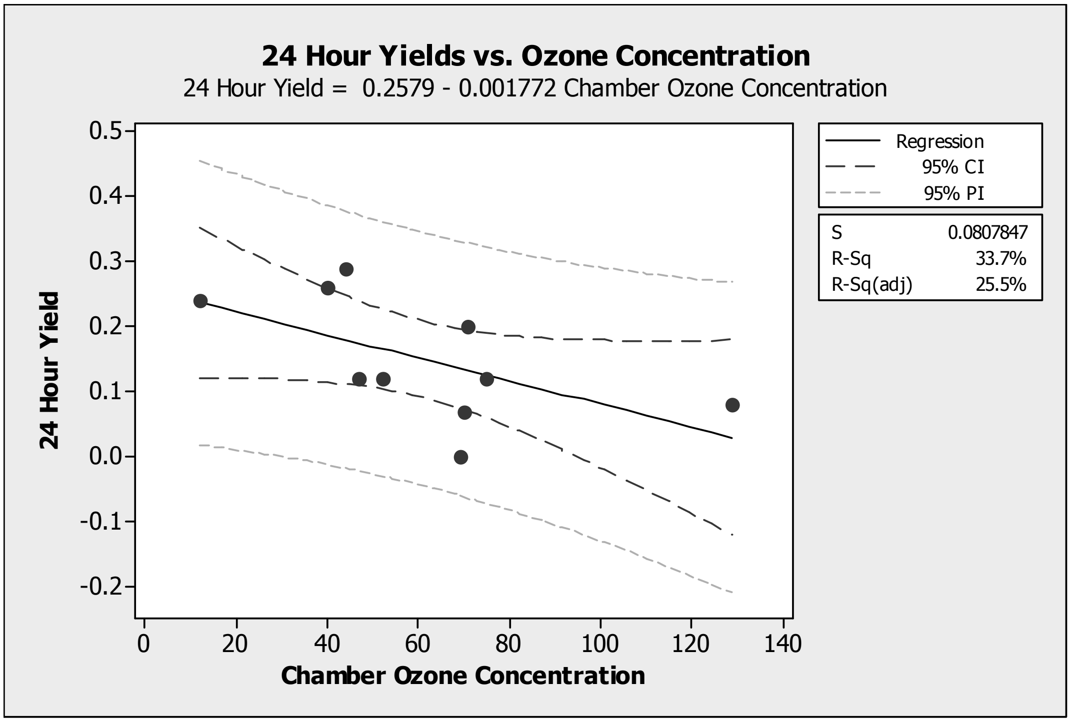


Figure 4.30. a) 24 Hour Yields versus Temperature for FC-1 b) 24 Hour Yields versus Humidity for FC-1 c) 24 Hour Yields versus Ozone Concentration for FC-1 (continued)

4.4.3. American Clay Wall Plaster. Deposition velocity and reaction probability for the clay wall plaster are not significantly influenced by temperature and relative humidity. The deposition velocities remain relatively constant (average 5.9 m h^{-1} ± 0.45 m h^{-1}). With an increase in chamber ozone concentration there is a small, though apparent reduction in deposition velocity and reaction probability as shown in Figure 4.31. Both low ozone (8.4 m h^{-1}) and low humidity (7.3 m h^{-1}) result in higher deposition velocities, but not significantly deviating from the ranges found using the standard protocol (5.1 - 7.7 m h^{-1}). Over a seven day exposure period, there was no significant reduction in deposition velocity or reaction probability.

Figure 4.32 shows the regression analysis performed for all parameter variations performed with WCP-1. The data are more scattered than for FC-1 and the resulting regression is weaker. However, the slope is steeper than for FC-1 and the resulting downward trend is statistically significant (based upon an F value of 10.50, a P value of 0.05 and a sample size of 18).

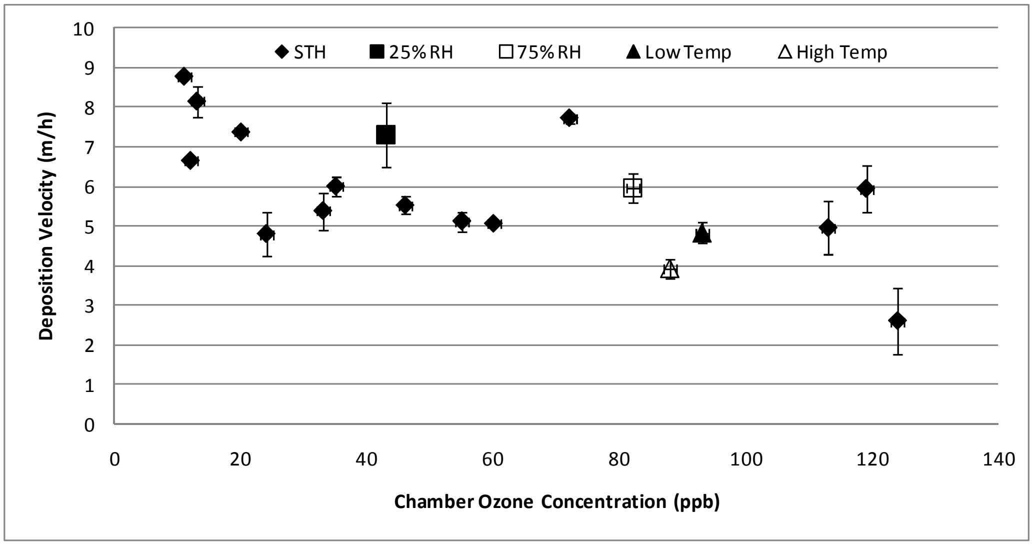


Figure 4.31. Deposition velocity versus chamber ozone concentration for WCP-1

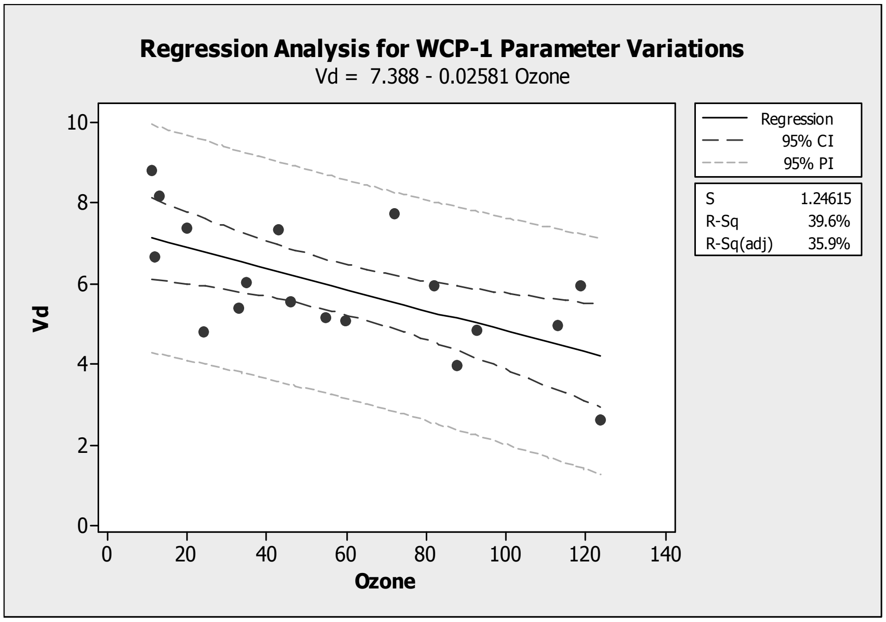


Figure 4.32. Regression analysis for WCP-1 parameter variations

Due to this apparent relationship between ozone concentration and deposition velocity, the ozone concentration will be an important parameter for further experimentation or for specification in commercial testing of materials. Given the observed relationship and uncertainty, a commercial test protocol may provide reasonable results if the ozone concentration (outlet) is maintained within 5 ppb of a nominal value such as 50 ppb.

In Figure 4.33 and Figure 4.34 the results of deposition velocity and reaction probability (from all protocols) are plotted against the total integrated ozone uptake on the materials for all protocols. On both figures the point to the far right is the total integrated ozone uptake after the long duration (7 day) exposure experiment. The is very little correlation based on the R^2 values between these values.

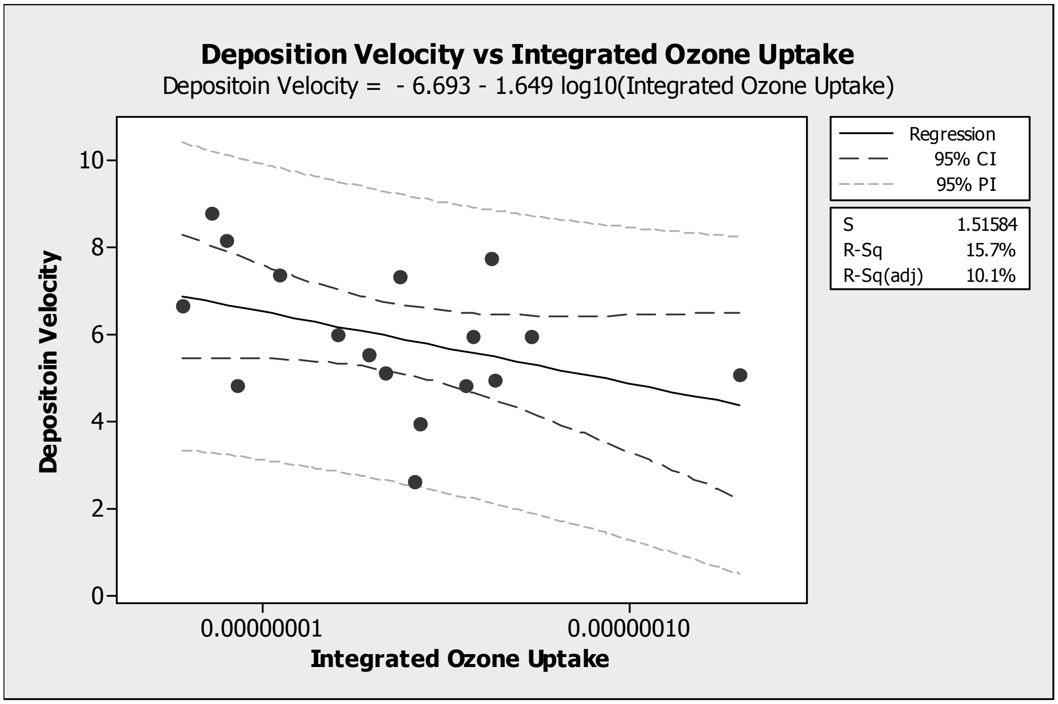


Figure 4.33. v_d versus IOU for WCP-1

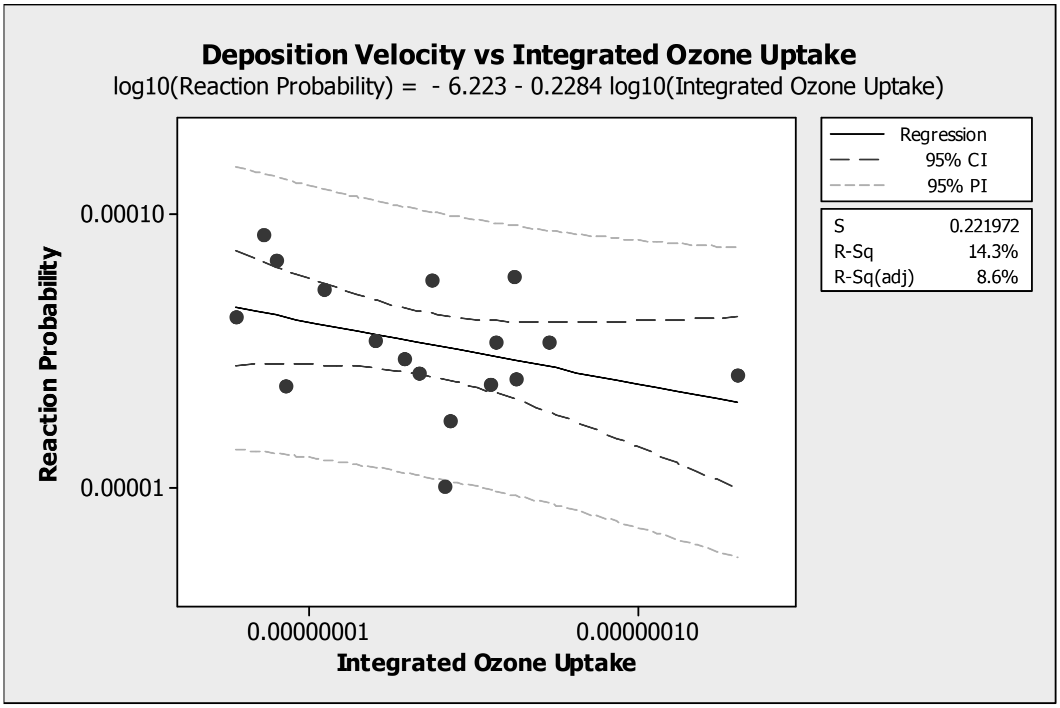


Figure 4.34 γ versus IOU for WCP-1

4.5. COMPARISON TO UT AUSTIN

Research conducted at Missouri University of Science and Technology (S&T) was performed in parallel with the University of Texas at Austin (UT). Research was conducted to compare scaling and the effects of different test methods. At S&T a large number of materials were tested a few times; at UT a small number of materials were tested many times over a wide range of conditions. Tests at UT were conducted in a 48 liter chamber, a test room, a test house, and ‘soiling’ tests were performed on various samples. The parallel lab research has broad implications for the application of this research, and relationships between the research conducted for this thesis and the work at UT are discussed below. Only the results for the 48 liter chamber at UT will be compared to those results found by S&T. Further research that was conducted at UT exceeds the research conducted at S&T and correlations will be difficult to draw. Figure 4.35 shows the deposition velocities for the materials tested at UT. The materials tested were the carpet (FC-1), ceiling panel (CP-2) and wall paint (WP-1). Average deposition velocity results for FC-1 were slightly less than those found for different samples of the same material at S&T. Deposition velocities for both the ceiling tile and the paint were observed to be higher at UT than at S&T. These differences may be due to the heterogeneous nature of the materials or possibly due to differences in the testing method and chambers. At UT the experiments are performed in 48 liter chambers, a test room and a test house, while experiments at S&T are performed in a 10 liter chamber.

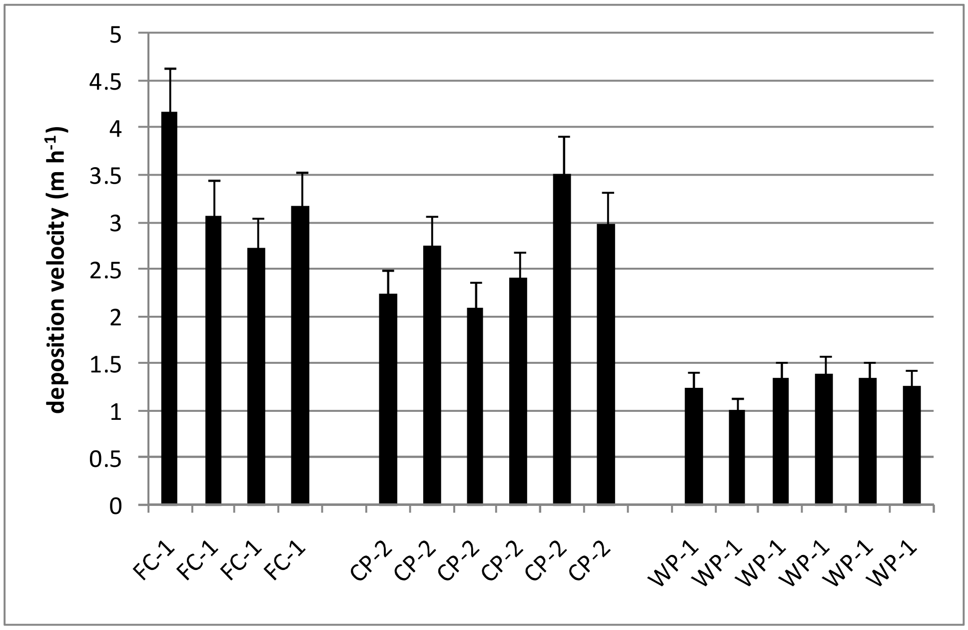


Figure 4.35. Deposition velocity results from UT

Figure 4.36 shows the mean deposition velocity associated with the three materials tested at both UT and S&T. Note that deposition velocity is not directly comparable between experimental protocols, because chamber size, air exchange rates and chamber air velocities were not identical. A better comparison would be reaction probabilities, however, UT was unable to perform the transport limited deposition velocity experiments due to material and size constraints. Due to chamber differences, we would anticipate that one of the chambers would consistently produce higher deposition velocity results for an identical material. However, we observe that the deposition velocity for FC-1 is higher at S&T, but lower for CP-2 and WP-1. This suggests that variations in the surface reactivity of same lot of the same material can be large.

Figure 4.37 is compiled at UT and is used for the comparison of scaling up from the large quantity experiments performed at S&T. Of significance are the higher primary emission rates observed in S&T samples. This may be due to differences in laboratory conditions (absorption from lab air) during materials storage and transfer.

Figure 4.38 shows a side by side comparison of yields of materials tested at both UT and S&T. The yields appear to be quite different between the two labs. Possibilities include: differences among samples of the same material (one part of carpet may have a different surface composition than another), differences in experimental protocol (UT appeared to have lower primary emissions, suggesting the possibility that S&T samples were "precontaminated" and had not sufficiently aired out in the chamber prior to being subjected to ozone).

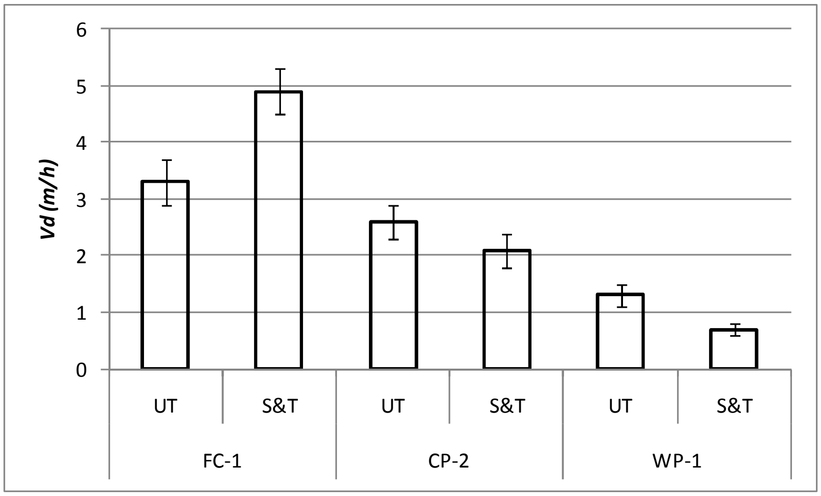


Figure 4.36. Deposition velocity results from UT with results from S&T

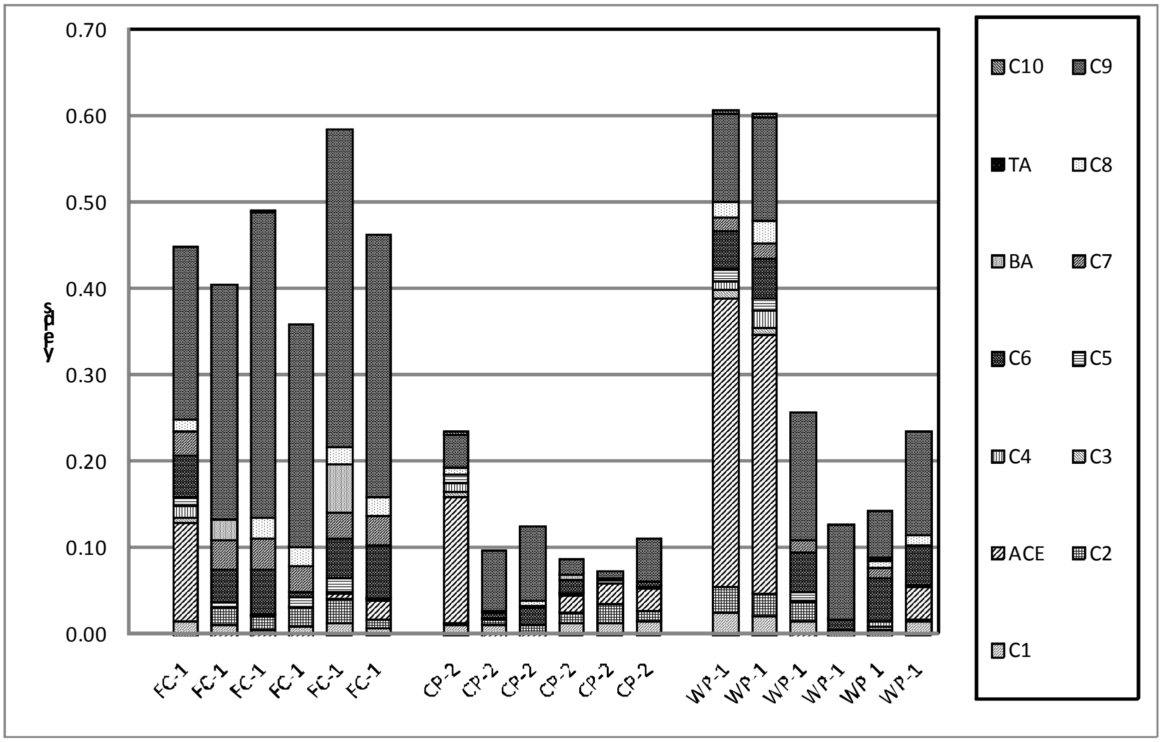


Figure 4.37. Yield results from UT.

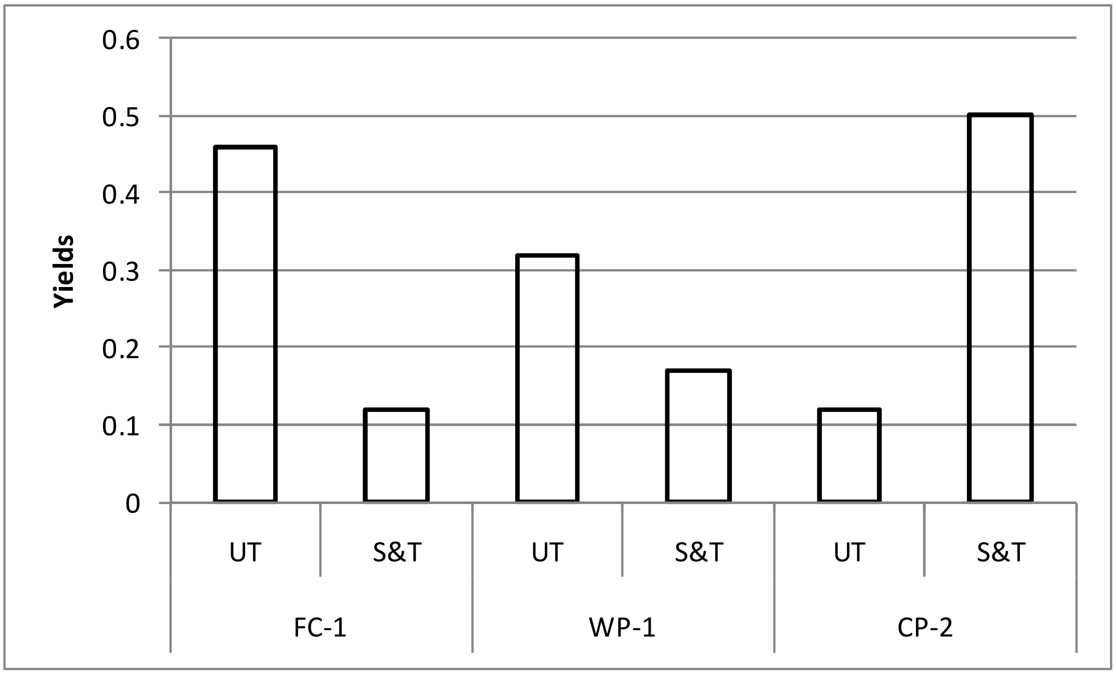


Figure 4.38. Average yields for UT set next to average yields for S&T.

The materials do follow trends similar to that for S&T experiments; the carpet has high yields while the ceiling panel has low yields. There is a significant difference in the yields for painted drywall, with UT's being significantly higher. This may have to do with the aging of the material, for the samples tested at Missouri S&T were painted at the same time as those tested at UT, but not tested at the same time.

5. CONCLUSIONS AND IMPACTS

5.1. SUMMARY

The number of materials that would fulfill any possible 'green' criteria is huge and continuing to grow. Research has been conducted on many different types of normal materials and so there is a vast knowledge base to draw upon, while for 'green' materials the knowledge base is just beginning to form. This means the research must begin looking into the positive and negative health effects of ‘green’ building materials. Of the materials tested, the impact of ozone on green materials, in general terms, is as follows: Materials that exhibited fleecy or porous surfaces proved to have the highest deposition velocities and reaction probabilities. Low surface-area materials that were coated or sealed had lower ozone deposition velocities and lower yields indicating that reaction was inhibited with the base material. Materials were minimally influenced by changes in environmental conditions.

Nine of the materials exhibited high ozone deposition velocities, but had relatively high yields, balancing out anticipated health impacts. Fourteen of the nineteen materials had yields (both 2 and 24 h) less than 0.10 but only five of those materials had significant deposition velocities (>2 m h^{-1}). These levels were arbitrarily chosen, but they do indicate that few materials provide the positive benefits of high ozone consumption rates combined with low secondary emission rates. . The high secondary emissions from certain materials, such as WP-2 and WC-2, demonstrate that while they both have very high reactivity with ozone, the secondary emissions accompanying them disqualify their effectiveness towards improving indoor air quality.

5.2. IMPACTS

Taking typical values as reported by Grontoft (2004) for deposition velocities, along with for a single room a typical air exchange rate of 0.5 h^{-1}, a total volume of 40 m^3 and a total surface area of 120 m^2 estimates of the ozone reduction can be estimated. Using materials such as latex paint (walling and ceiling) and linoleum flooring in a typical residence, with an outdoor ozone concentration of 50 ppb, a net reduction of 63% to 19 ppb is predicted. Replacing these materials with the more highly reactive materials tested, such as the clay wall plaster (ceiling and walling) would result in an indoor ozone concentration of less than 5 ppb. This is an 85% improvement over typical values, and a 90% ozone reduction. Not only would ozone inhalation risks be reduced, there would also be a corresponding decrease in exposure to the products of heterogeneous AND homogeneous ozone reactions. With less ozone available, reaction rates with surfaces and with gas-phase reactants (such as terpenes) are reduced.

It is also helpful to consider the benefit in terms of fresh air exchange rates in homes. A typical volumetric flow-rate through a home by passive air exchange is 150 m^3 h^{-1}. For a relatively high deposition velocity of 5 m h^{-1} observed for some materials in this research, and an indoor surface area equal to approximately 800 m^2, the effective volumetric air exchange rate is (associated with removal of ozone) is 25 times higher (4000 m^3 h^{-1}). This is achieved entirely from passive reactions; unlike active filtration, no additional energy would be required to improve indoor environmental quality.

5.3. CONCLUSIONS

Green building materials, like their traditional counterparts, exhibit a diverse response when exposed to ozone. Carpets have high reaction probabilities and high byproduct yields. The majority of the “sealed” materials (mostly flooring) exhibited very low ozone reactivity and very low secondary emissions. Ceiling tile materials all have promise in significantly improving indoor air quality. With high available surface areas, and a reduced need for durability (no need for sealing), manufacturers may be able to design long-lasting, pollution absorbing surfaces with ease. The clay based wall plaster is also promising. It can easily be used to coat any surface (ceiling, walls or other architectural features), has a very high reaction probability while also having very low byproduct yields. Overall the materials all behaved as their common counterparts do, indicating that possibly the ‘green’ criteria as it is currently defined would benefit from modification, so that materials truly live up to the implied promise of being green and healthy.

6. FUTURE RESEARCH

6.1. ONGOING RESEARCH

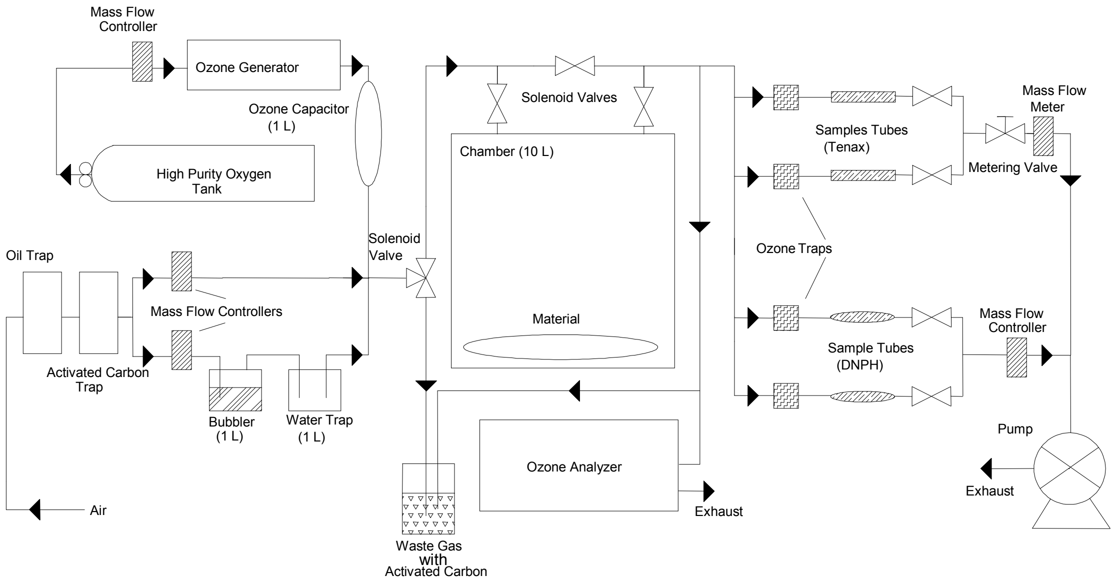
Additional research with promising materials is being performed including parameter variations and differences in preparation method. Issues with high primary emissions also need to be examined to determine where the contaminants are coming from and methods of reducing the contamination to allow more accurate calculation of byproducts, particularly with variations offered by the clay wall plaster available through the manufacturer. This includes a hardening agent, to increase durability, a moisture agent, to increase durability in high humidity areas, and mica/straw additives which change the texture of the clay wall plaster. Also to be tested is a clay wall plaster made to be applied via conventional paint sprayer, made by the same company that manufactures the tested clay wall plaster, which would greatly ease the application process, though through the use of the mixed in adhesive there may also be more pronounced secondary emissions as ozone reacts with the organic additives. Additional testing in field settings will be necessary to further enhance the understanding of the impacts of the material choices that can be made. Further research in the ability for materials to reduce occupant exposure to other air pollutants will also be considered.

6.2. MANUFACTURERS AND TEST METHOD

All of the research conducted is preliminary work for the USGBC to determine if there is value for a grading criteria associated with the impact on indoor pollution concentrations from the building materials chosen. Testing would be performed by third party testing laboratories and the results would be advertised with other green credentials of materials. Manufacturers may have to limit the types of materials that are tested for the ozone reactivity, possibly only to those materials that have been certified green, or meet expected criteria for high reactivity and low emitting materials. This could eliminate many carpets and paint based products, though this may also encourage manufacturers to research better designs of products. For that trend certain inorganic materials (clay paints and mineral fiber ceiling tiles) have shown both good reactivity and low byproduct emissions, perhaps designs for porous building materials, that do not contain the types of oils and compounds that carpets and paints do, would be a wise choice for the types of building materials manufacturers would be able to focus on for this type of research.

The final testing method and thresholds will have to be determined by the capabilities and accuracy of the commercial testing laboratories available to manufacturers. The grading metric should be based on ozone reduction capabilities and byproduct formation as the two testing criteria. Recommendation of having an ozone deposition velocity being >1 m h^{-1} should be the bare minimum of lower range for deposition velocity. It is not until the deposition velocity exceeds 1 m h^{-1} does a net ozone reduction begin to be noticed compared to commonly available commercial materials. This calculation comes from the same analysis performed to compare the impacts of 'green' building materials versus common building materials. If the point of the grading criteria is to encourage the use of these materials as a passive ozone reduction mechanism, materials with values greater than those commonly found should be encouraged. While the byproduct yields will have to be determined by the accuracy of the commercial testing laboratories and the current research of the compound health effects towards human health. As a recommendation for a testing method small chambers of at least 10 L in volume, operated at 25^{o} C and 50% RH with an internal ozone concentration in the 50-100 ppb range should adequately generate reliable deposition velocity values that can be extrapolated to real-world settings. This recommendation is being given so that results from future testing, either for commercial or research application, can be most easily compared with work done previously. Another reason is that by performing the test in smaller chambers less material has to be used, and the work from UT can be used to extrapolate the date out to full scale use. Given the potential impact of relative humidity, we recommend that the condition of 50% relative humidity be adhered to in commercial labs. A consistency across testing labs would have to exist for the results to be dependable in the reporting.

APPENDIX A.
SYSTEM DIAGRAM



1.System Diagram

APPENDIX B.

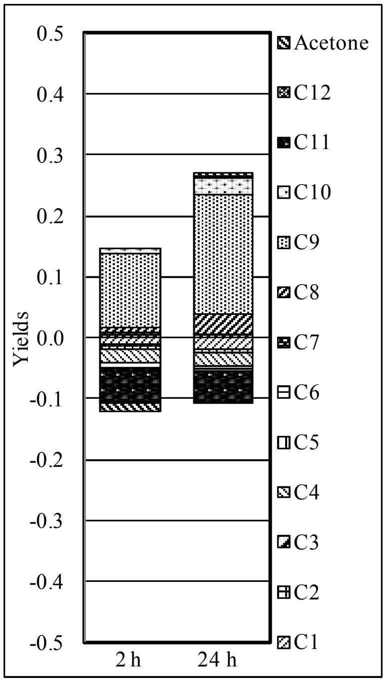
RESULTS

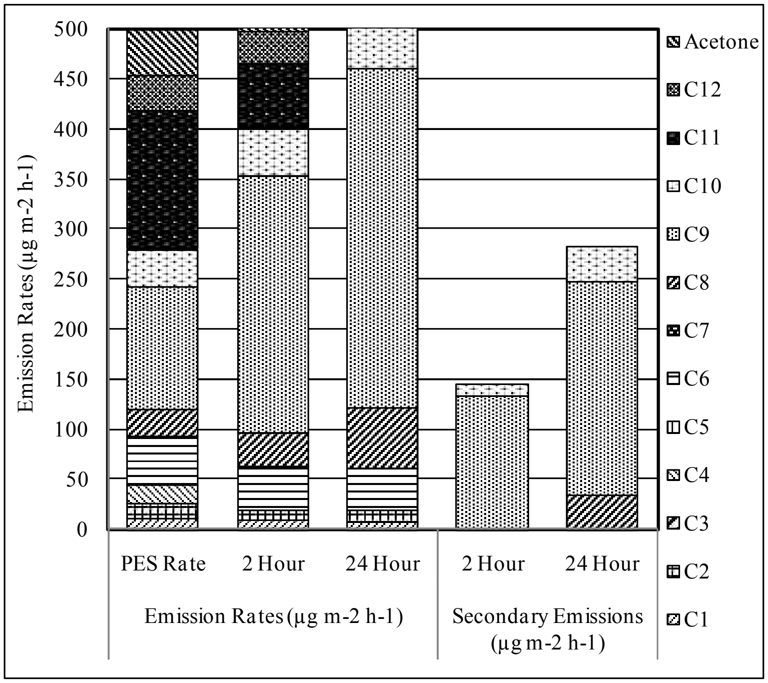
1. Potassium Iodide

Material	Transport Limited Deposition Velocity (m h-1)	Error
Shaw Carpet	8.31	0.3
Porcelain Tile	10.49	0.26
Rubber Tile	6.06	0.13
Corkboard	12.66	0.42
American Clay	12.97	0.47
EcoTrend	5.05	0.1

2. Interface Carpet - First Experiment

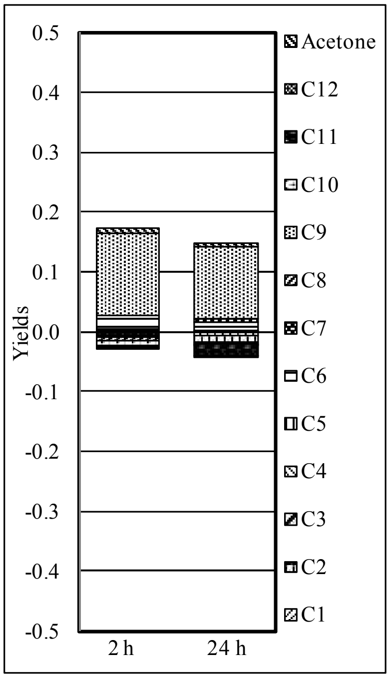
	Yields				Emission Rates (µg m^{-2} h^{-1})						Secondary Emissions (µg m^{-2} h^{-1})			
	2 Hour	Error	24 Hour	Error	PES Rate	Error	2 Hour	Error	24 Hour	Error	2 Hour	Error	24 Hour	Error
C1	(-)	n/a	(-)	n/a	11.31	5.65	8.50	0.59	6.74	0.02	0.00	0.00	0.00	0.00
C2	(-)	n/a	(-)	n/a	13.91	3.20	11.36	0.13	12.31	0.03	0.00	0.00	0.00	0.00
C3	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C4	(-)	n/a	(-)	n/a	19.46	4.47	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C5	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C6	(-)	n/a	(-)	n/a	48.35	11.12	42.79	4.37	42.33	5.14	0.00	0.00	0.00	0.00
C7	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C8	LOD	n/a	0.03	0.00	26.09	6.00	33.08	0.95	59.96	14.74	0.00	0.00	33.87	10.37
C9	0.12	0.00	0.19	0.01	124.11	28.54	258.20	28.95	338.79	56.83	134.10	28.75	214.69	42.68
C10	LOD	n/a	0.03	0.02	36.57	8.41	47.25	9.28	70.40	2.86	10.68	4.27	33.83	5.64
C11	(-)	n/a	(-)	n/a	137.66	31.66	63.72	21.61	66.12	21.75	0.00	0.00	0.00	0.00
C12	(-)	n/a	LOD	n/a	35.69	8.21	31.46	9.86	38.12	1.80	0.00	0.00	0.00	0.00
Acetone	(-)	n/a	LOD	n/a	44.87	10.32	38.69	1.95	47.22	8.34	0.00	0.00	0.00	0.00

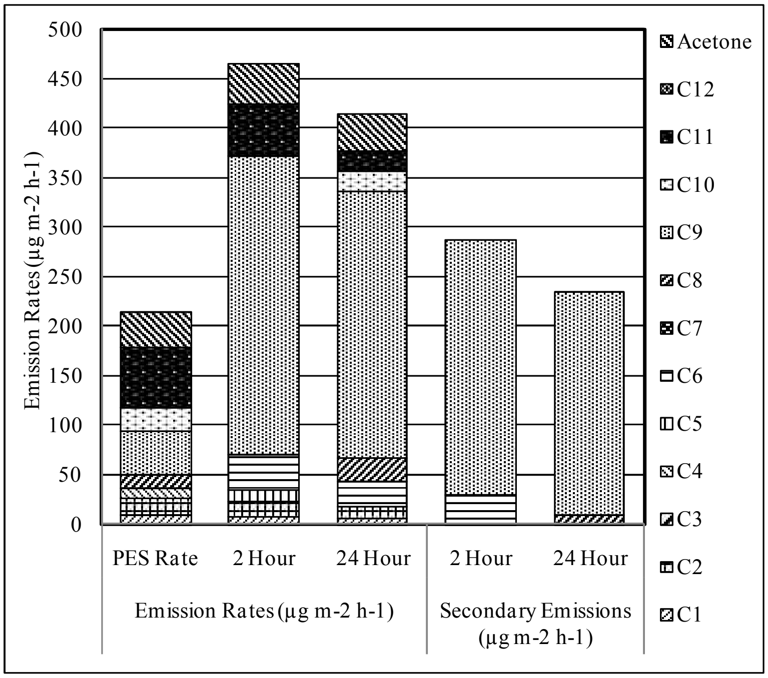




3. Interface Carpet - Replicate

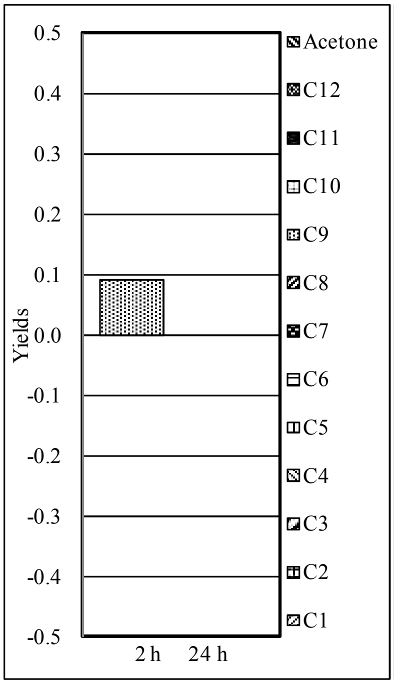
	Yields				Emission Rates ($\mu g\ m^{-2}\ h^{-1}$)						Secondary Emissions ($\mu g\ m^{-2}\ h^{-1}$)			
	2 Hour	Error	24 Hour	Error	PES Rate	Error	2 Hour	Error	24 Hour	Error	2 Hour	Error	24 Hour	Error
C1	(-)	n/a	(-)	n/a	8.86	4.43	8.28	0.00	6.04	0.00	0.00	0.00	0.00	0.00
C2	(-)	n/a	(-)	n/a	17.64	0.00	14.95	0.00	12.00	0.01	0.00	0.00	0.00	0.00
C3	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C4	(-)	n/a	(-)	n/a	9.08	0.00	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C5	LOD	n/a	LOD	n/a	LOD	n/a	12.07	0.00	LOD	n/a	0.00	0.00	0.00	0.00
C6	LOD	n/a	LOD	n/a	LOD	n/a	35.16	2.37	25.72	0.07	30.02	1.19	0.00	0.00
C7	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C8	(-)	n/a	LOD	n/a	14.30	2.28	LOD	n/a	23.69	4.57	0.00	0.00	9.39	3.42
C9	0.14	0.00	0.12	0.01	44.02	2.50	300.95	22.76	269.17	122.31	256.92	12.63	225.15	62.40
C10	(-)	n/a	(-)	n/a	24.24	7.27	LOD	n/a	19.96	0.06	0.00	0.00	0.00	0.00
C11	(-)	n/a	(-)	n/a	60.77	6.94	53.16	2.78	19.82	0.24	0.00	0.00	0.00	0.00
C12	(-)	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
Acetone	LOD	n/a	LOD	n/a	34.86	0.00	40.96	0.00	38.56	1.65	0.00	0.00	0.00	0.00

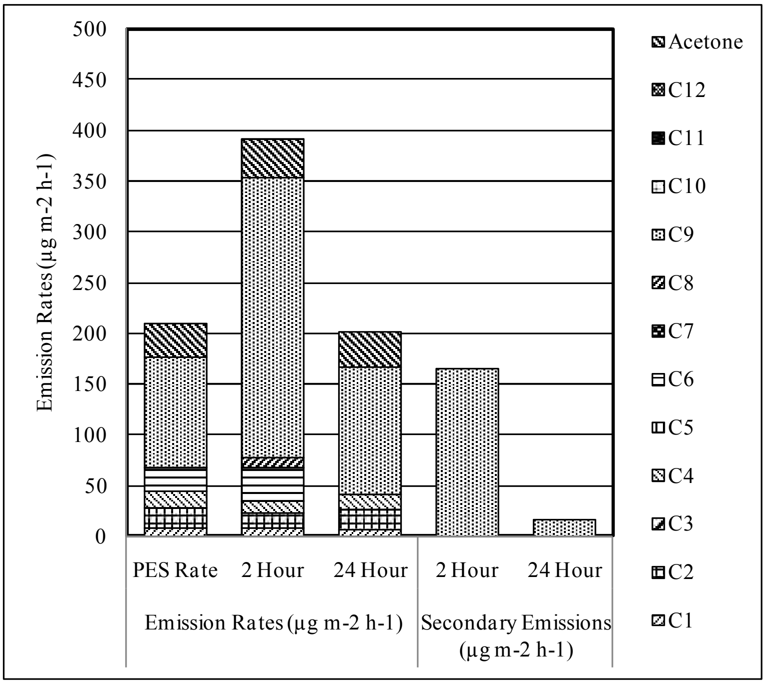




4. Interface Carpet - Second Replicate

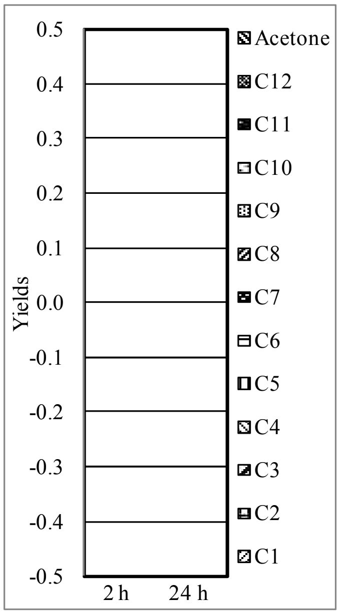
	Yields				Emission Rates (μg m^{-2} h^{-1})						Secondary Emissions (μg m^{-2} h^{-1})			
	2 Hour	Error	24 Hour	Error	PES Rate	Error	2 Hour	Error	24 Hour	Error	2 Hour	Error	24 Hour	Error
C1	(-)	n/a	(-)	n/a	8.70	3.37	8.07	0.13	7.43	0.01	0.00	0.00	0.00	0.00
C2	(-)	n/a	(-)	n/a	20.36	2.58	16.04	1.74	18.76	0.04	0.00	0.00	0.00	0.00
C3	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C4	(-)	n/a	(-)	n/a	16.18	2.04	10.50	1.04	16.07	0.06	0.00	0.00	0.00	0.00
C5	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C6	LOD	n/a	(-)	n/a	22.14	6.64	32.79	7.98	LOD	n/a	0.00	0.00	0.00	0.00
C7	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C8	LOD	n/a	(-)	n/a	LOD	n/a	10.95	3.29	LOD	n/a	0.00	0.00	0.00	0.00
C9	0.09	0.00	LOD	n/a	109.23	32.77	274.87	84.34	125.75	37.72	165.64	58.56	16.52	6.61
C10	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C11	(-)	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C12	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
Acetone	LOD	n/a	LOD	n/a	33.59	2.05	37.90	0.57	33.62	0.61	0.00	0.00	0.00	0.00

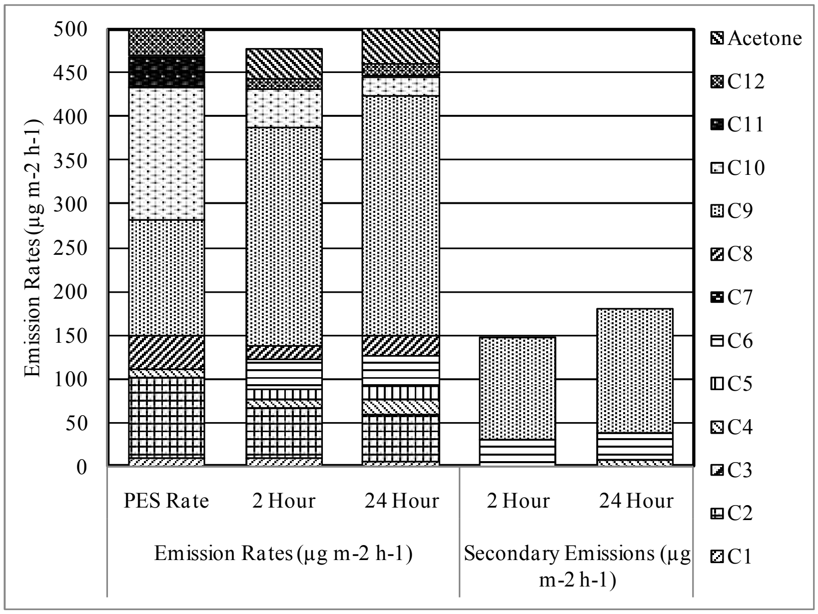




5. Interface Carpet - Third Replicate

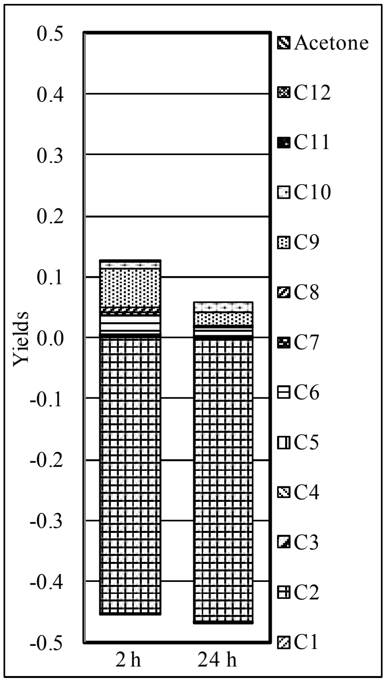
	Yields				Emission Rates (μg m^{-2} h^{-1})						Secondary Emissions (μg m^{-2} h^{-1})			
	2 Hour	Error	24 Hour	Error	PES Rate	Error	2 Hour	Error	24 Hour	Error	2 Hour	Error	24 Hour	Error
C1	LOD	n/a	(-)	n/a	9.15	3.49	10.53	3.67	7.10	0.02	0.00	0.00	0.00	0.00
C2	(-)	n/a	(-)	n/a	93.57	7.33	56.96	5.88	53.49	0.09	0.00	0.00	0.00	0.00
C3	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C4	LOD	n/a	LOD	n/a	8.32	0.21	10.49	4.85	16.08	0.00	0.00	0.00	7.76	0.10
C5	LOD	n/a	LOD	n/a	LOD	n/a	10.96	2.65	16.03	0.08	0.00	0.00	0.00	0.00
C6	LOD	n/a	LOD	n/a	LOD	n/a	33.70	0.28	33.54	5.33	31.18	0.14	31.02	2.66
C7	(-)	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C8	(-)	n/a	(-)	n/a	38.64	10.89	16.62	7.15	23.15	6.95	0.00	0.00	0.00	0.00
C9	(-)	n/a	(-)	n/a	132.99	61.45	249.47	25.49	275.53	111.87	116.48	43.47	142.54	57.02
C10	(-)	n/a	(-)	n/a	150.36	66.50	42.43	12.73	20.51	6.15	0.00	0.00	0.00	0.00
C11	(-)	n/a	(-)	n/a	35.65	14.12	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C12	(-)	n/a	(-)	n/a	31.89	10.48	11.46	3.44	14.96	4.49	0.00	0.00	0.00	0.00
Acetone	LOD	n/a	LOD	n/a	33.57	2.64	34.20	4.22	40.49	6.44	0.00	0.00	0.00	0.00

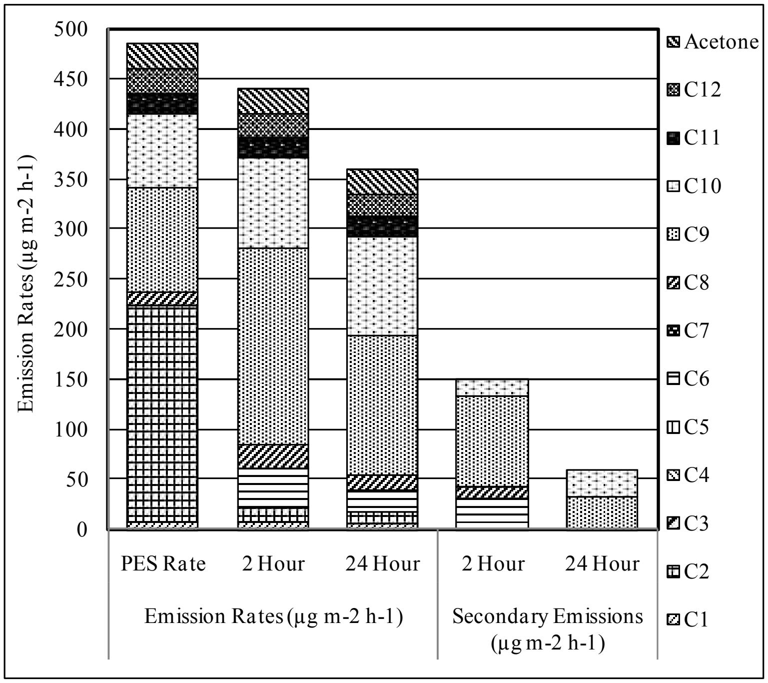




6. Shaw Carpet - First Experiment

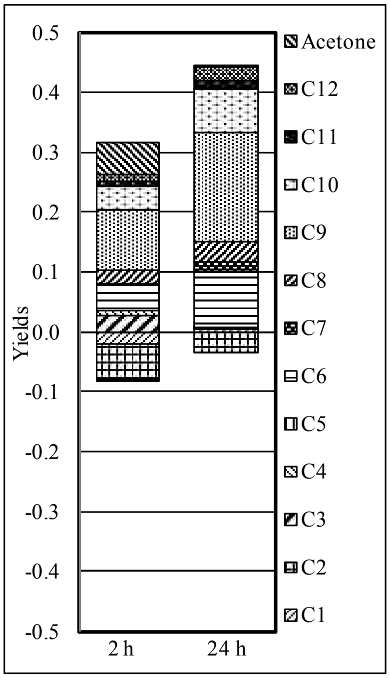
	Yields				Emission Rates (μg m^{-2} h^{-1})						Secondary Emissions (μg m^{-2} h^{-1})			
	2 Hour	Error	24 Hour	Error	PES Rate	Error	2 Hour	Error	24 Hour	Error	2 Hour	Error	24 Hour	Error
C1	LOD	n/a	(-)	n/a	6.84	2.05	7.27	0.32	5.82	0.00	0.00	0.00	0.00	0.00
C2	(-)	n/a	(-)	n/a	216.60	64.98	16.02	4.07	12.00	0.03	0.00	0.00	0.00	0.00
C3	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C4	LOD	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C5	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C6	LOD	n/a	LOD	n/a	LOD	n/a	37.34	1.53	20.75	3.68	31.83	0.77	0.00	0.00
C7	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C8	LOD	n/a	LOD	n/a	13.56	1.75	23.87	0.14	15.90	4.77	10.31	0.94	0.00	0.00
C9	0.06	0.00	LOD	n/a	105.05	25.06	196.62	9.98	138.52	53.44	91.56	17.52	33.47	13.39
C10	LOD	n/a	LOD	n/a	73.52	19.15	89.67	32.23	100.35	32.96	16.15	6.46	26.83	10.73
C11	LOD	n/a	(-)	n/a	20.31	6.85	21.24	6.37	19.91	2.97	0.00	0.00	0.00	0.00
C12	(-)	n/a	(-)	n/a	24.77	9.55	22.95	6.88	22.29	6.25	0.00	0.00	0.00	0.00
Acetone	LOD	n/a	(-)	n/a	25.09	0.23	25.82	1.07	24.57	0.63	0.00	0.00	0.00	0.00

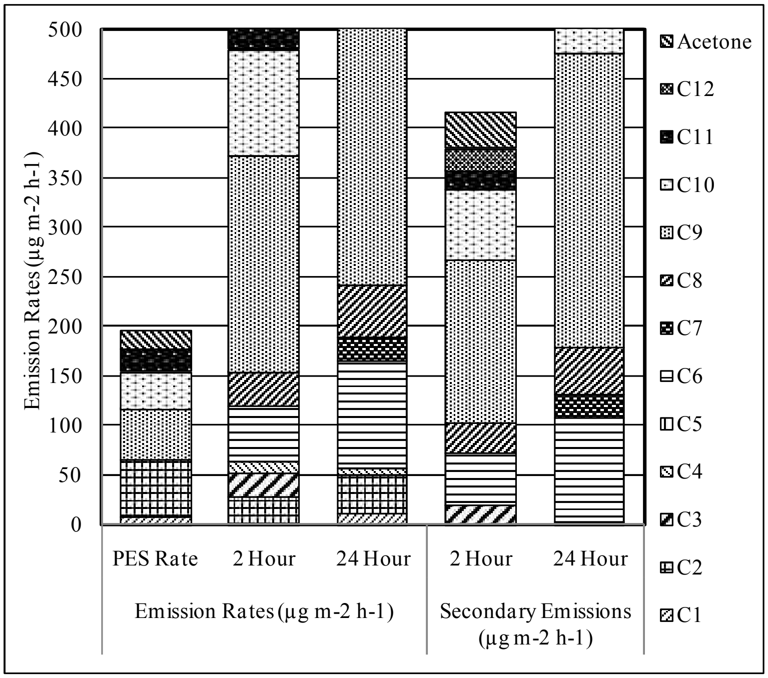




7. Shaw Carpet - Replicate

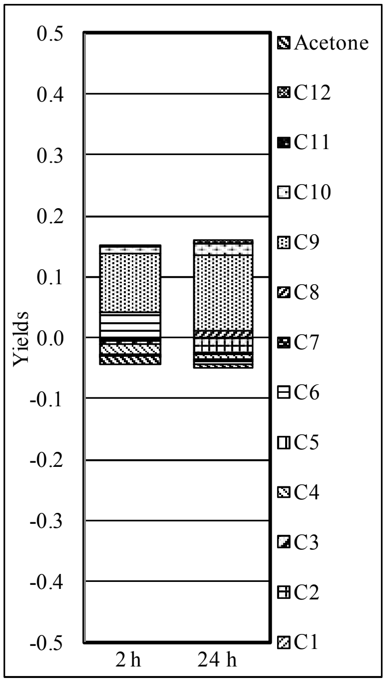
	Yields				Emission Rates (µg m^{-2} h^{-1})						Secondary Emissions (µg m^{-2} h^{-1})			
	2 Hour	Error	24 Hour	Error	PES Rate	Error	2 Hour	Error	24 Hour	Error	2 Hour	Error	24 Hour	Error
C1	(-)	n/a	LOD	n/a	8.13	2.44	LOD	n/a	10.33	0.04	0.00	0.00	2.20	0.88
C2	(-)	n/a	(-)	n/a	56.54	3.81	27.84	7.09	39.02	0.22	0.00	0.00	0.00	0.00
C3	LOD	n/a	LOD	n/a	LOD	n/a	23.25	0.86	LOD	n/a	19.10	0.43	0.00	0.00
C4	LOD	n/a	LOD	n/a	LOD	n/a	11.74	0.56	7.58	0.04	0.00	0.00	0.00	0.00
C5	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C6	LOD	n/a	0.09	0.01	LOD	n/a	56.42	16.86	108.79	32.64	52.92	8.43	105.29	16.32
C7	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	23.94	7.18	0.00	0.00	23.94	3.59
C8	0.02	0.00	0.03	0.00	LOD	n/a	35.19	10.56	52.43	15.73	30.88	5.28	48.12	7.86
C9	0.10	0.01	0.18	0.01	52.51	7.36	217.41	65.22	349.69	####	164.90	36.29	297.18	56.13
C10	0.04	0.00	0.07	0.01	37.37	5.11	107.41	32.22	169.75	46.44	70.04	18.67	132.38	25.78
C11	LOD	n/a	LOD	n/a	21.21	5.04	41.09	15.88	51.48	16.29	19.88	7.95	30.27	10.66
C12	LOD	n/a	0.02	0.00	LOD	n/a	26.31	7.89	50.05	15.02	21.46	3.95	45.20	7.51
Acetone	0.05	0.00	LOD	n/a	18.69	0.71	54.75	2.27	21.10	2.86	36.06	1.49	0.00	0.00

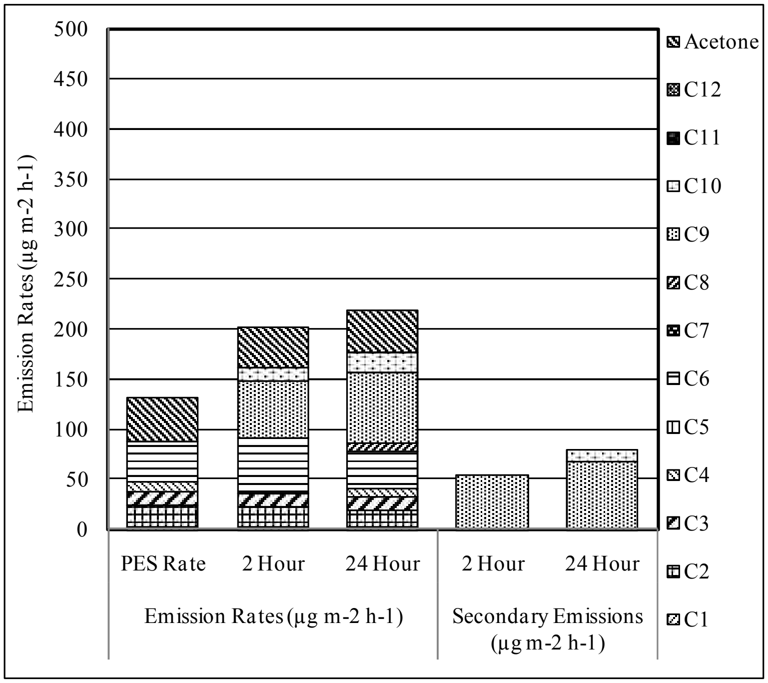




8. Forbo - First Experiment

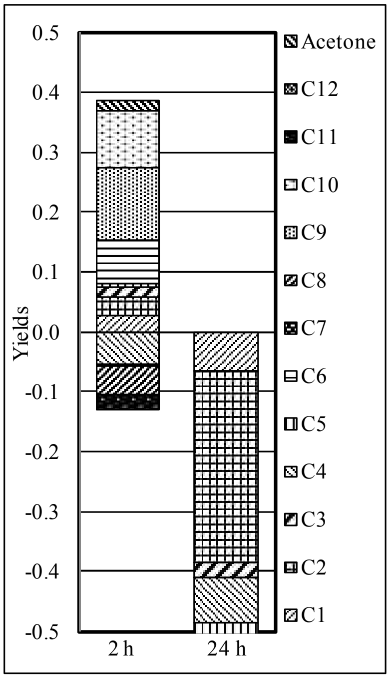
	Yields				Emission Rates (µg m^{-2} h^{-1})						Secondary Emissions (µg m^{-2} h^{-1})			
	2 Hour	Error	24 Hour	Error	PES Rate	Error	2 Hour	Error	24 Hour	Error	2 Hour	Error	24 Hour	Error
C1	(-)	n/a	(-)	n/a	3.22	0.96	2.85	0.27	3.22	0.01	0.00	0.00	0.00	0.00
C2	(-)	n/a	(-)	n/a	20.95	3.89	20.16	5.59	16.71	0.01	0.00	0.00	0.00	0.00
C3	(-)	n/a	(-)	n/a	13.70	0.04	12.70	0.29	12.70	0.01	0.00	0.00	0.00	0.00
C4	(-)	n/a	(-)	n/a	10.62	1.42	LOD	n/a	8.13	0.01	0.00	0.00	0.00	0.00
C5	(-)	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C6	LOD	n/a	(-)	n/a	39.46	12.61	55.19	5.02	36.83	4.88	0.00	0.00	0.00	0.00
C7	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C8	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	8.55	2.56	0.00	0.00	0.00	0.00
C9	0.10	0.01	0.12	0.04	LOD	n/a	57.11	9.66	71.32	32.56	54.43	4.83	68.63	16.28
C10	LOD	n/a	LOD	n/a	LOD	n/a	13.71	4.11	19.84	3.93	0.00	0.00	11.81	1.96
C11	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C12	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
Acetone	(-)	n/a	(-)	n/a	43.13	0.67	40.36	0.40	42.07	0.15	0.00	0.00	0.00	0.00

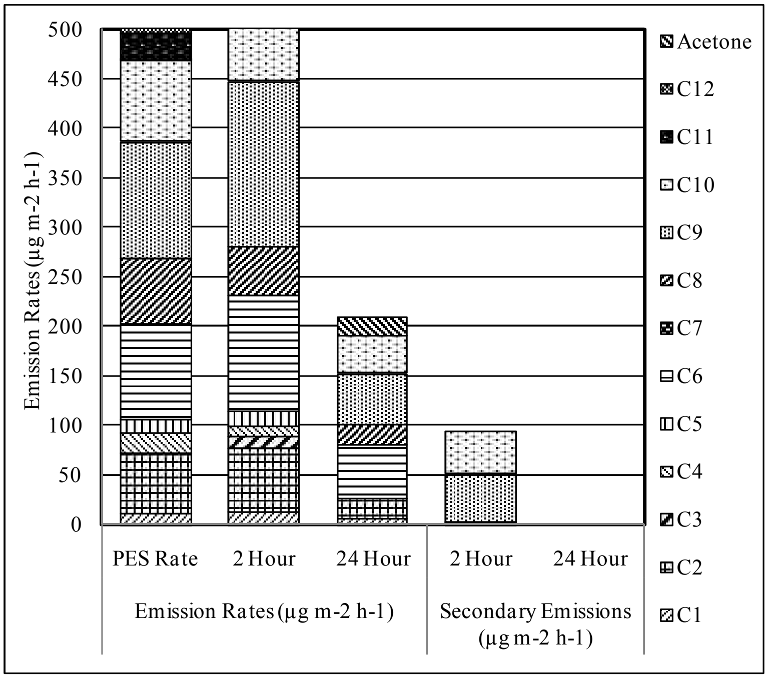




9. Forbo - Replicate

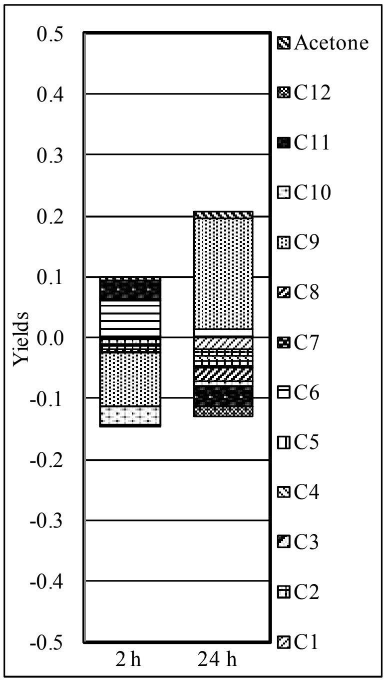
	Yields				Emission Rates (µg m^{-2} h^{-1})						Secondary Emissions (µg m^{-2} h^{-1})			
	2 Hour	Error	24 Hour	Error	PES Rate	Error	2 Hour	Error	24 Hour	Error	2 Hour	Error	24 Hour	Error
C1	LOD	n/a	(-)	n/a	10.94	3.87	13.18	4.88	5.45	0.03	2.24	0.00	0.00	0.00
C2	LOD	n/a	(-)	n/a	60.55	14.61	64.64	32.11	20.47	0.17	0.00	0.00	0.00	0.00
C3	LOD	n/a	(-)	n/a	LOD	n/a	11.95	5.88	LOD	n/a	0.00	0.00	0.00	0.00
C4	(-)	n/a	(-)	n/a	20.97	4.36	9.83	3.14	LOD	n/a	0.00	0.00	0.00	0.00
C5	LOD	n/a	(-)	n/a	13.44	3.27	14.89	5.77	LOD	n/a	0.00	0.00	0.00	0.00
C6	LOD	n/a	(-)	n/a	96.03	16.84	116.39	19.68	53.86	11.58	0.00	0.00	0.00	0.00
C7	(-)	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C8	(-)	n/a	(-)	n/a	66.93	26.56	50.29	10.70	20.59	2.46	0.00	0.00	0.00	0.00
C9	0.12	0.07	(-)	n/a	117.49	32.73	166.00	5.89	52.03	18.14	48.51	19.31	0.00	0.00
C10	0.10	0.05	(-)	n/a	82.89	8.60	125.13	30.84	37.87	16.01	42.25	19.72	0.00	0.00
C11	(-)	n/a	(-)	n/a	26.62	1.30	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C12	LOD	n/a	(-)	n/a	9.54	3.77	10.56	0.69	LOD	n/a	0.00	0.00	0.00	0.00
Acetone	LOD	n/a	(-)	n/a	26.76	4.49	29.52	6.47	18.59	2.40	0.00	0.00	0.00	0.00

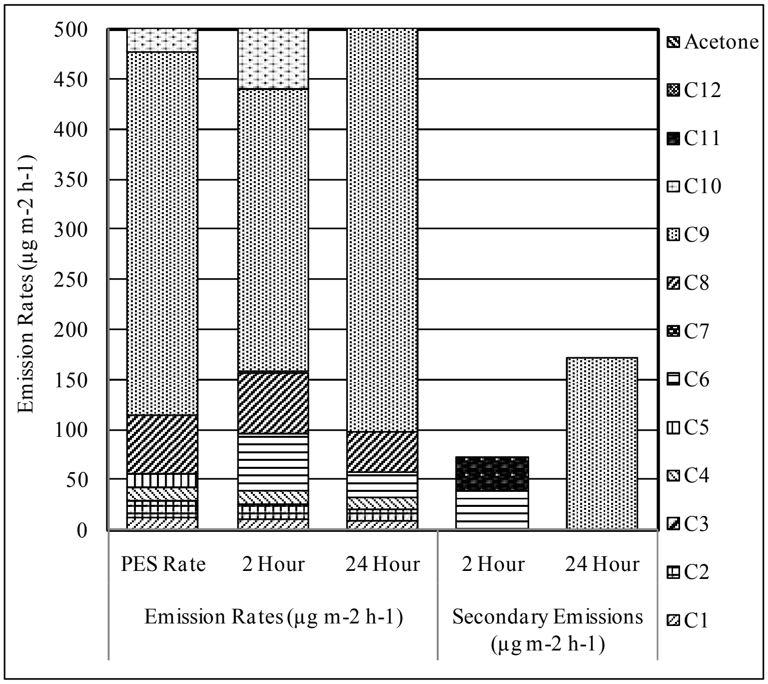




10. Rubber - First Experiment

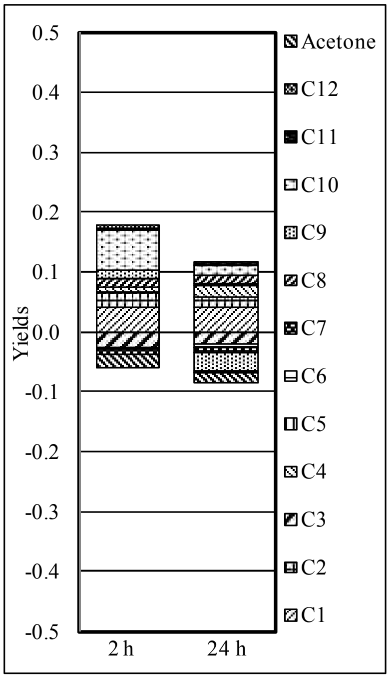
	Yields				Emission Rates (µg m^{-2} h^{-1})						Secondary Emissions (µg m^{-2} h^{-1})			
	2 Hour	Error	24 Hour	Error	PES Rate	Error	2 Hour	Error	24 Hour	Error	2 Hour	Error	24 Hour	Error
C1	(-)	n/a	(-)	n/a	12.45	6.22	11.62	0.39	8.45	0.01	0.00	0.00	0.00	0.00
C2	(-)	n/a	(-)	n/a	16.54	0.00	14.01	0.30	13.32	0.01	0.00	0.00	0.00	0.00
C3	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C4	(-)	n/a	(-)	n/a	14.19	0.00	14.03	0.28	10.55	0.01	0.00	0.00	0.00	0.00
C5	(-)	n/a	(-)	n/a	12.79	0.00	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C6	LOD	n/a	LOD	n/a	LOD	n/a	56.99	0.00	25.47	7.64	39.23	0.00	0.00	0.00
C7	(-)	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C8	LOD	n/a	(-)	n/a	58.27	6.14	60.46	8.58	39.93	3.48	0.00	0.00	0.00	0.00
C9	(-)	n/a	0.18	0.07	363.41	12.46	282.55	46.51	533.90	####	0.00	0.00	170.49	68.20
C10	(-)	n/a	(-)	n/a	102.78	6.85	70.53	10.59	94.60	38.44	0.00	0.00	0.00	0.00
C11	LOD	n/a	(-)	n/a	96.42	4.75	130.34	24.35	60.14	2.88	33.92	14.55	0.00	0.00
C12	(-)	n/a	(-)	n/a	38.12	3.47	35.48	8.09	16.98	4.16	0.00	0.00	0.00	0.00
Acetone	LOD	n/a	LOD	n/a	45.87	0.00	47.78	1.52	49.54	1.82	0.00	0.00	0.00	0.00

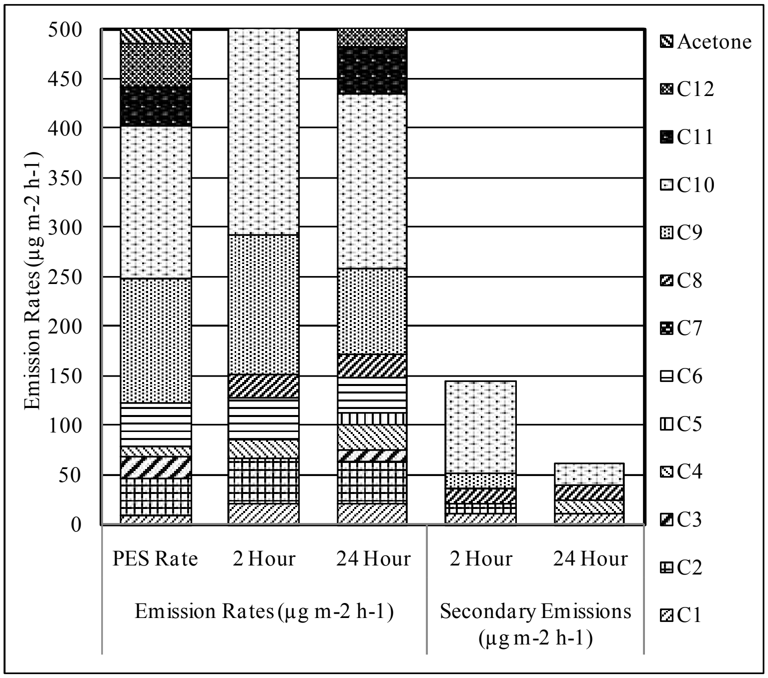




11. Rubber - Replicate Experiment

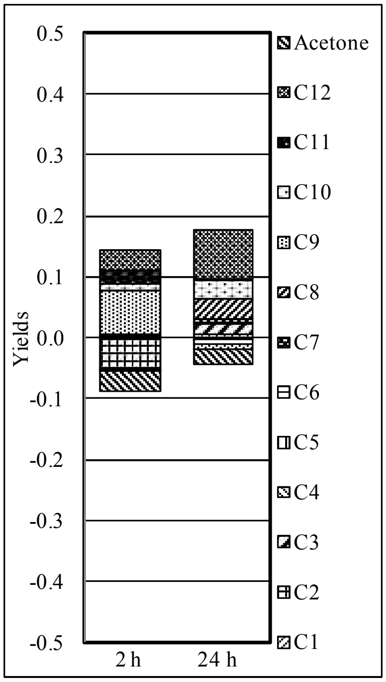
	Yields				Emission Rates (μg m^{-2} h^{-1})						Secondary Emissions (μg m^{-2} h^{-1})			
	2 Hour	Error	24 Hour	Error	PES Rate	Error	2 Hour	Error	24 Hour	Error	2 Hour	Error	24 Hour	Error
C1	0.04	0.01	0.04	0.01	10.08	4.84	21.32	6.39	21.24	0.23	11.23	2.53	11.15	2.53
C2	LOD	n/a	LOD	n/a	36.82	11.05	46.22	14.20	42.88	0.30	9.40	3.76	0.00	0.00
C3	(-)	n/a	(-)	n/a	20.96	6.29	LOD	n/a	11.08	0.10	0.00	0.00	0.00	0.00
C4	LOD	n/a	LOD	n/a	11.69	3.51	18.03	6.77	25.69	0.32	0.00	0.00	14.00	1.91
C5	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	11.33	0.04	0.00	0.00	0.00	0.00
C6	(-)	n/a	(-)	n/a	43.24	1.05	42.76	3.88	36.86	7.26	0.00	0.00	0.00	0.00
C7	(-)	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C8	LOD	n/a	LOD	n/a	LOD	n/a	23.65	8.55	22.85	10.74	15.84	4.27	15.04	5.37
C9	LOD	n/a	(-)	n/a	125.01	14.33	139.80	6.95	86.83	26.48	14.79	5.92	0.00	0.00
C10	0.07	0.01	LOD	n/a	153.98	46.19	246.96	48.39	175.70	52.71	92.98	37.19	21.72	8.69
C11	LOD	n/a	LOD	n/a	40.22	9.74	47.67	4.95	48.54	8.46	0.00	0.00	0.00	0.00
C12	LOD	n/a	(-)	n/a	43.25	15.10	49.49	11.96	38.75	13.61	0.00	0.00	0.00	0.00
Acetone	(-)	n/a	(-)	n/a	63.73	7.29	52.51	24.20	54.22	16.27	0.00	0.00	0.00	0.00

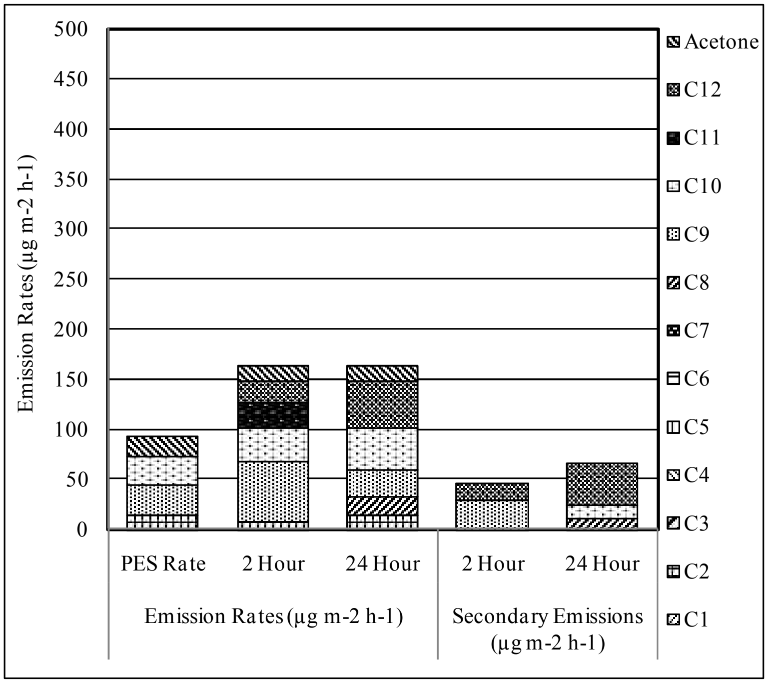




12. Armstrong - First Experiment

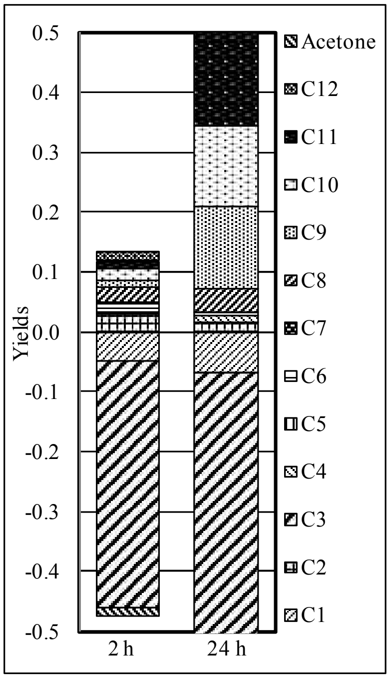
	Yields				Emission Rates (μg m^{-2} h^{-1})						Secondary Emissions (μg m^{-2} h^{-1})			
	2 Hour	Error	24 Hour	Error	PES Rate	Error	2 Hour	Error	24 Hour	Error	2 Hour	Error	24 Hour	Error
C1	(-)	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C2	(-)	n/a	LOD	n/a	13.64	2.25	7.96	1.89	14.39	0.10	0.00	0.00	0.00	0.00
C3	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C4	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C5	(-)	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C6	LOD	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C7	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C8	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	17.93	5.38	0.00	0.00	11.49	2.69
C9	LOD	n/a	(-)	n/a	30.72	9.22	59.61	17.88	26.50	7.95	28.89	13.55	0.00	0.00
C10	LOD	n/a	LOD	n/a	28.94	14.00	33.80	10.14	42.16	7.02	0.00	0.00	13.22	5.29
C11	LOD	n/a	LOD	n/a	LOD	n/a	24.54	5.97	LOD	n/a	0.00	0.00	0.00	0.00
C12	LOD	n/a	0.08	0.07	LOD	n/a	22.66	3.67	46.97	14.09	17.90	1.83	42.21	7.05
Acetone	(-)	n/a	(-)	n/a	20.07	1.48	14.60	0.19	16.28	0.01	0.00	0.00	0.00	0.00

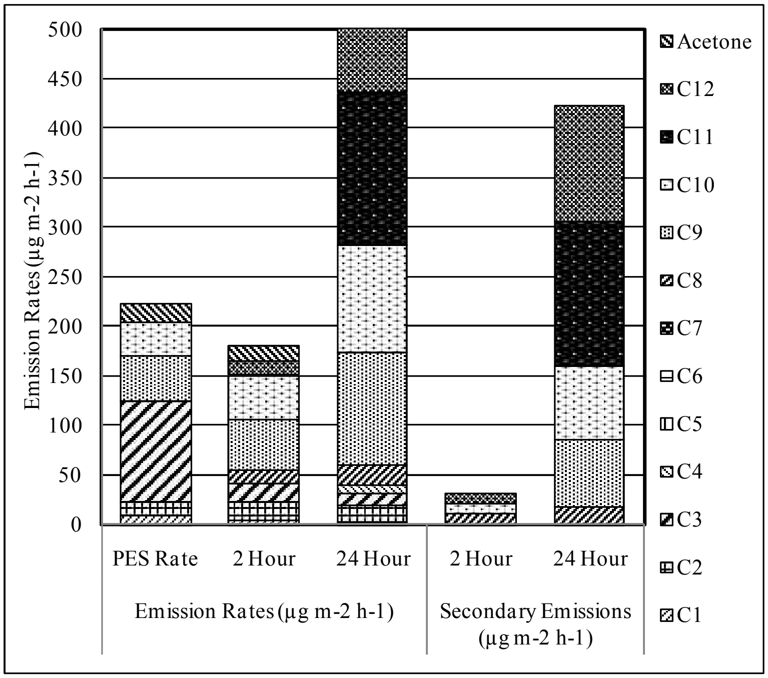




13. Armstrong - Replicate

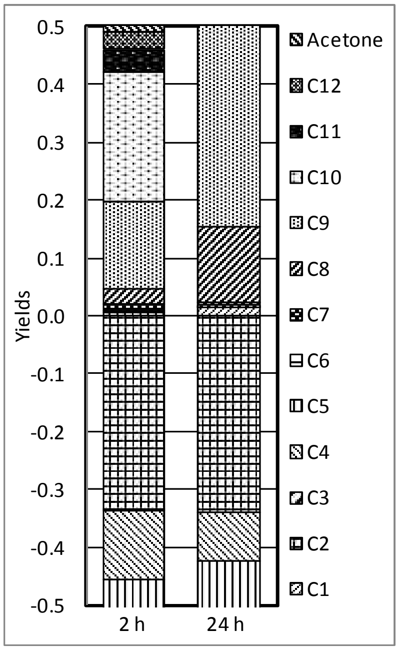
	Yields				Emission Rates (µg m^{-2} h^{-1})						Secondary Emissions (µg m^{-2} h^{-1})			
	2 Hour	Error	24 Hour	Error	PES Rate	Error	2 Hour	Error	24 Hour	Error	2 Hour	Error	24 Hour	Error
C1	(-)	n/a	(-)	n/a	9.38	4.51	4.21	1.26	2.22	0.01	0.00	0.00	0.00	0.00
C2	LOD	n/a	LOD	n/a	14.07	3.74	18.89	6.33	16.75	0.00	0.00	0.00	0.00	0.00
C3	(-)	n/a	(-)	n/a	101.42	12.24	18.11	5.43	12.00	0.12	0.00	0.00	0.00	0.00
C4	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	8.65	0.05	0.00	0.00	0.00	0.00
C5	(-)	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C6	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C7	LOD	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C8	LOD	n/a	LOD	n/a	LOD	n/a	13.03	0.99	20.11	7.38	10.28	0.49	17.35	3.69
C9	LOD	n/a	0.14	0.03	45.41	21.90	51.63	8.48	113.90	34.17	0.00	0.00	68.49	28.04
C10	LOD	n/a	0.13	0.05	34.31	10.29	44.43	18.81	108.08	32.42	10.12	4.05	73.78	21.36
C11	LOD	n/a	0.24	0.07	LOD	n/a	LOD	n/a	153.66	46.10	0.00	0.00	145.70	23.05
C12	LOD	n/a	0.18	0.04	LOD	n/a	14.41	3.94	121.42	36.42	9.41	1.97	116.42	18.21
Acetone	(-)	n/a	LOD	n/a	18.30	6.79	15.69	7.65	24.34	1.40	0.00	0.00	0.00	0.00

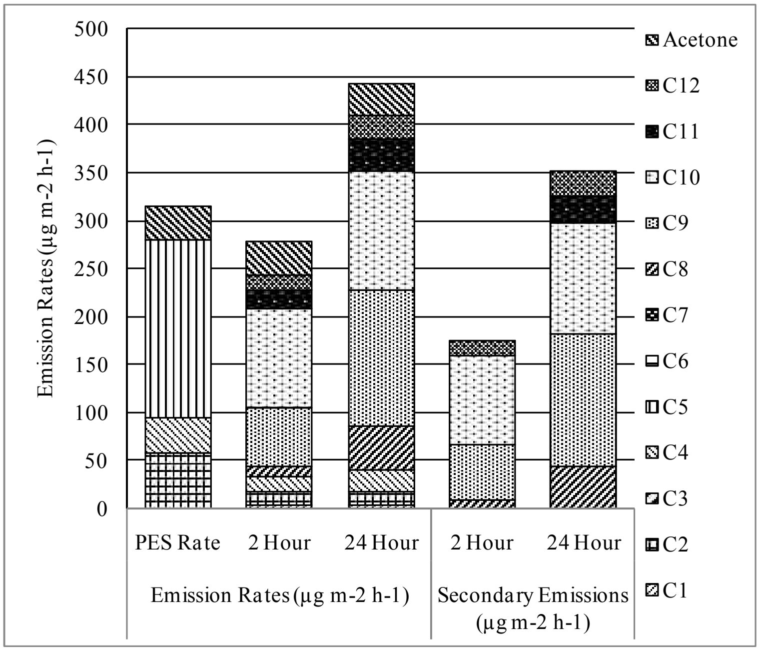




14. Armstrong - Second Replicate Experiment

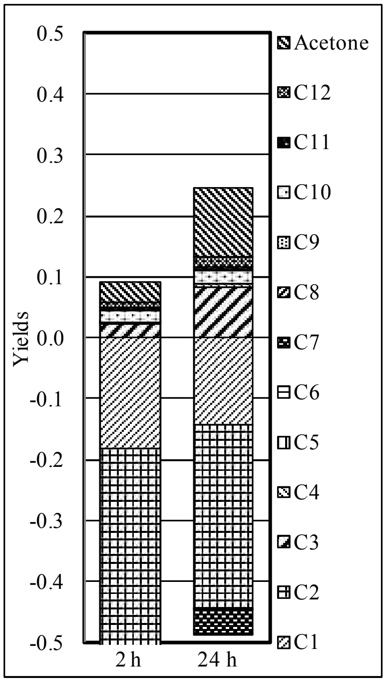
	Yields				Emission Rates (μg m^{-2} h^{-1})						Secondary Emissions (μg m^{-2} h^{-1})			
	2 Hour	Error	24 Hour	Error	PES Rate	Error	2 Hour	Error	24 Hour	Error	2 Hour	Error	24 Hour	Error
C1	LOD	n/a	LOD	n/a	2.64	0.79	2.96	0.47	3.63	0.01	0.00	0.00	0.00	0.00
C2	(-)	n/a	(-)	n/a	54.93	7.44	15.58	2.60	14.89	0.05	0.00	0.00	0.00	0.00
C3	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C4	(-)	n/a	(-)	n/a	37.40	1.90	14.21	4.37	21.38	0.01	0.00	0.00	0.00	0.00
C5	(-)	n/a	(-)	n/a	186.20	55.86	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C6	LOD	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C7	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C8	LOD	n/a	0.13	0.06	LOD	n/a	12.02	5.53	46.31	13.89	9.72	2.77	44.01	6.95
C9	0.15	0.03	0.37	0.15	LOD	n/a	60.03	25.93	141.17	42.35	56.90	12.97	138.04	21.18
C10	0.23	0.06	0.28	0.07	LOD	n/a	103.19	30.96	124.79	37.44	93.68	15.48	115.29	18.72
C11	LOD	n/a	LOD	n/a	LOD	n/a	20.53	8.52	32.60	9.78	0.00	0.00	29.34	4.89
C12	LOD	n/a	LOD	n/a	LOD	n/a	14.68	4.40	25.10	7.53	14.68	2.20	25.10	3.77
Acetone	LOD	n/a	LOD	n/a	33.28	3.71	35.41	0.36	33.57	0.93	0.00	0.00	0.00	0.00

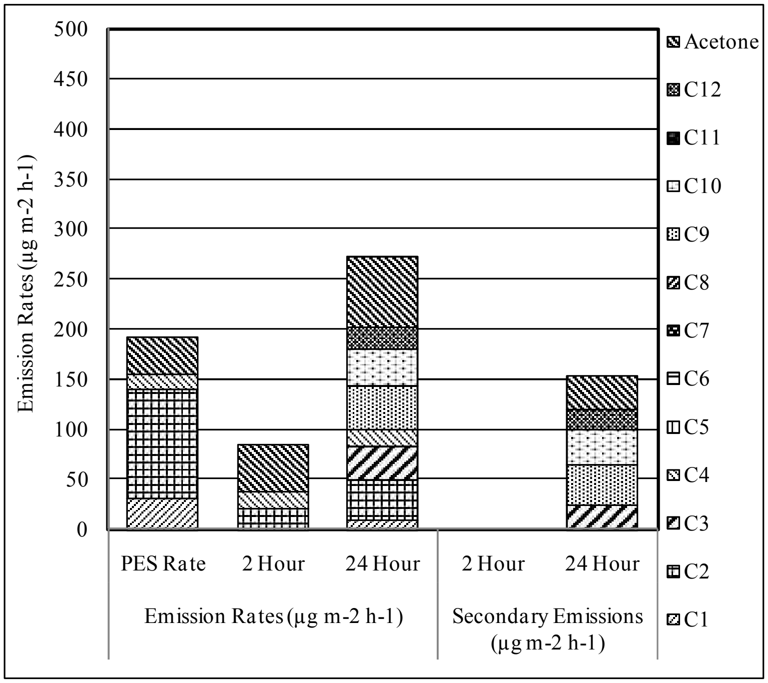




15. Clay Tile - First Experiment

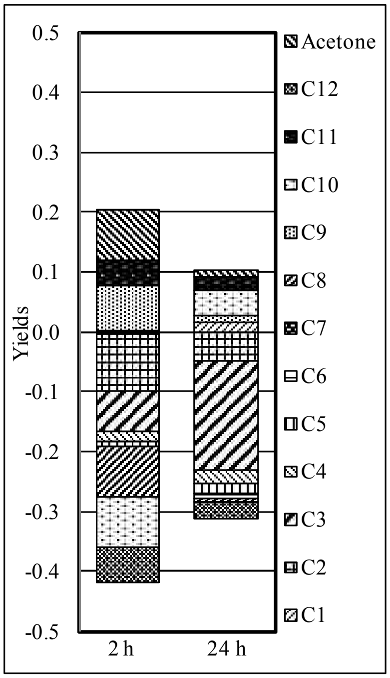
	Yields				Emission Rates (μg m^{-2} h^{-1})						Secondary Emissions (μg m^{-2} h^{-1})			
	2 Hour	Error	24 Hour	Error	PES Rate	Error	2 Hour	Error	24 Hour	Error	2 Hour	Error	24 Hour	Error
C1	(-)	n/a	(-)	n/a	30.79	9.24	LOD	n/a	8.38	0.02	0.00	0.00	0.00	0.00
C2	(-)	n/a	(-)	n/a	109.62	37.68	21.55	8.76	41.36	0.12	0.00	0.00	0.00	0.00
C3	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	32.53	0.42	0.00	0.00	24.44	0.21
C4	LOD	n/a	LOD	n/a	14.45	1.31	15.48	5.05	16.81	0.11	0.00	0.00	0.00	0.00
C5	LOD	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C6	(-)	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C7	(-)	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C8	(-)	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C9	(-)	n/a	(-)	n/a	LOD	n/a	LOD	n/a	43.78	13.14	0.00	0.00	40.25	6.57
C10	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	37.50	2.23	0.00	0.00	35.85	1.12
C11	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C12	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	21.54	6.46	0.00	0.00	18.73	3.23
Acetone	LOD	n/a	LOD	n/a	37.34	0.35	47.21	9.68	70.79	21.24	0.00	0.00	33.45	10.79

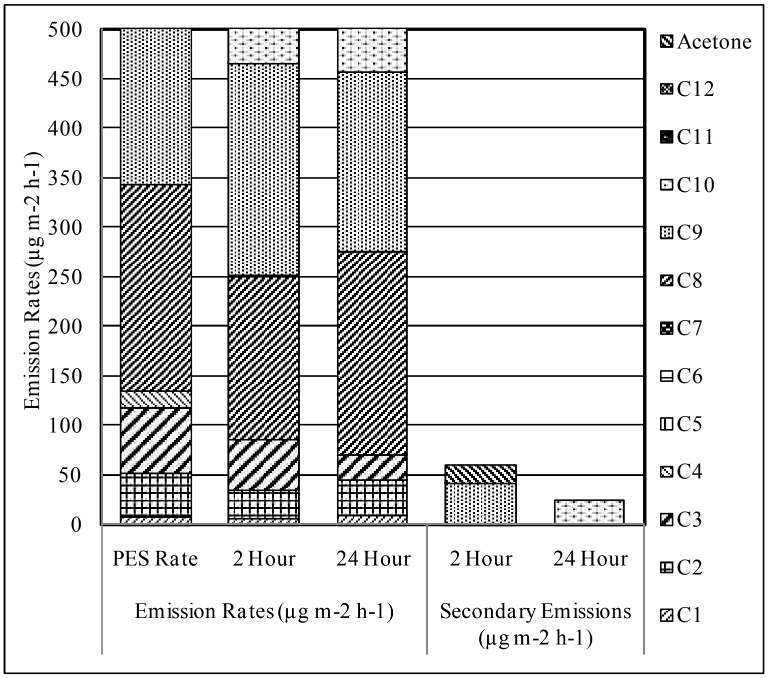




16. Clay Tile - Replicate Experiment

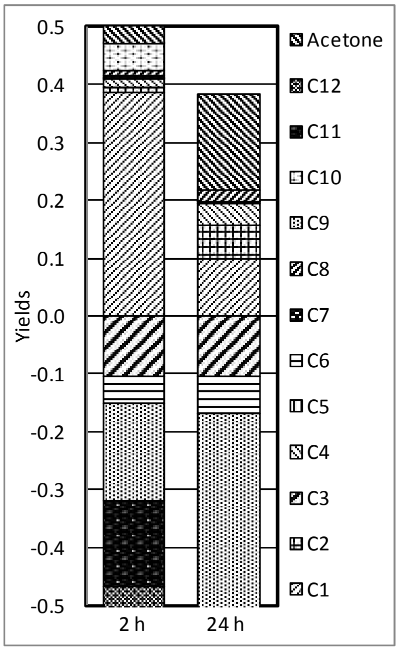
	Yields				Emission Rates (μg m^{-2} h^{-1})						Secondary Emissions (μg m^{-2} h^{-1})			
	2 Hour	Error	24 Hour	Error	PES Rate	Error	2 Hour	Error	24 Hour	Error	2 Hour	Error	24 Hour	Error
C1	(-)	n/a	LOD	n/a	6.85	2.05	6.50	0.17	8.64	0.01	0.00	0.00	0.00	0.00
C2	(-)	n/a	(-)	n/a	44.38	5.98	27.99	1.75	36.01	0.19	0.00	0.00	0.00	0.00
C3	(-)	n/a	(-)	n/a	66.62	5.11	51.58	13.39	25.72	0.30	0.00	0.00	0.00	0.00
C4	(-)	n/a	(-)	n/a	17.30	1.12	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C5	(-)	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C6	LOD	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C7	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C8	(-)	n/a	(-)	n/a	207.32	67.86	164.62	49.39	204.64	52.62	0.00	0.00	0.00	0.00
C9	0.08	0.05	0.01	0.12	173.70	86.85	215.44	69.82	181.25	42.86	41.73	16.69	0.00	0.00
C10	(-)	n/a	LOD	n/a	162.13	33.80	111.28	33.38	187.11	69.94	0.00	0.00	24.98	9.99
C11	0.04	0.00	0.02	0.01	91.43	30.11	120.26	36.08	106.83	32.56	0.00	0.00	0.00	0.00
C12	(-)	n/a	(-)	n/a	145.41	65.33	103.41	31.02	124.79	20.34	0.00	0.00	0.00	0.00
Acetone	0.08	0.00	0.01	0.00	LOD	n/a	27.63	8.29	LOD	n/a	19.07	4.14	0.00	0.00

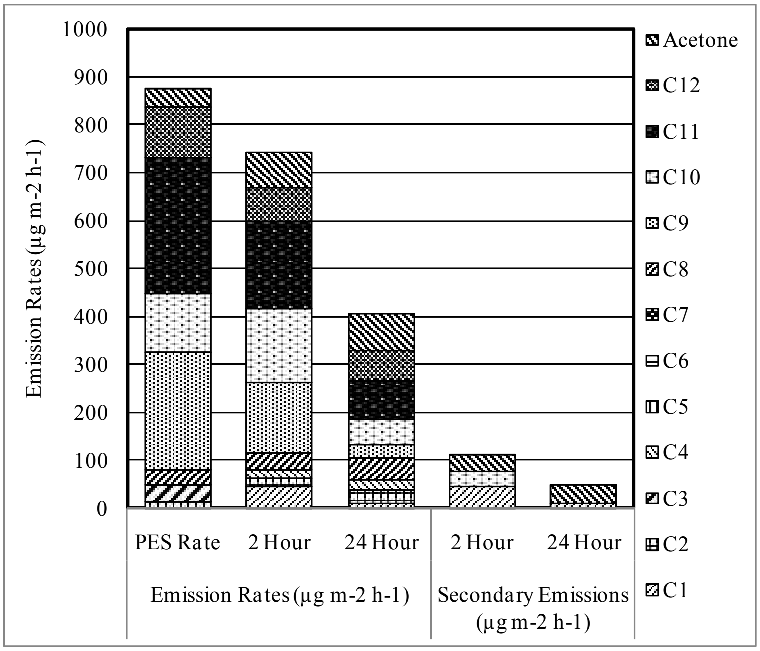




17. Clay Tile - Second Replicate Experiment

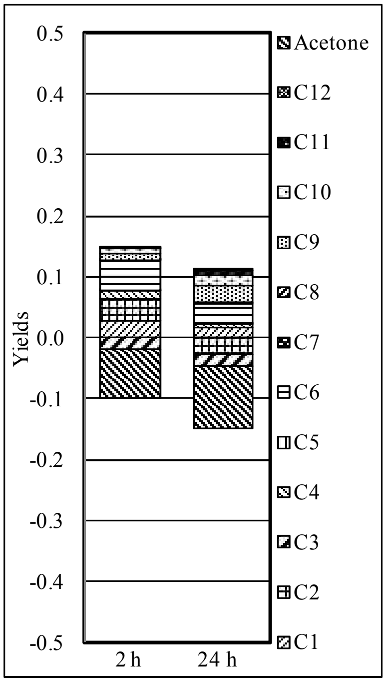
	Yields				Emission Rates (μg m^{-2} h^{-1})						Secondary Emissions (μg m^{-2} h^{-1})			
	2 Hour	Error	24 Hour	Error	PES Rate	Error	2 Hour	Error	24 Hour	Error	2 Hour	Error	24 Hour	Error
C1	0.38	0.22	0.10	0.04	(-)	n/a	46.02	13.81	11.30	0.12	46.52	0.06	11.80	0.06
C2	LOD	n/a	LOD	n/a	16.08	3.22	17.79	0.59	26.66	0.15	0.00	0.00	0.00	0.00
C3	(-)	n/a	(-)	n/a	32.37	6.47	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C4	LOD	n/a	LOD	n/a	LOD	n/a	15.71	2.06	21.73	0.13	0.00	0.00	0.00	0.00
C5	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C6	(-)	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C7	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C8	LOD	n/a	LOD	n/a	34.04	6.81	37.57	6.83	44.83	21.97	0.00	0.00	0.00	0.00
C9	(-)	n/a	(-)	n/a	243.34	48.67	147.68	11.67	28.17	0.00	0.00	0.00	0.00	0.00
C10	LOD	n/a	(-)	n/a	122.22	24.44	153.21	40.86	52.98	2.02	30.99	12.40	0.00	0.00
C11	(-)	n/a	(-)	n/a	284.68	56.94	181.70	65.32	82.31	24.35	0.00	0.00	0.00	0.00
C12	(-)	n/a	(-)	n/a	104.67	20.93	69.72	11.92	62.85	18.86	0.00	0.00	0.00	0.00
Acetone	0.16	0.04	0.16	0.04	38.28	7.66	74.99	1.05	76.55	0.49	36.71	4.35	38.27	4.08

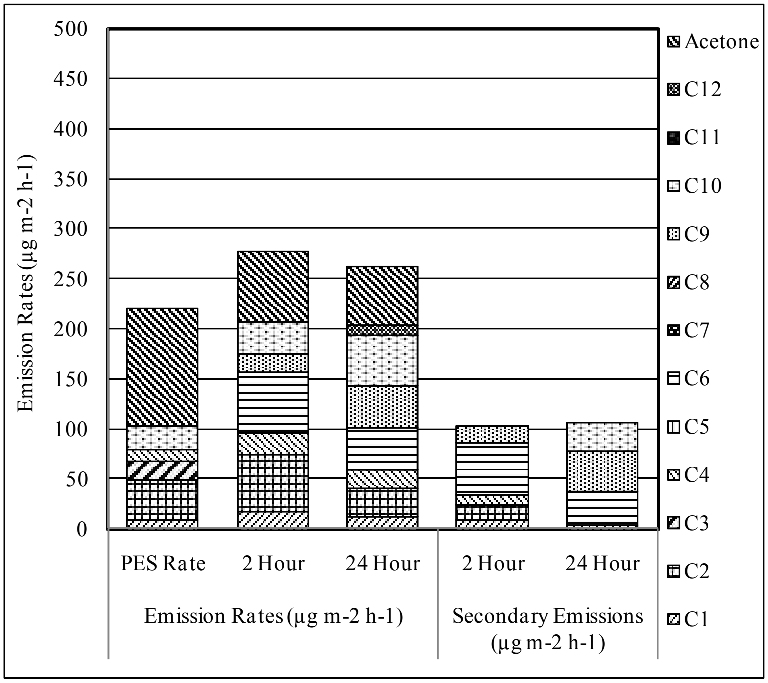




18. Ecotimbers - First Experiment

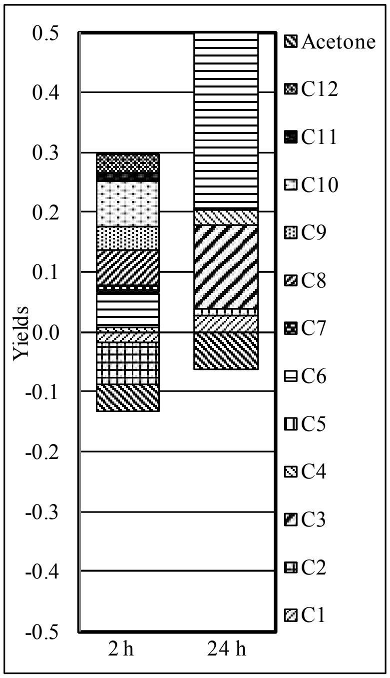
	Yields				Emission Rates (μg m^{-2} h^{-1})						Secondary Emissions (μg m^{-2} h^{-1})			
	2 Hour	Error	24 Hour	Error	PES Rate	Error	2 Hour	Error	24 Hour	Error	2 Hour	Error	24 Hour	Error
C1	0.03	0.00	LOD	n/a	8.39	3.97	16.87	7.77	13.00	0.09	8.48	2.03	4.61	2.03
C2	LOD	n/a	(-)	n/a	41.86	12.56	57.47	17.40	28.80	0.21	15.61	6.24	0.00	0.00
C3	(-)	n/a	(-)	n/a	17.12	5.14	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C4	LOD	n/a	LOD	n/a	12.64	3.79	22.90	5.15	17.49	0.12	10.26	4.47	0.00	0.00
C5	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C6	LOD	n/a	LOD	n/a	LOD	n/a	60.22	13.38	42.08	10.13	51.77	6.69	33.63	5.07
C7	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C8	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C9	LOD	n/a	LOD	n/a	LOD	n/a	17.99	2.13	41.60	8.09	16.21	1.06	39.82	4.04
C10	LOD	n/a	LOD	n/a	22.37	6.71	32.01	9.60	50.56	7.61	0.00	0.00	28.19	7.16
C11	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C12	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	11.09	3.86	0.00	0.00	0.00	0.00
Acetone	(-)	n/a	(-)	n/a	118.79	35.64	70.93	21.28	57.78	17.33	0.00	0.00	0.00	0.00

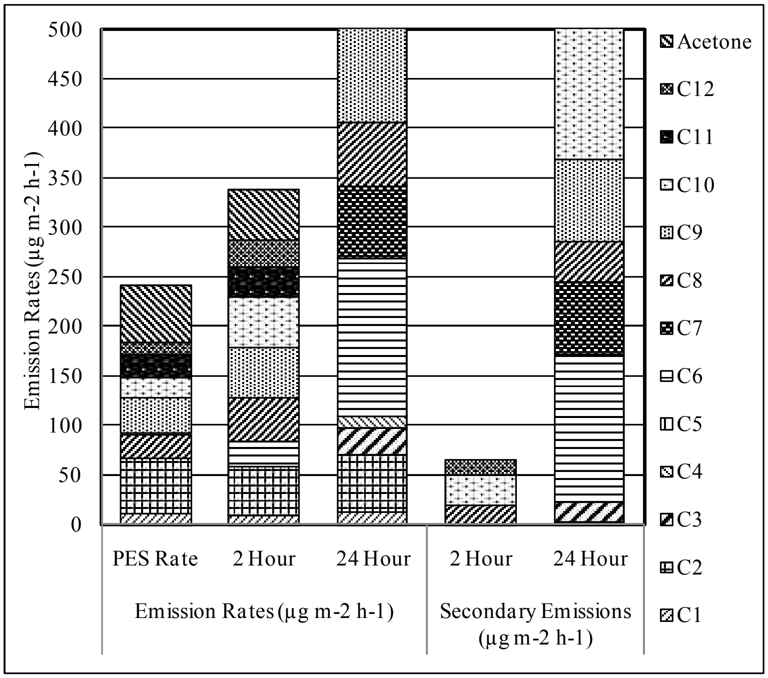




19. Ecotimbers - Replicate Experiment

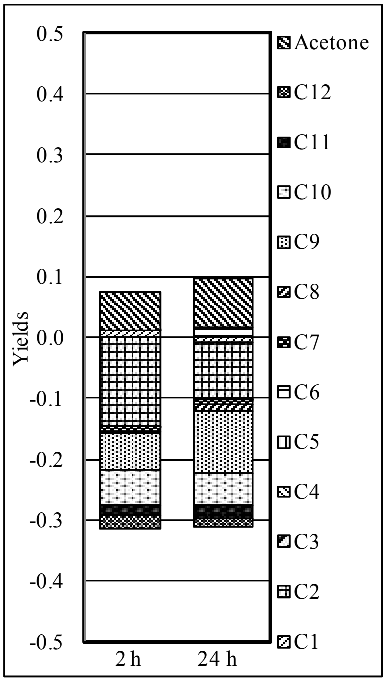
	Yields				Emission Rates ($\mu g\ m^{-2}\ h^{-1}$)						Secondary Emissions ($\mu g\ m^{-2}\ h^{-1}$)			
	2 Hour	Error	24 Hour	Error	PES Rate	Error	2 Hour	Error	24 Hour	Error	2 Hour	Error	24 Hour	Error
C1	(-)	n/a	LOD	n/a	10.76	3.57	9.41	0.63	13.03	0.05	0.00	0.00	2.27	0.91
C2	(-)	n/a	LOD	n/a	56.66	7.91	48.58	7.30	57.81	0.04	0.00	0.00	0.00	0.00
C3	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	26.08	0.35	0.00	0.00	21.17	0.18
C4	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	11.65	0.01	0.00	0.00	0.00	0.00
C5	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C6	LOD	n/a	0.57	0.33	LOD	n/a	26.14	7.84	159.42	47.83	0.00	0.00	147.95	23.91
C7	LOD	n/a	0.25	0.20	LOD	n/a	LOD	n/a	73.26	21.98	0.00	0.00	73.26	10.99
C8	LOD	n/a	0.12	0.06	23.68	7.10	43.17	1.66	64.40	19.32	19.49	4.38	40.72	13.21
C9	LOD	n/a	0.22	0.00	37.41	11.22	52.47	7.68	120.80	34.74	0.00	0.00	83.38	22.98
C10	LOD	n/a	0.40	0.19	19.95	5.99	50.70	15.98	182.26	86.06	30.75	10.98	162.31	46.03
C11	LOD	n/a	LOD	n/a	23.35	7.01	30.00	11.63	42.55	16.88	0.00	0.00	0.00	0.00
C12	LOD	n/a	LOD	n/a	11.68	5.09	26.25	9.12	33.34	2.57	14.57	7.11	21.66	3.83
Acetone	(-)	n/a	(-)	n/a	58.06	17.87	51.16	7.13	48.56	14.57	0.00	0.00	0.00	0.00

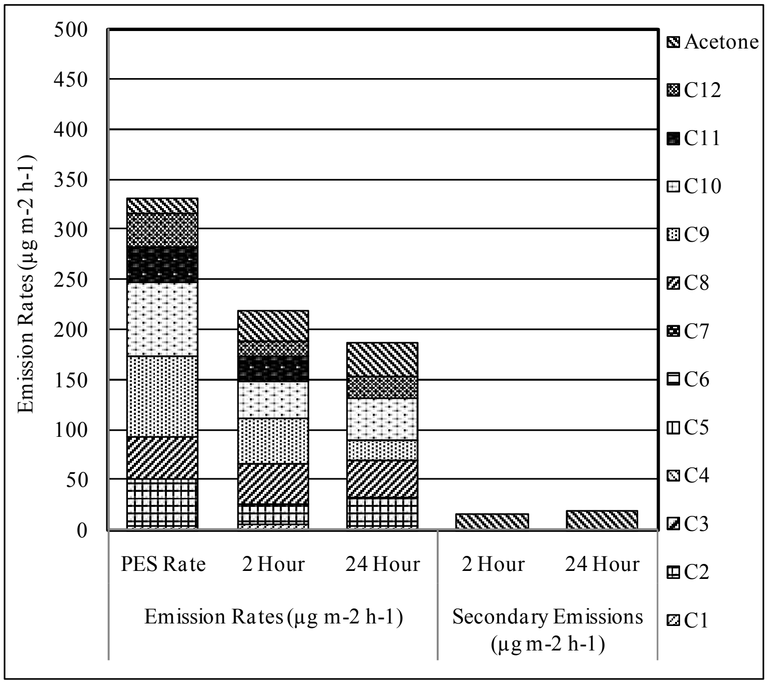




20. Plyboo - First Experiment

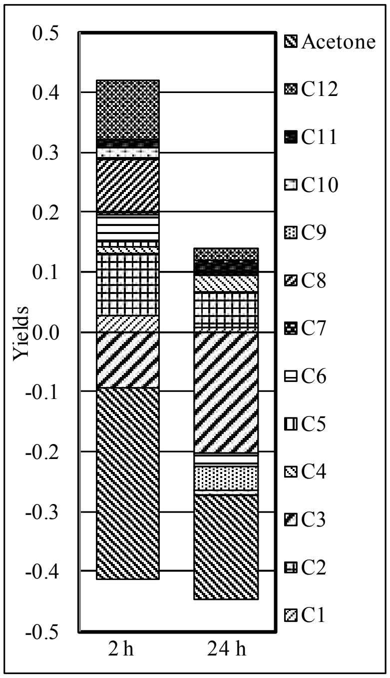
	Yields				Emission Rates (μg m^{-2} h^{-1})						Secondary Emissions (μg m^{-2} h^{-1})			
	2 Hour	Error	24 Hour	Error	PES Rate	Error	2 Hour	Error	24 Hour	Error	2 Hour	Error	24 Hour	Error
C1	LOD	n/a	(-)	n/a	4.70	2.23	5.87	0.94	3.66	0.01	0.00	0.00	0.00	0.00
C2	(-)	n/a	(-)	n/a	45.85	0.29	19.39	3.32	29.34	0.18	0.00	0.00	0.00	0.00
C3	(-)	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C4	LOD	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C5	(-)	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C6	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C7	(-)	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C8	(-)	n/a	(-)	n/a	42.23	12.67	41.23	12.37	36.64	10.99	0.00	0.00	0.00	0.00
C9	(-)	n/a	(-)	n/a	80.04	24.01	45.38	15.93	20.62	6.19	0.00	0.00	0.00	0.00
C10	(-)	n/a	(-)	n/a	74.75	22.42	36.65	11.00	41.13	3.07	0.00	0.00	0.00	0.00
C11	(-)	n/a	(-)	n/a	35.13	11.76	25.03	1.57	LOD	n/a	0.00	0.00	0.00	0.00
C12	(-)	n/a	(-)	n/a	33.15	9.94	15.79	6.23	22.67	6.80	0.00	0.00	0.00	0.00
Acetone	LOD	n/a	LOD	n/a	14.67	7.18	29.77	5.09	33.55	1.33	15.10	6.13	18.88	4.25

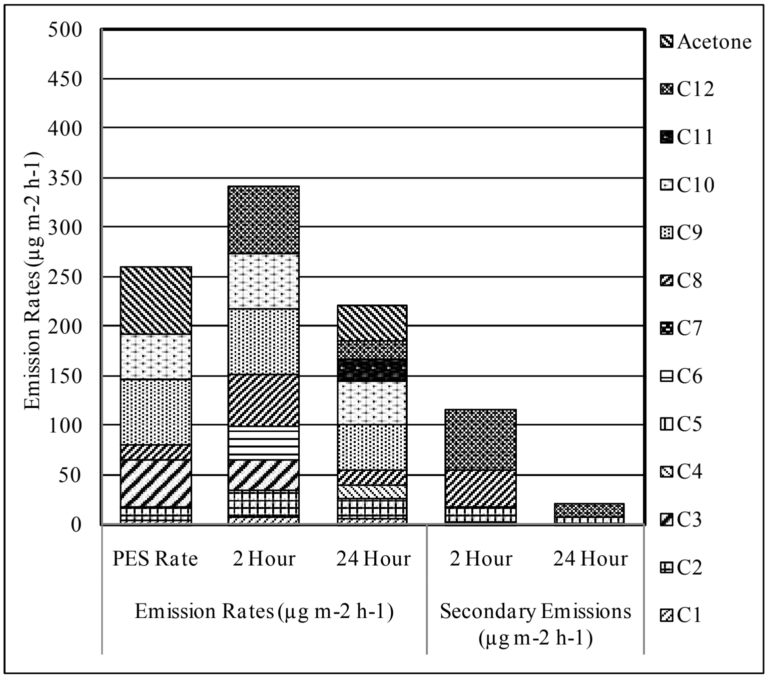




21. Plyboo - Replicate Experiment

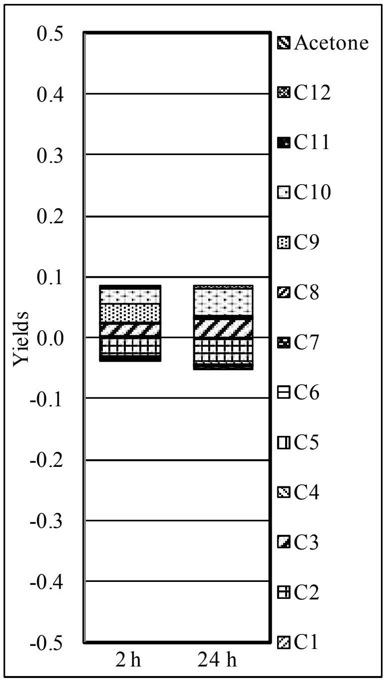
	Yields				Emission Rates (μg m^{-2} h^{-1})						Secondary Emissions (μg m^{-2} h^{-1})			
	2 Hour	Error	24 Hour	Error	PES Rate	Error	2 Hour	Error	24 Hour	Error	2 Hour	Error	24 Hour	Error
C1	LOD	n/a	LOD	n/a	4.61	1.38	7.28	0.00	5.50	0.05	2.67	0.35	0.00	0.00
C2	LOD	n/a	LOD	n/a	12.52	3.90	28.05	0.00	20.82	0.04	15.53	1.95	8.30	1.97
C3	(-)	n/a	(-)	n/a	47.90	14.37	30.02	0.00	LOD	n/a	0.00	0.00	0.00	0.00
C4	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	12.98	0.04	0.00	0.00	0.00	0.00
C5	LOD	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C6	LOD	n/a	(-)	n/a	LOD	n/a	34.07	0.32	LOD	n/a	0.00	0.00	0.00	0.00
C7	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C8	0.09	0.00	LOD	n/a	15.46	5.04	52.54	0.49	15.96	4.79	37.07	2.77	0.00	0.00
C9	LOD	n/a	(-)	n/a	65.56	19.67	66.50	0.62	46.27	13.88	0.00	0.00	0.00	0.00
C10	LOD	n/a	(-)	n/a	46.79	14.04	54.97	0.52	42.51	18.84	0.00	0.00	0.00	0.00
C11	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	22.23	8.61	0.00	0.00	0.00	0.00
C12	0.10	0.00	LOD	n/a	LOD	n/a	68.34	0.64	20.04	4.83	60.48	0.32	12.19	2.41
Acetone	(-)	n/a	(-)	n/a	67.74	20.32	LOD	n/a	34.37	12.07	0.00	0.00	0.00	0.00

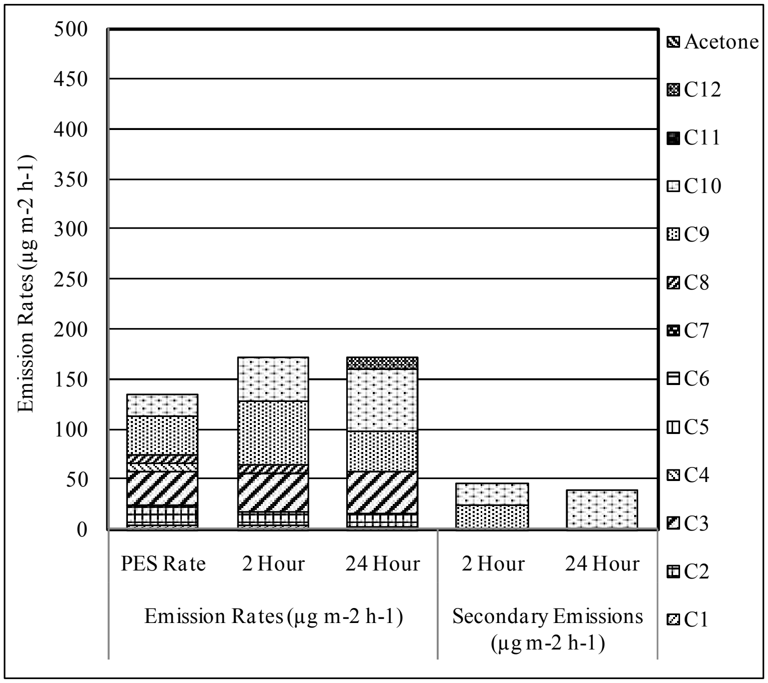




22. Cork - First Experiment

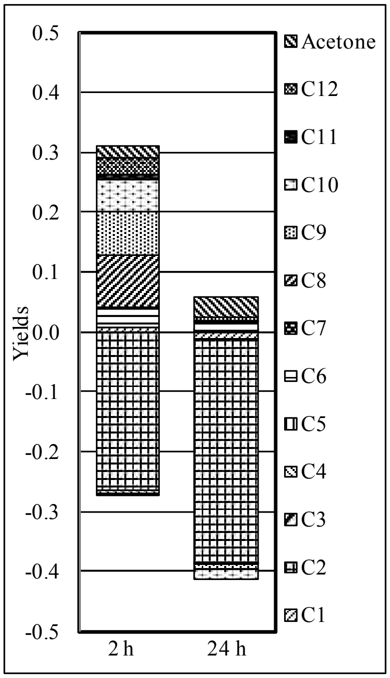
	Yields				Emission Rates (µg m^{-2} h^{-1})						Secondary Emissions (µg m^{-2} h^{-1})			
	2 Hour	Error	24 Hour	Error	PES Rate	Error	2 Hour	Error	24 Hour	Error	2 Hour	Error	24 Hour	Error
C1	LOD	n/a	(-)	n/a	3.69	1.81	3.81	0.43	3.22	0.00	0.00	0.00	0.00	0.00
C2	(-)	n/a	(-)	n/a	21.41	0.52	13.79	0.62	12.13	0.01	0.00	0.00	0.00	0.00
C3	LOD	n/a	LOD	n/a	32.73	0.09	39.21	0.03	41.97	0.03	0.00	0.00	0.00	0.00
C4	(-)	n/a	(-)	n/a	7.64	0.79	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C5	LOD	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C6	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C7	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C8	(-)	n/a	(-)	n/a	8.93	2.24	8.27	0.96	LOD	n/a	0.00	0.00	0.00	0.00
C9	LOD	n/a	LOD	n/a	38.81	10.14	62.60	18.78	40.94	12.28	23.78	9.51	0.00	0.00
C10	LOD	n/a	0.05	0.03	22.11	0.85	44.42	13.33	61.94	18.58	22.31	7.09	39.83	9.72
C11	(-)	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C12	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	12.02	3.61	0.00	0.00	0.00	0.00
Acetone	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00

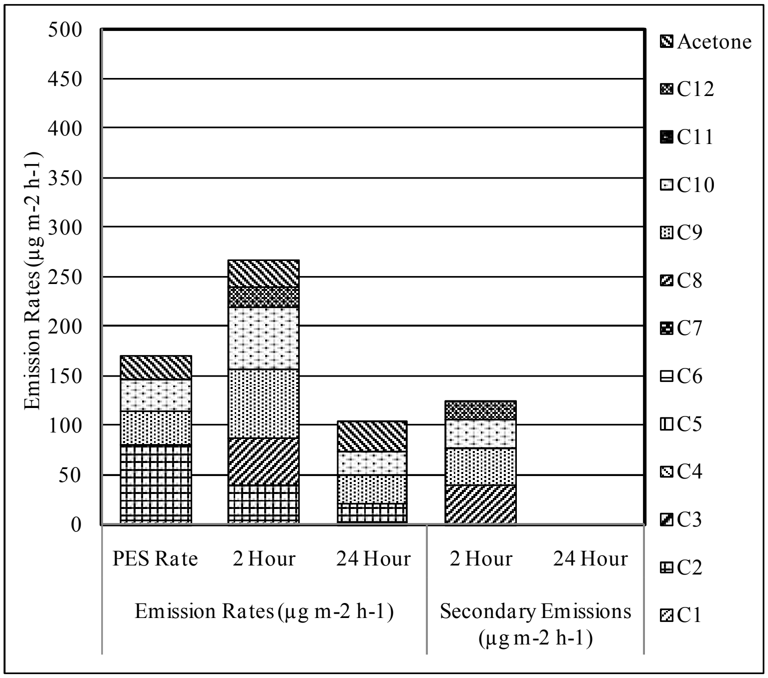




23. Cork - Replicate Experiment

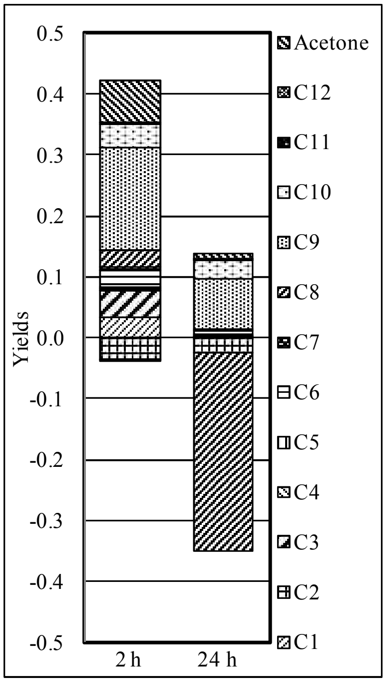
	Yields				Emission Rates (μg m^{-2} h^{-1})						Secondary Emissions (μg m^{-2} h^{-1})			
	2 Hour	Error	24 Hour	Error	PES Rate	Error	2 Hour	Error	24 Hour	Error	2 Hour	Error	24 Hour	Error
C1	LOD	n/a	(-)	n/a	4.18	1.87	5.00	0.45	2.81	0.00	0.00	0.00	0.00	0.00
C2	(-)	n/a	(-)	n/a	76.00	5.29	34.65	10.40	18.05	0.03	0.00	0.00	0.00	0.00
C3	(-)	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C4	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C5	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C6	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C7	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C8	0.09	0.02	(-)	n/a	LOD	n/a	46.79	14.04	LOD	n/a	39.82	7.02	0.00	0.00
C9	LOD	n/a	(-)	n/a	33.72	3.75	70.42	21.13	29.95	2.28	36.70	12.44	0.00	0.00
C10	LOD	n/a	(-)	n/a	32.59	11.97	62.01	18.60	23.60	5.99	29.42	11.77	0.00	0.00
C11	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C12	LOD	n/a	LOD	n/a	LOD	n/a	20.58	6.18	LOD	n/a	19.06	3.09	0.00	0.00
Acetone	LOD	n/a	LOD	n/a	23.44	1.88	27.35	1.26	30.55	0.08	0.00	0.00	0.00	0.00

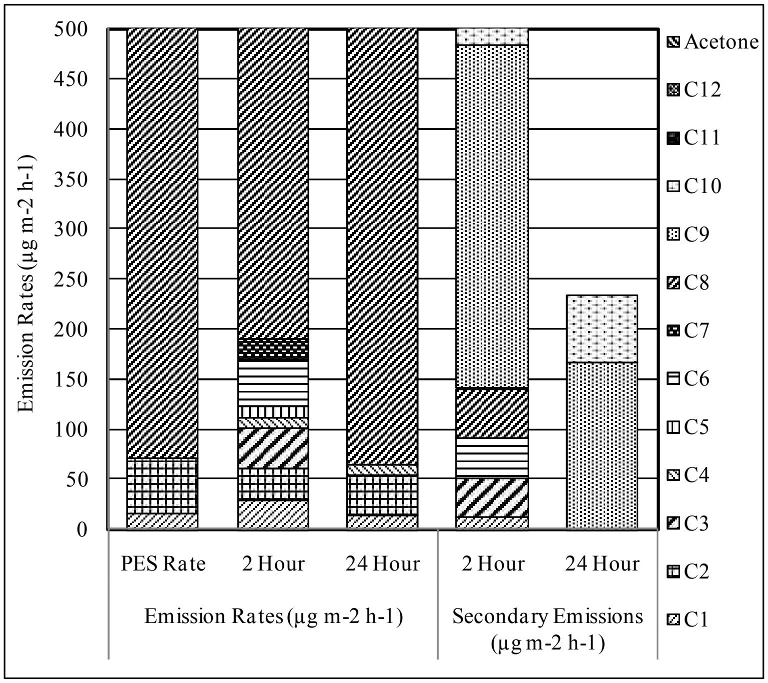




24. Acoustic - First Experiment

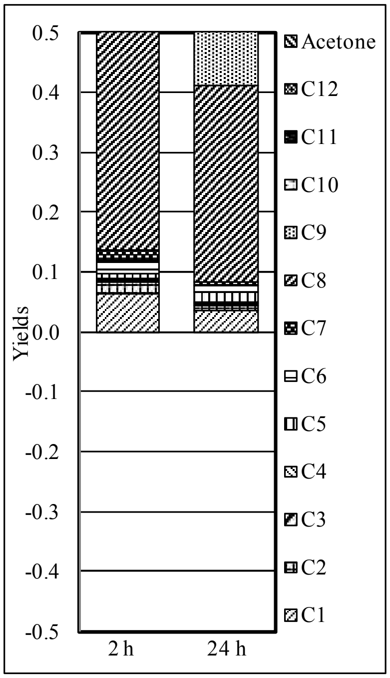
	Yields				Emission Rates (µg m^{-2} h^{-1})						Secondary Emissions (µg m^{-2} h^{-1})			
	2 Hour	Error	24 Hour	Error	PES Rate	Error	2 Hour	Error	24 Hour	Error	2 Hour	Error	24 Hour	Error
C1	0.03	0.00	(-)	n/a	15.22	6.30	28.57	6.18	14.82	0.06	13.35	0.00	0.00	0.00
C2	(-)	n/a	(-)	n/a	55.45	9.03	32.02	9.61	39.70	0.02	0.00	0.00	0.00	0.00
C3	0.05	0.00	LOD	n/a	LOD	n/a	41.57	12.47	LOD	n/a	37.42	6.24	0.00	0.00
C4	LOD	n/a	LOD	n/a	LOD	n/a	9.70	0.96	9.58	0.00	0.00	0.00	0.00	0.00
C5	LOD	n/a	LOD	n/a	LOD	n/a	10.90	1.50	LOD	n/a	0.00	0.00	0.00	0.00
C6	LOD	n/a	LOD	n/a	LOD	n/a	47.94	1.67	LOD	n/a	40.93	0.84	0.00	0.00
C7	LOD	n/a	LOD	n/a	LOD	n/a	20.38	3.62	LOD	n/a	0.00	0.00	0.00	0.00
C8	0.03	0.03	(-)	n/a	1708.38	328.84	1757.13	865.21	1116.27	176.65	48.75	19.50	0.00	0.00
C9	0.17	0.00	0.08	0.00	72.48	25.76	415.18	80.27	238.71	20.35	342.69	53.01	166.23	23.06
C10	0.04	0.00	0.03	0.01	47.68	17.68	134.17	37.59	114.58	6.38	86.49	27.63	66.90	12.03
C11	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	19.61	6.99	0.00	0.00	0.00	0.00
C12	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	11.64	0.44	0.00	0.00	0.00	0.00
Acetone	0.07	0.00	LOD	n/a	35.88	3.26	92.89	39.99	42.65	4.90	57.01	21.63	0.00	0.00

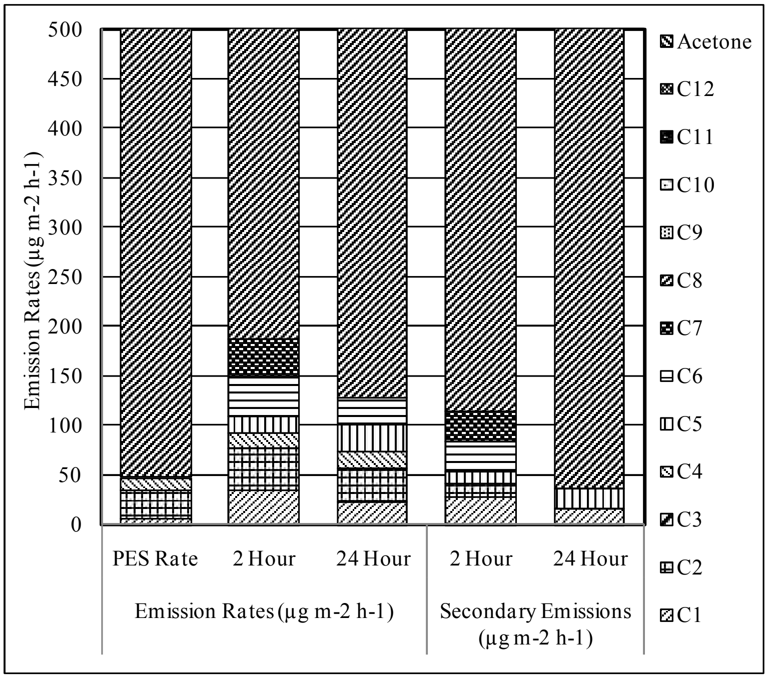




25. Acoustic - Replicate Experiment

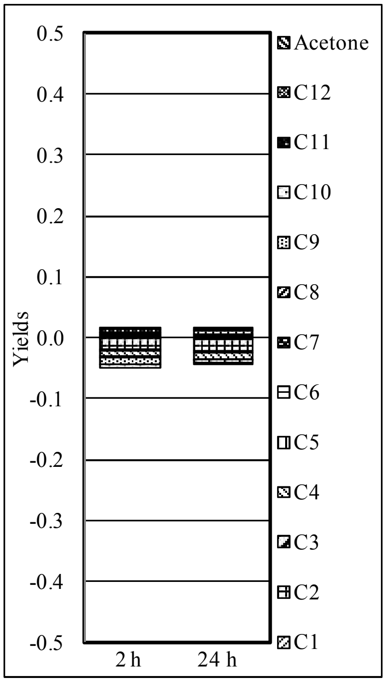
	Yields				Emission Rates (μg m^{-2} h^{-1})						Secondary Emissions (μg m^{-2} h^{-1})			
	2 Hour	Error	24 Hour	Error	PES Rate	Error	2 Hour	Error	24 Hour	Error	2 Hour	Error	24 Hour	Error
C1	0.06	0.00	0.03	0.00	6.51	1.95	35.16	10.55	22.20	0.19	28.66	1.07	15.69	1.07
C2	LOD	n/a	LOD	n/a	28.82	8.65	42.41	14.19	34.89	0.19	13.59	5.43	0.00	0.00
C3	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C4	LOD	n/a	LOD	n/a	12.02	3.85	15.32	6.69	16.60	0.14	0.00	0.00	0.00	0.00
C5	LOD	n/a	LOD	n/a	LOD	n/a	17.15	6.93	27.04	0.02	10.47	3.46	20.36	0.01
C6	LOD	n/a	LOD	n/a	LOD	n/a	40.64	6.17	27.44	3.62	31.57	3.08	0.00	0.00
C7	LOD	n/a	LOD	n/a	LOD	n/a	36.08	10.81	LOD	n/a	29.39	5.40	0.00	0.00
C8	0.55	0.02	0.33	0.01	466.89	15.82	1529.74	557.45	1097.40	295.13	1062.85	286.64	630.51	155.47
C9	0.15	0.01	0.10	0.01	133.99	40.83	462.06	186.66	354.75	172.74	328.06	113.74	220.76	106.78
C10	0.02	0.00	LOD	n/a	173.06	22.81	208.93	77.29	190.81	57.24	35.86	14.35	17.75	7.10
C11	LOD	n/a	LOD	n/a	36.44	3.31	42.77	12.59	37.97	11.71	0.00	0.00	0.00	0.00
C12	LOD	n/a	LOD	n/a	16.78	0.38	24.82	6.51	22.56	6.79	0.00	0.00	0.00	0.00
Acetone	0.11	0.01	0.06	0.00	30.33	10.74	127.11	38.13	78.31	35.37	96.78	24.44	47.98	23.05

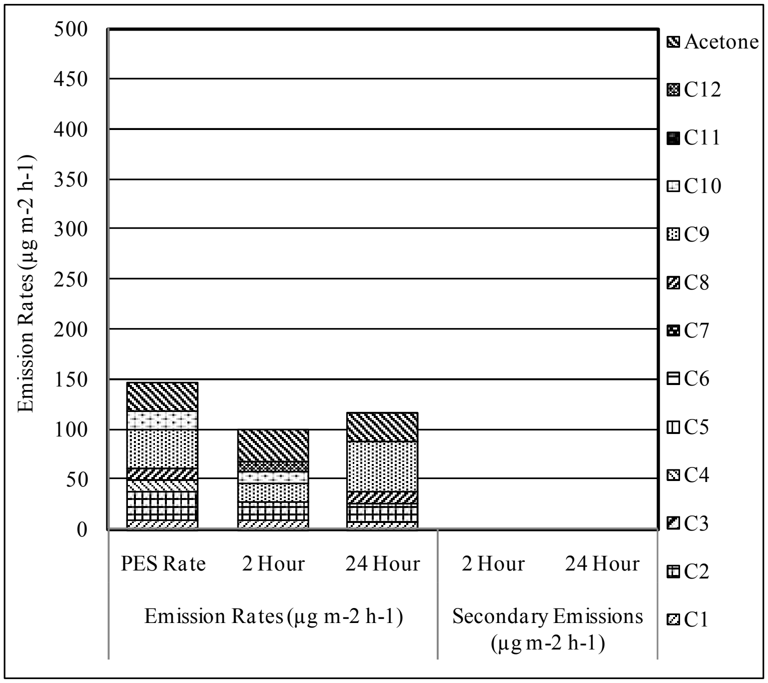




26. Rayon - First Experiment

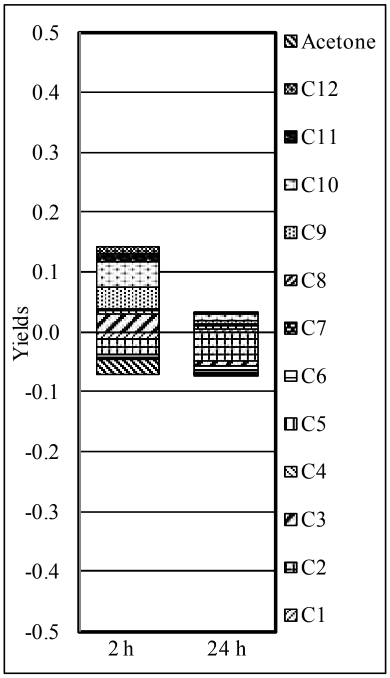
	Yields				Emission Rates (μg m^{-2} h^{-1})						Secondary Emissions (μg m^{-2} h^{-1})			
	2 Hour	Error	24 Hour	Error	PES Rate	Error	2 Hour	Error	24 Hour	Error	2 Hour	Error	24 Hour	Error
C1	(-)	n/a	(-)	n/a	9.68	2.90	9.25	1.67	8.03	0.02	0.00	0.00	0.00	0.00
C2	(-)	n/a	(-)	n/a	27.66	5.82	17.91	5.34	18.24	0.07	0.00	0.00	0.00	0.00
C3	(-)	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C4	(-)	n/a	(-)	n/a	12.58	5.79	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C5	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C6	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C7	LOD	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C8	(-)	n/a	LOD	n/a	11.12	3.34	LOD	n/a	12.17	3.42	0.00	0.00	0.00	0.00
C9	(-)	n/a	LOD	n/a	39.02	11.70	19.07	7.94	50.40	15.12	0.00	0.00	0.00	0.00
C10	(-)	n/a	(-)	n/a	18.69	9.11	11.47	4.68	LOD	n/a	0.00	0.00	0.00	0.00
C11	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C12	LOD	n/a	LOD	n/a	LOD	n/a	10.33	3.40	LOD	n/a	0.00	0.00	0.00	0.00
Acetone	LOD	n/a	(-)	n/a	28.73	7.26	31.79	3.81	28.12	5.39	0.00	0.00	0.00	0.00

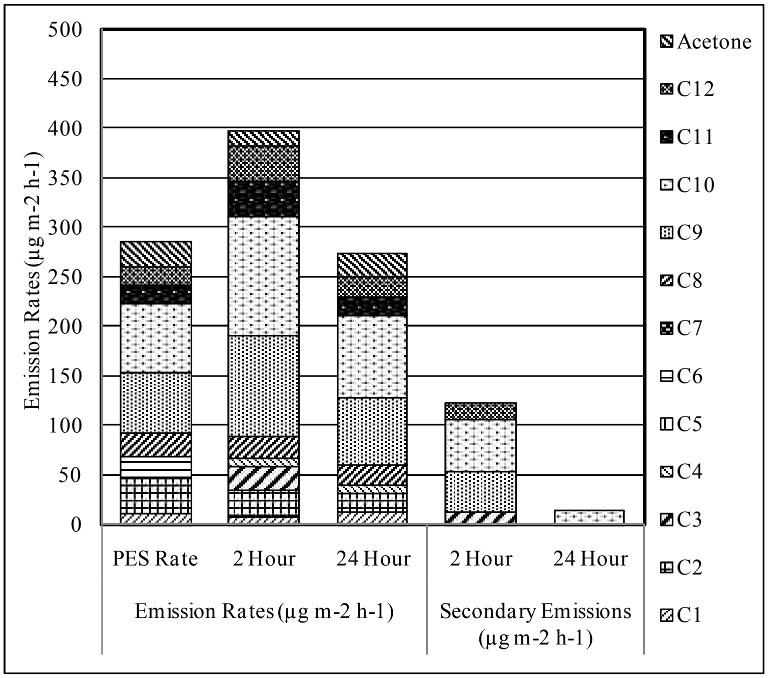




27. Rayon - Replicate Experiment

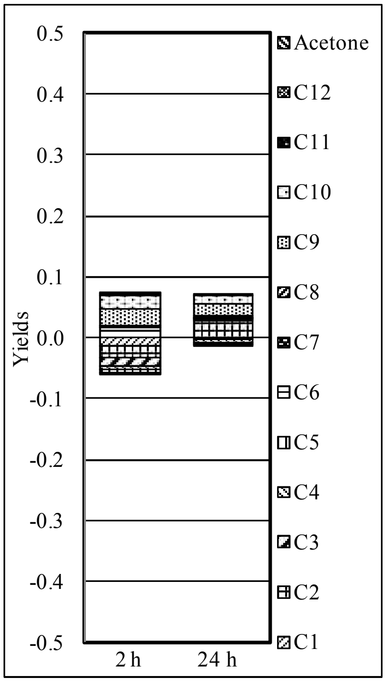
	Yields				Emission Rates (µg m^{-2} h^{-1})						Secondary Emissions (µg m^{-2} h^{-1})			
	2 Hour	Error	24 Hour	Error	PES Rate	Error	2 Hour	Error	24 Hour	Error	2 Hour	Error	24 Hour	Error
C1	(-)	n/a	LOD	n/a	10.58	4.58	7.70	2.73	12.05	0.15	0.00	0.00	0.00	0.00
C2	(-)	n/a	(-)	n/a	35.16	1.23	26.91	11.95	18.62	0.06	0.00	0.00	0.00	0.00
C3	LOD	n/a	(-)	n/a	LOD	n/a	23.04	6.91	LOD	n/a	13.17	3.46	0.00	0.00
C4	LOD	n/a	LOD	n/a	LOD	n/a	9.37	0.30	8.74	0.06	0.00	0.00	0.00	0.00
C5	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C6	(-)	n/a	(-)	n/a	23.55	10.18	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C7	LOD	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C8	(-)	n/a	(-)	n/a	22.66	7.17	21.24	6.37	21.00	6.30	0.00	0.00	0.00	0.00
C9	0.04	0.00	LOD	n/a	61.90	27.58	101.90	48.39	67.93	28.70	40.00	16.00	0.00	0.00
C10	0.04	0.00	LOD	n/a	68.34	31.00	121.25	53.43	82.05	16.85	52.91	21.16	13.70	5.48
C11	LOD	n/a	LOD	n/a	18.61	8.87	35.53	13.20	19.55	7.74	0.00	0.00	0.00	0.00
C12	LOD	n/a	LOD	n/a	19.58	6.26	35.99	10.70	19.81	8.00	16.40	6.56	0.00	0.00
Acetone	(-)	n/a	(-)	n/a	25.73	4.95	14.21	5.96	24.26	8.69	0.00	0.00	0.00	0.00

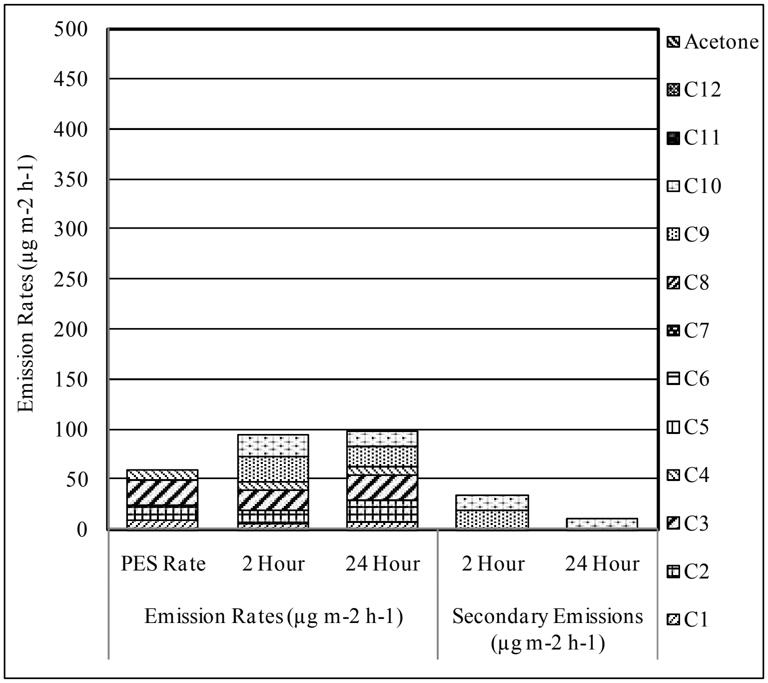




28. Ecospec - First Experiment

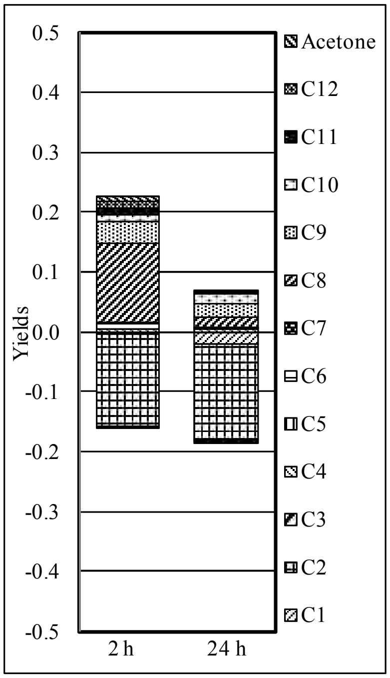
	Yields				Emission Rates (µg m^{-2} h^{-1})						Secondary Emissions (µg m^{-2} h^{-1})			
	2 Hour	Error	24 Hour	Error	PES Rate	Error	2 Hour	Error	24 Hour	Error	2 Hour	Error	24 Hour	Error
C1	(-)	n/a	(-)	n/a	8.57	3.23	6.35	0.45	8.18	0.04	0.00	0.00	0.00	0.00
C2	(-)	n/a	LOD	n/a	16.07	4.82	12.65	1.20	21.44	0.05	0.00	0.00	0.00	0.00
C3	(-)	n/a	LOD	n/a	25.06	1.48	20.91	5.56	25.60	0.05	0.00	0.00	0.00	0.00
C4	(-)	n/a	(-)	n/a	9.68	2.55	7.68	0.08	7.95	0.03	0.00	0.00	0.00	0.00
C5	(-)	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C6	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C7	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C8	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C9	LOD	n/a	LOD	n/a	LOD	n/a	25.12	4.24	19.08	9.14	18.98	2.12	0.00	0.00
C10	LOD	n/a	LOD	n/a	LOD	n/a	21.35	3.07	16.52	4.96	15.63	1.53	10.80	2.48
C11	(-)	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C12	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
Acetone	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00

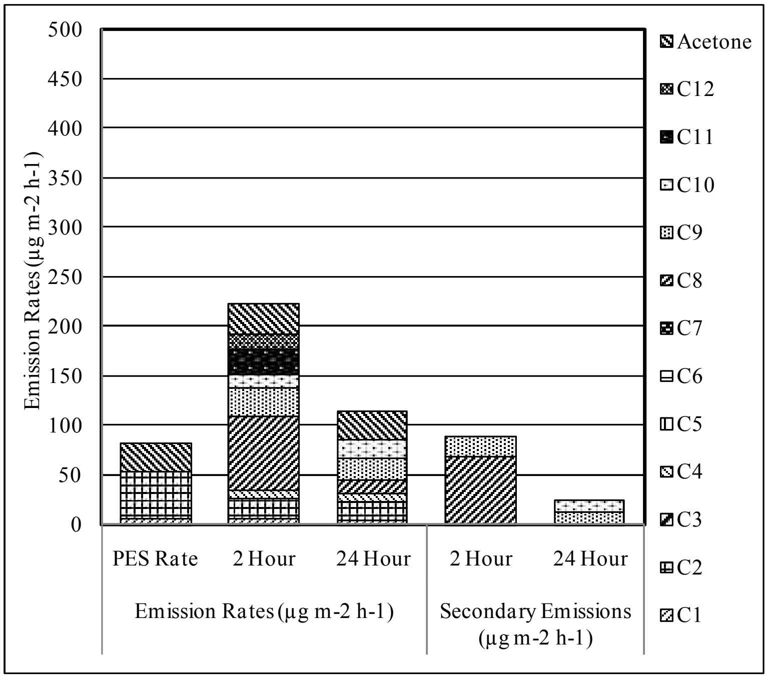




29. Ecospec - Replicate Experiment

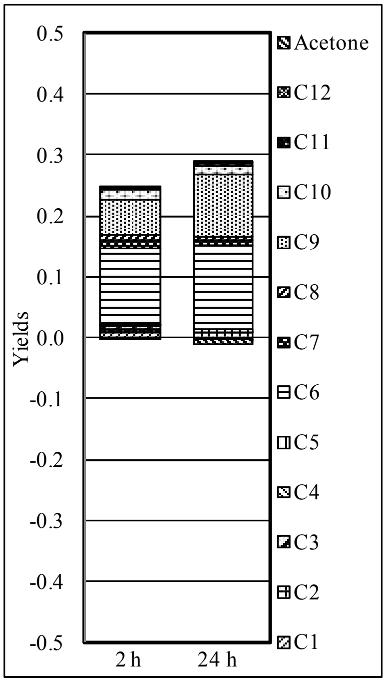
	Yields				Emission Rates (µg m^{-2} h^{-1})						Secondary Emissions (µg m^{-2} h^{-1})			
	2 Hour	Error	24 Hour	Error	PES Rate	Error	2 Hour	Error	24 Hour	Error	2 Hour	Error	24 Hour	Error
C1	(-)	n/a	(-)	n/a	6.66	2.00	6.27	0.96	4.40	0.00	0.00	0.00	0.00	0.00
C2	(-)	n/a	(-)	n/a	47.19	0.83	19.93	4.64	18.42	0.14	0.00	0.00	0.00	0.00
C3	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C4	LOD	n/a	LOD	n/a	LOD	n/a	7.98	0.37	7.87	0.00	0.00	0.00	0.00	0.00
C5	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C6	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C7	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C8	0.13	0.04	LOD	n/a	LOD	n/a	74.56	22.37	14.33	0.62	68.40	11.18	0.00	0.00
C9	LOD	n/a	LOD	n/a	LOD	n/a	28.56	8.57	22.15	6.65	19.89	4.28	13.48	3.32
C10	LOD	n/a	LOD	n/a	LOD	n/a	14.85	4.46	18.63	5.59	0.00	0.00	10.55	2.79
C11	LOD	n/a	(-)	n/a	LOD	n/a	25.30	8.97	LOD	n/a	0.00	0.00	0.00	0.00
C12	LOD	n/a	LOD	n/a	LOD	n/a	15.20	4.56	LOD	n/a	0.00	0.00	0.00	0.00
Acetone	LOD	n/a	LOD	n/a	28.23	1.02	30.08	2.90	28.47	1.33	0.00	0.00	0.00	0.00

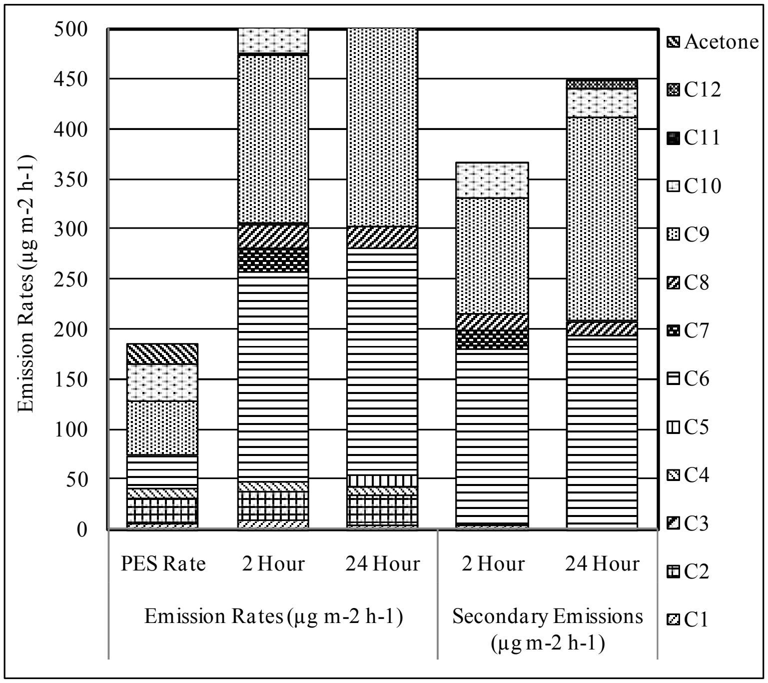




30. Bioshield - First Experiment

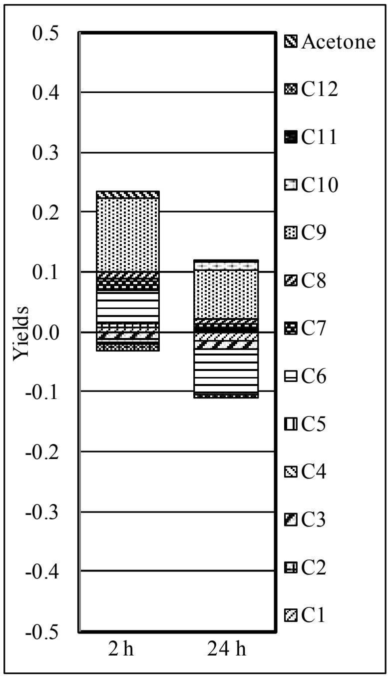
	Yields				Emission Rates (μg m^{-2} h^{-1})						Secondary Emissions (μg m^{-2} h^{-1})			
	2 Hour	Error	24 Hour	Error	PES Rate	Error	2 Hour	Error	24 Hour	Error	2 Hour	Error	24 Hour	Error
C1	LOD	n/a	(-)	n/a	6.07	1.82	9.48	3.08	4.37	0.01	3.41	0.00	0.00	0.00
C2	LOD	n/a	LOD	n/a	24.91	1.36	28.51	9.41	29.45	0.01	0.00	0.00	0.00	0.00
C3	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C4	LOD	n/a	(-)	n/a	10.06	2.09	10.59	1.05	9.24	0.01	0.00	0.00	0.00	0.00
C5	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	11.55	0.01	0.00	0.00	0.00	0.00
C6	0.13	0.00	0.14	0.00	32.01	5.95	208.78	27.06	226.01	20.46	176.77	16.51	194.00	13.21
C7	LOD	n/a	LOD	n/a	LOD	n/a	23.40	1.03	LOD	n/a	18.88	0.51	0.00	0.00
C8	LOD	n/a	LOD	n/a	LOD	n/a	23.88	0.01	21.58	1.30	15.95	0.01	13.66	0.65
C9	0.06	0.00	0.10	0.00	54.23	20.77	169.37	25.38	257.44	37.91	115.14	23.07	203.20	29.34
C10	0.02	0.00	LOD	n/a	37.17	5.66	72.01	2.44	66.86	1.90	34.85	4.05	29.69	3.78
C11	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C12	LOD	n/a	LOD	n/a	LOD	n/a	10.81	2.37	14.89	3.16	0.00	0.00	9.24	1.58
Acetone	(-)	n/a	(-)	n/a	20.80	0.04	19.99	0.31	16.07	1.39	0.00	0.00	0.00	0.00

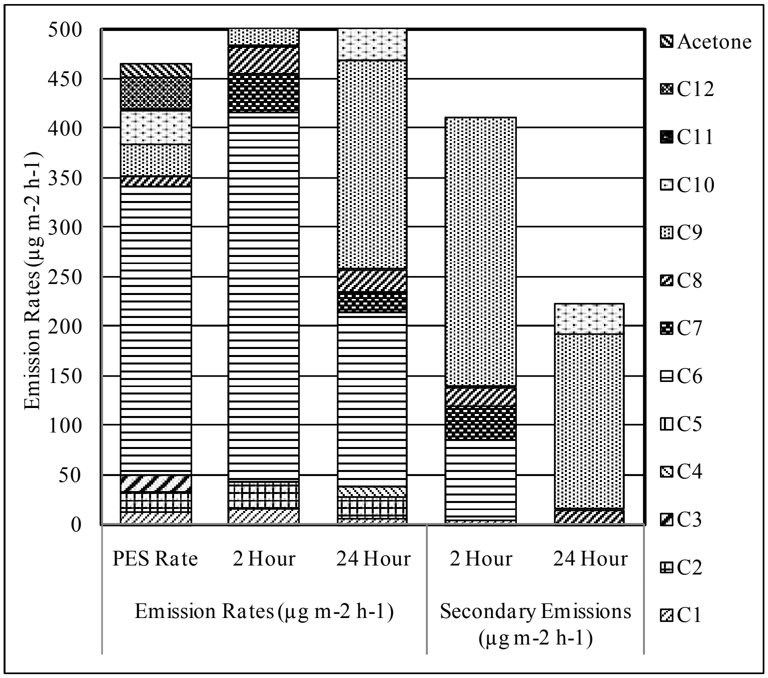




31. Bioshield - Replicate Experiment

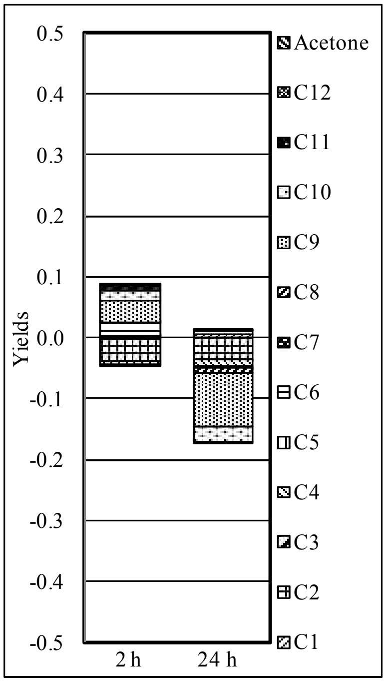
	Yields				Emission Rates (μg m^{-2} h^{-1})						Secondary Emissions (μg m^{-2} h^{-1})			
	2 Hour	Error	24 Hour	Error	PES Rate	Error	2 Hour	Error	24 Hour	Error	2 Hour	Error	24 Hour	Error
C1	LOD	n/a	(-)	n/a	12.55	3.17	16.68	8.04	5.36	0.03	4.13	0.00	0.00	0.00
C2	LOD	n/a	LOD	n/a	20.79	9.81	25.94	1.13	23.06	0.06	0.00	0.00	0.00	0.00
C3	(-)	n/a	(-)	n/a	16.39	4.92	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C4	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	9.00	0.04	0.00	0.00	0.00	0.00
C5	LOD	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C6	0.05	0.00	(-)	n/a	292.23	67.60	373.34	94.16	176.74	27.42	81.11	32.44	0.00	0.00
C7	LOD	n/a	LOD	n/a	LOD	n/a	39.33	11.80	19.80	5.94	34.97	5.90	0.00	0.00
C8	LOD	n/a	LOD	n/a	9.26	2.78	27.21	6.21	23.57	7.07	17.95	4.49	14.32	4.92
C9	0.12	0.00	0.08	0.00	33.18	10.18	304.49	132.00	211.76	####	271.32	71.09	178.58	57.35
C10	(-)	n/a	0.01	0.00	34.12	10.24	20.03	3.09	64.41	19.32	0.00	0.00	30.29	14.78
C11	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C12	(-)	n/a	(-)	n/a	32.09	9.63	LOD	n/a	16.18	4.85	0.00	0.00	0.00	0.00
Acetone	LOD	n/a	LOD	n/a	13.60	4.84	22.55	2.11	17.11	1.61	0.00	0.00	0.00	0.00

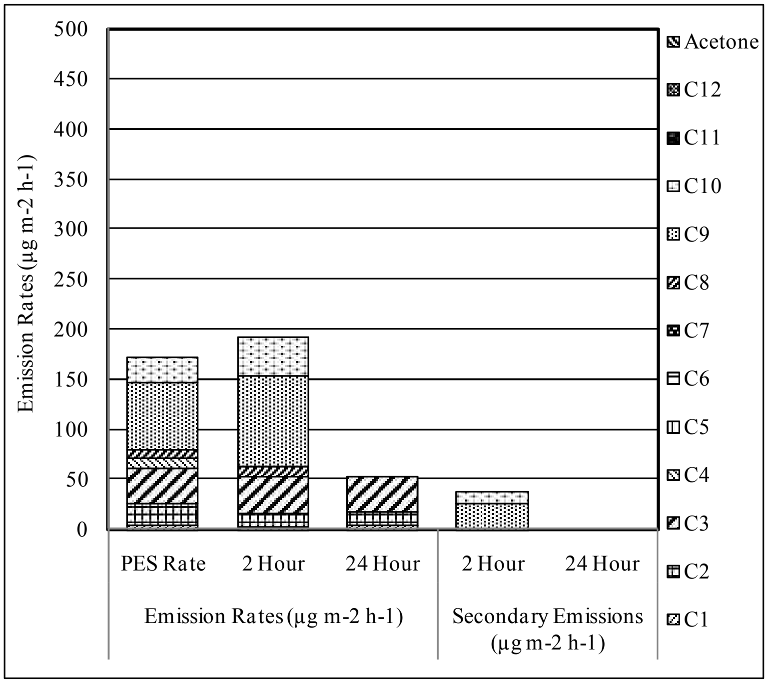




32. Ecotrend - First Experiment

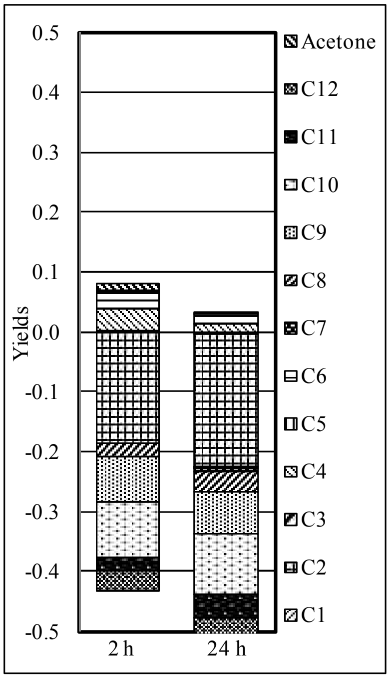
	Yields				Emission Rates (µg m^{-2} h^{-1})						Secondary Emissions (µg m^{-2} h^{-1})			
	2 Hour	Error	24 Hour	Error	PES Rate	Error	2 Hour	Error	24 Hour	Error	2 Hour	Error	24 Hour	Error
C1	(-)	n/a	LOD	n/a	3.63	1.09	3.14	0.30	4.30	0.00	0.00	0.00	0.00	0.00
C2	(-)	n/a	(-)	n/a	21.59	0.55	13.41	0.43	13.44	0.01	0.00	0.00	0.00	0.00
C3	LOD	n/a	(-)	n/a	35.69	1.28	36.01	1.09	35.34	0.01	0.00	0.00	0.00	0.00
C4	(-)	n/a	(-)	n/a	9.59	1.45	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C5	LOD	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C6	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C7	(-)	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C8	LOD	n/a	(-)	n/a	9.80	3.51	10.09	3.03	LOD	n/a	0.00	0.00	0.00	0.00
C9	LOD	n/a	(-)	n/a	66.40	19.92	91.64	27.49	LOD	n/a	25.24	10.10	0.00	0.00
C10	LOD	n/a	(-)	n/a	25.76	7.73	38.00	11.40	LOD	n/a	12.24	4.90	0.00	0.00
C11	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C12	LOD	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
Acetone	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00

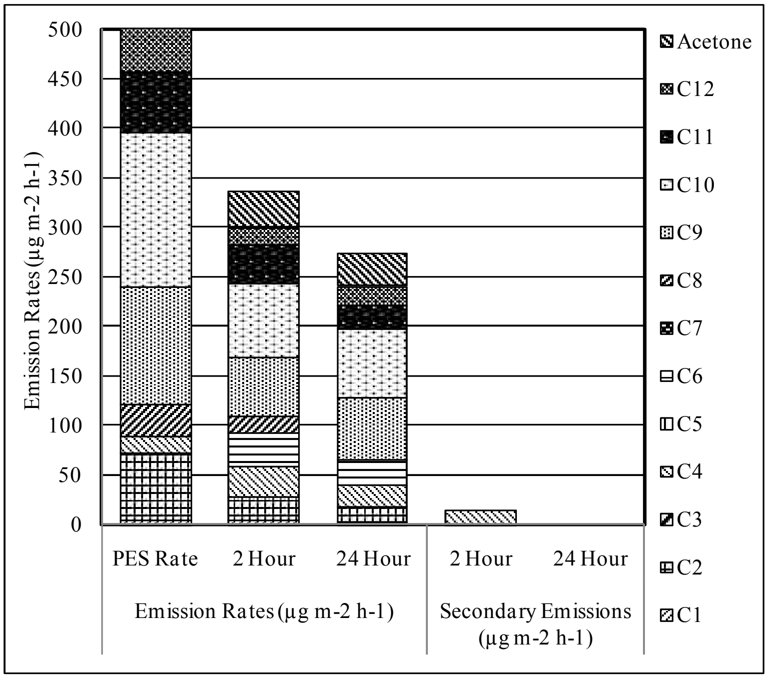




33. Ecotrend - Replicate Experiments

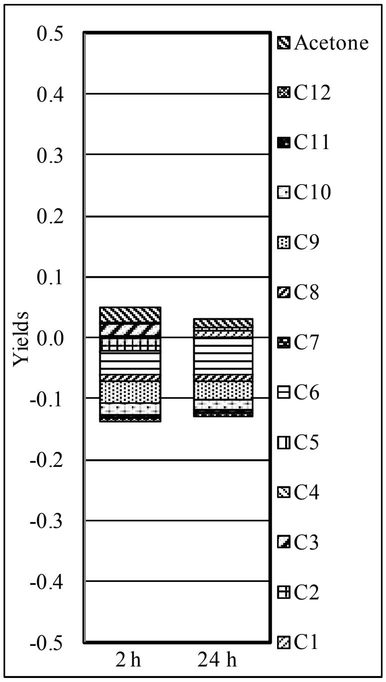
	Yields				Emission Rates (µg m^{-2} h^{-1})						Secondary Emissions (µg m^{-2} h^{-1})			
	2 Hour	Error	24 Hour	Error	PES Rate	Error	2 Hour	Error	24 Hour	Error	2 Hour	Error	24 Hour	Error
C1	LOD	n/a	(-)	n/a	3.72	1.83	4.08	0.71	3.08	0.01	0.00	0.00	0.00	0.00
C2	(-)	n/a	(-)	n/a	69.05	2.02	23.65	2.37	15.00	0.00	0.00	0.00	0.00	0.00
C3	LOD	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C4	LOD	n/a	LOD	n/a	16.74	7.85	31.02	1.95	22.16	0.07	14.27	4.90	0.00	0.00
C5	(-)	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C6	LOD	n/a	LOD	n/a	LOD	n/a	33.39	3.86	25.59	4.66	0.00	0.00	0.00	0.00
C7	LOD	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C8	(-)	n/a	(-)	n/a	32.16	2.16	16.55	7.75	LOD	n/a	0.00	0.00	0.00	0.00
C9	(-)	n/a	(-)	n/a	118.74	47.68	59.27	17.78	62.79	3.35	0.00	0.00	0.00	0.00
C10	(-)	n/a	(-)	n/a	155.80	67.46	75.33	22.60	68.91	2.35	0.00	0.00	0.00	0.00
C11	(-)	n/a	(-)	n/a	60.34	5.29	38.54	1.08	23.46	7.48	0.00	0.00	0.00	0.00
C12	(-)	n/a	(-)	n/a	51.46	0.41	17.70	5.31	18.86	4.56	0.00	0.00	0.00	0.00
Acetone	LOD	n/a	LOD	n/a	31.80	2.00	35.80	1.41	32.40	1.44	0.00	0.00	0.00	0.00

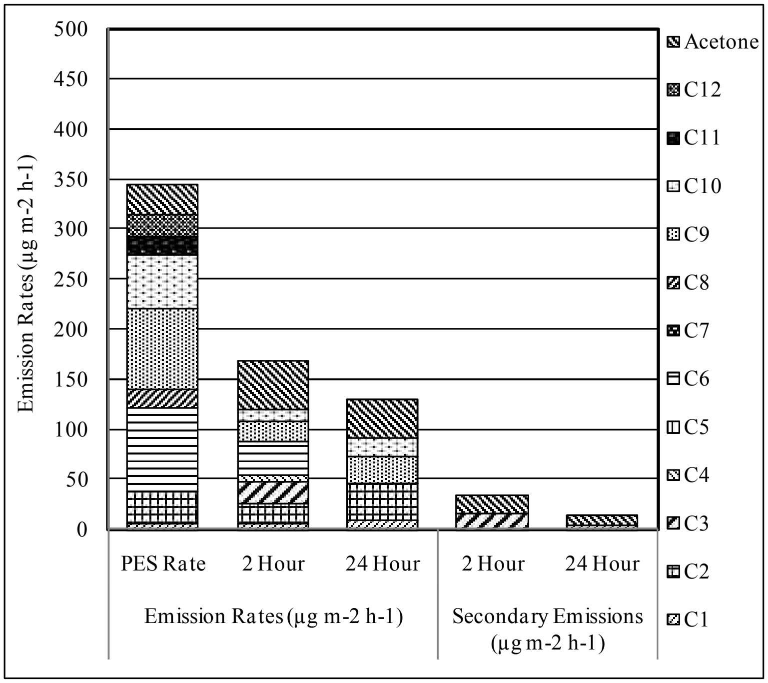




34. American Clay - First Experiment

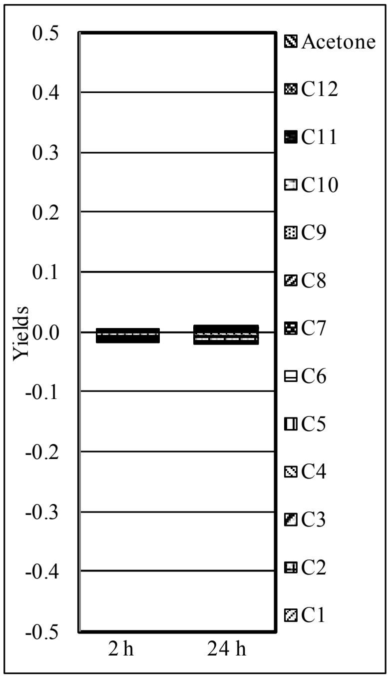
	Yields				Emission Rates (μg m^{-2} h^{-1})						Secondary Emissions (μg m^{-2} h^{-1})			
	2 Hour	Error	24 Hour	Error	PES Rate	Error	2 Hour	Error	24 Hour	Error	2 Hour	Error	24 Hour	Error
C1	LOD	n/a	LOD	n/a	5.30	2.32	5.63	1.69	9.03	0.01	0.00	0.00	3.73	1.16
C2	(-)	n/a	LOD	n/a	32.99	1.50	20.97	2.69	36.83	0.12	0.00	0.00	0.00	0.00
C3	LOD	n/a	(-)	n/a	LOD	n/a	20.46	6.14	LOD	n/a	15.63	3.07	0.00	0.00
C4	LOD	n/a	LOD	n/a	LOD	n/a	8.07	0.41	LOD	n/a	0.00	0.00	0.00	0.00
C5	(-)	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C6	(-)	n/a	(-)	n/a	82.49	27.54	32.86	4.19	LOD	n/a	0.00	0.00	0.00	0.00
C7	(-)	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C8	(-)	n/a	(-)	n/a	18.73	1.35	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C9	(-)	n/a	(-)	n/a	81.75	4.79	19.87	1.26	26.65	2.27	0.00	0.00	0.00	0.00
C10	(-)	n/a	(-)	n/a	53.18	25.35	12.77	2.70	18.60	6.45	0.00	0.00	0.00	0.00
C11	(-)	n/a	(-)	n/a	18.74	6.74	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C12	(-)	n/a	(-)	n/a	21.78	1.62	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
Acetone	LOD	n/a	LOD	n/a	29.85	2.70	48.50	17.47	39.64	1.19	18.65	7.46	9.79	1.94

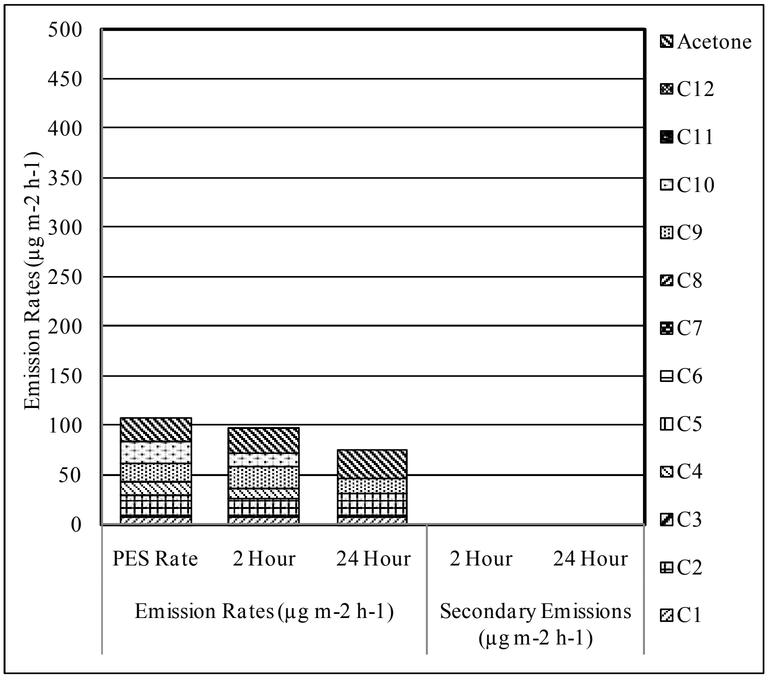




35. American Clay - Replicate Experiment

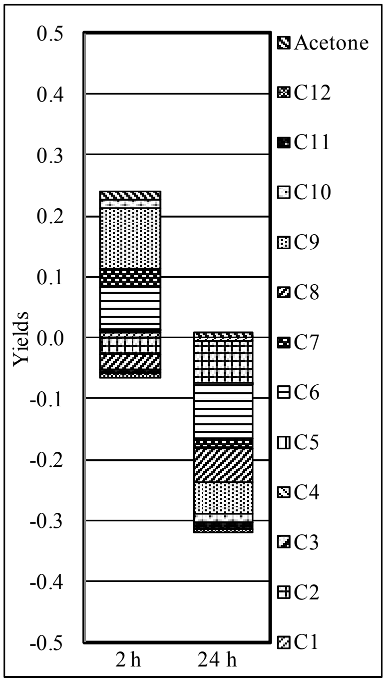
	Yields				Emission Rates (µg m^{-2} h^{-1})						Secondary Emissions (µg m^{-2} h^{-1})			
	2 Hour	Error	24 Hour	Error	PES Rate	Error	2 Hour	Error	24 Hour	Error	2 Hour	Error	24 Hour	Error
C1	(-)	n/a	LOD	n/a	7.63	2.29	7.43	0.83	8.27	0.01	0.00	0.00	0.00	0.00
C2	(-)	n/a	LOD	n/a	21.98	0.23	18.26	0.52	23.78	0.06	0.00	0.00	0.00	0.00
C3	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C4	(-)	n/a	(-)	n/a	14.29	0.45	11.34	1.81	LOD	n/a	0.00	0.00	0.00	0.00
C5	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C6	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C7	(-)	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C8	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C9	LOD	n/a	(-)	n/a	18.05	7.81	21.14	6.34	13.90	4.17	0.00	0.00	0.00	0.00
C10	(-)	n/a	(-)	n/a	21.14	8.74	13.85	0.01	LOD	n/a	0.00	0.00	0.00	0.00
C11	(-)	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C12	LOD	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
Acetone	LOD	n/a	LOD	n/a	24.77	1.42	25.08	0.49	28.62	2.11	0.00	0.00	0.00	0.00

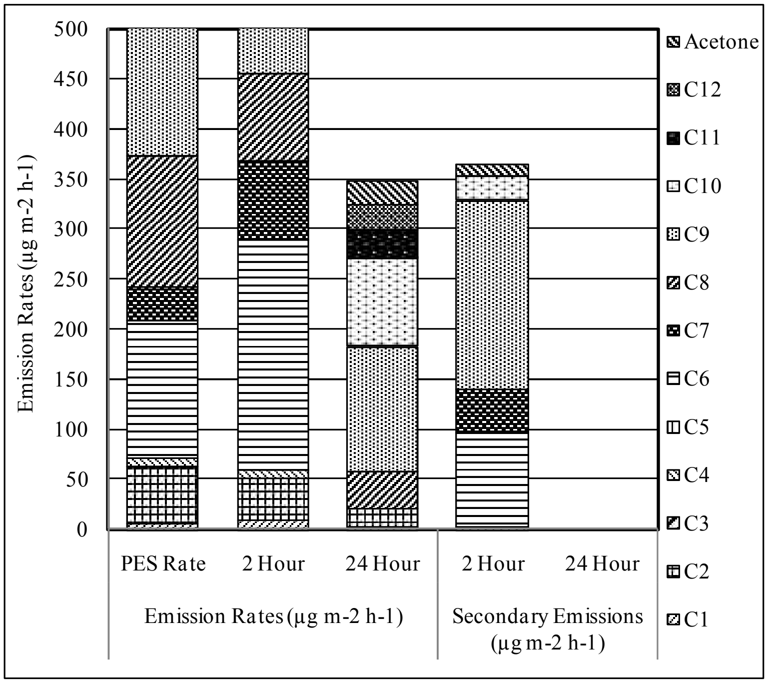




36. Drywall - First Experiment

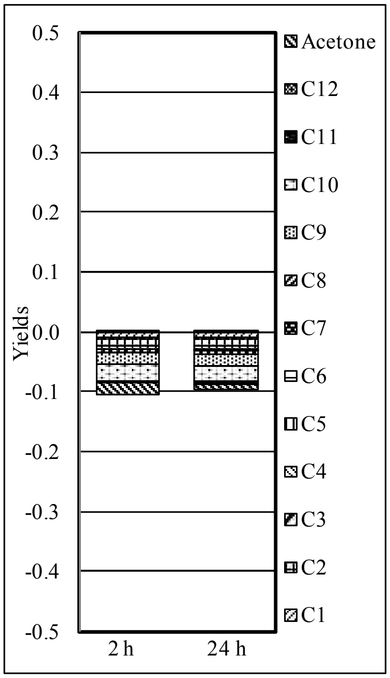
	Yields				Emission Rates ($\mu g\ m^{-2}\ h^{-1}$)						Secondary Emissions ($\mu g\ m^{-2}\ h^{-1}$)			
	2 Hour	Error	24 Hour	Error	PES Rate	Error	2 Hour	Error	24 Hour	Error	2 Hour	Error	24 Hour	Error
C1	LOD	n/a	(-)	n/a	5.98	2.38	9.13	4.23	3.18	0.02	3.15	0.00	0.00	0.00
C2	(-)	n/a	(-)	n/a	57.52	8.42	41.30	0.73	18.24	0.13	0.00	0.00	0.00	0.00
C3	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C4	LOD	n/a	(-)	n/a	8.09	0.82	8.43	1.85	LOD	n/a	0.00	0.00	0.00	0.00
C5	LOD	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C6	0.07	0.01	(-)	n/a	137.62	41.28	230.54	69.16	LOD	n/a	92.93	37.17	0.00	0.00
C7	LOD	n/a	(-)	n/a	34.01	10.20	78.33	23.50	LOD	n/a	44.32	16.85	0.00	0.00
C8	(-)	n/a	(-)	n/a	130.23	17.16	88.71	26.61	36.44	10.93	0.00	0.00	0.00	0.00
C9	0.10	0.01	(-)	n/a	221.62	66.48	409.72	122.92	125.16	37.55	188.10	75.24	0.00	0.00
C10	LOD	n/a	(-)	n/a	115.52	21.36	140.02	67.78	88.30	26.49	24.50	9.80	0.00	0.00
C11	(-)	n/a	(-)	n/a	56.73	22.53	39.29	11.79	27.83	8.35	0.00	0.00	0.00	0.00
C12	(-)	n/a	(-)	n/a	34.68	5.93	16.43	6.36	25.00	7.50	0.00	0.00	0.00	0.00
Acetone	LOD	n/a	LOD	n/a	18.07	5.42	29.64	3.34	23.74	2.06	11.57	4.38	0.00	0.00

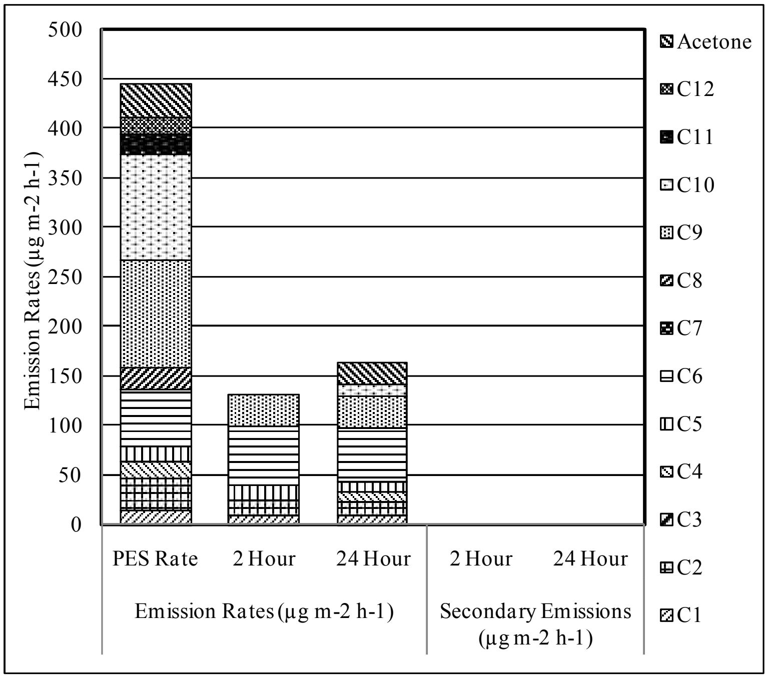




37. Drywall - Replicate Experiment

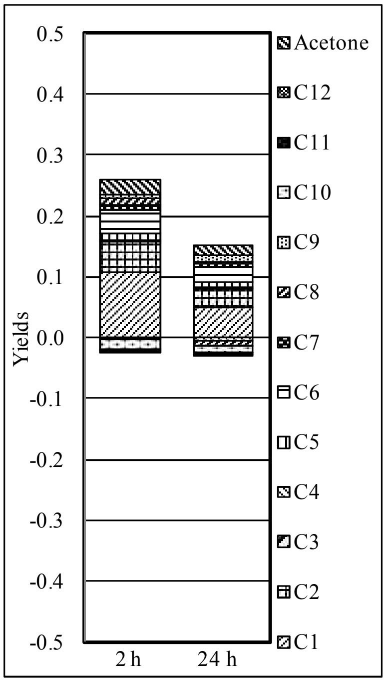
	Yields				Emission Rates (μg m^{-2} h^{-1})						Secondary Emissions (μg m^{-2} h^{-1})			
	2 Hour	Error	24 Hour	Error	PES Rate	Error	2 Hour	Error	24 Hour	Error	2 Hour	Error	24 Hour	Error
C1	(-)	n/a	(-)	n/a	15.00	5.33	9.38	0.00	9.38	0.00	0.00	0.00	0.00	0.00
C2	(-)	n/a	(-)	n/a	31.79	9.54	15.30	0.00	13.41	0.00	0.00	0.00	0.00	0.00
C3	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C4	(-)	n/a	(-)	n/a	17.54	6.67	LOD	n/a	9.68	0.00	0.00	0.00	0.00	0.00
C5	LOD	n/a	(-)	n/a	13.77	2.77	14.73	0.00	10.91	0.00	0.00	0.00	0.00	0.00
C6	LOD	n/a	(-)	n/a	58.57	0.51	59.07	0.00	53.62	0.94	0.00	0.00	0.00	0.00
C7	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C8	(-)	n/a	(-)	n/a	21.04	6.31	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C9	(-)	n/a	(-)	n/a	108.63	32.59	33.51	0.00	32.41	0.57	0.00	0.00	0.00	0.00
C10	(-)	n/a	(-)	n/a	108.07	50.14	LOD	n/a	12.65	0.22	0.00	0.00	0.00	0.00
C11	(-)	n/a	(-)	n/a	18.88	5.67	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C12	(-)	n/a	(-)	n/a	18.33	5.50	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
Acetone	(-)	n/a	(-)	n/a	33.72	10.67	LOD	n/a	21.29	0.00	0.00	0.00	0.00	0.00

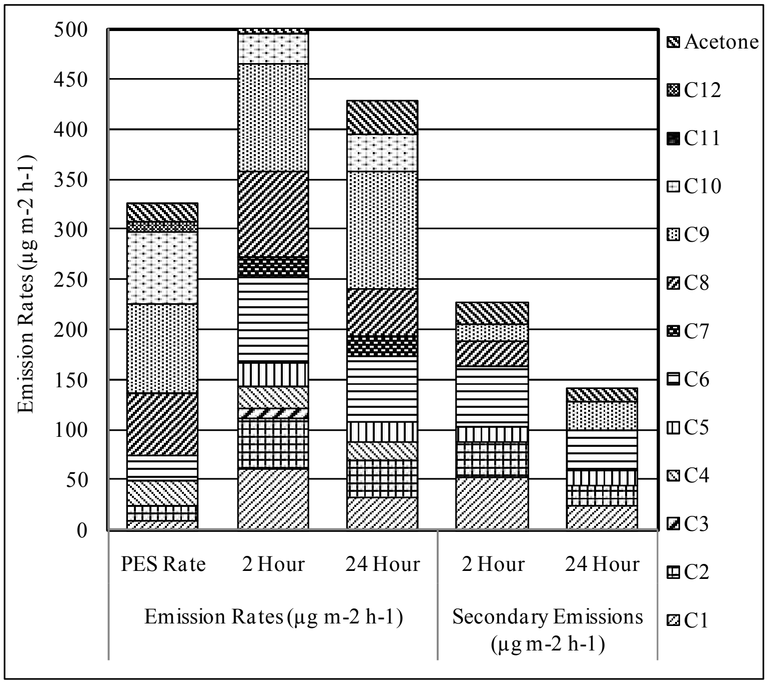




38. Armstrong Ceiling - First Experiment

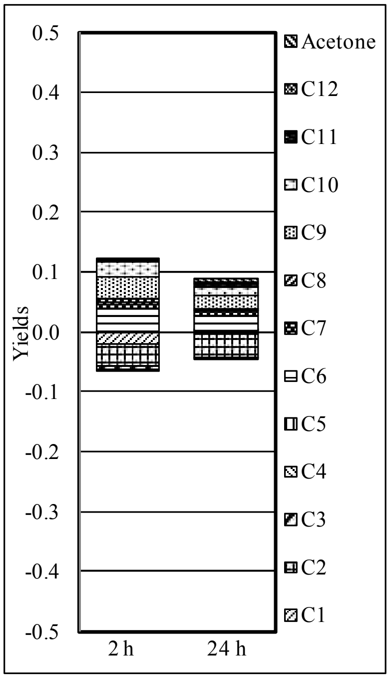
	Yields				Emission Rates (μg m^{-2} h^{-1})						Secondary Emissions (μg m^{-2} h^{-1})			
	2 Hour	Error	24 Hour	Error	PES Rate	Error	2 Hour	Error	24 Hour	Error	2 Hour	Error	24 Hour	Error
C1	0.11	0.01	0.05	0.00	8.79	2.64	61.27	18.38	32.43	0.27	52.47	1.45	23.64	1.45
C2	0.05	0.00	0.03	0.00	14.92	7.22	49.71	14.91	36.45	0.18	34.78	11.06	21.52	3.70
C3	LOD	n/a	LOD	n/a	LOD	n/a	10.43	3.13	LOD	n/a	0.00	0.00	0.00	0.00
C4	(-)	n/a	(-)	n/a	25.72	7.72	22.11	6.63	18.39	0.16	0.00	0.00	0.00	0.00
C5	LOD	n/a	LOD	n/a	LOD	n/a	23.57	7.07	20.90	0.13	16.73	3.53	14.07	0.07
C6	LOD	n/a	LOD	n/a	24.66	9.13	84.81	10.50	65.65	3.58	60.15	9.81	40.99	6.35
C7	LOD	n/a	LOD	n/a	LOD	n/a	20.60	5.22	19.57	5.15	0.00	0.00	0.00	0.00
C8	LOD	n/a	(-)	n/a	62.17	26.06	85.92	38.33	46.75	12.82	23.75	9.50	0.00	0.00
C9	LOD	n/a	LOD	n/a	89.76	6.81	107.73	10.46	117.65	17.80	17.97	8.63	27.89	12.30
C10	(-)	n/a	(-)	n/a	71.64	20.76	29.69	2.74	37.96	8.78	0.00	0.00	0.00	0.00
C11	(-)	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C12	(-)	n/a	(-)	n/a	10.60	2.77	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
Acetone	LOD	n/a	LOD	n/a	18.10	4.00	39.46	19.04	32.35	12.70	21.36	8.55	14.25	5.70

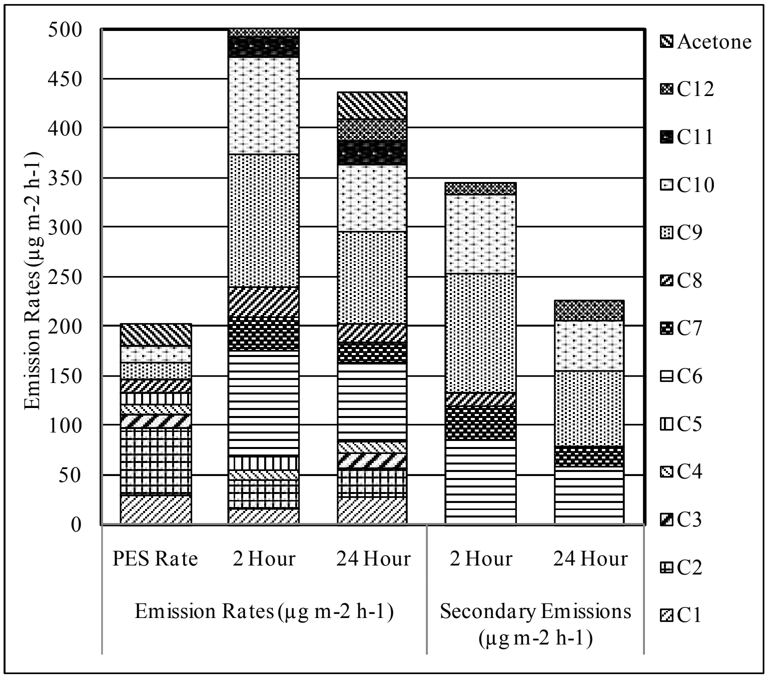




39. . Armstrong Ceiling - Replicate

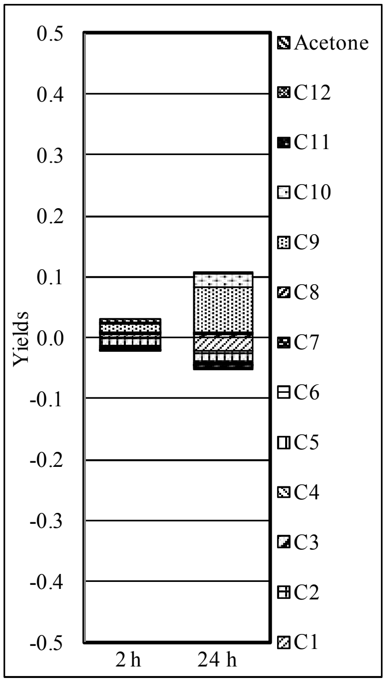
	Yields				Emission Rates ($\mu g\ m^{-2}\ h^{-1}$)						Secondary Emissions ($\mu g\ m^{-2}\ h^{-1}$)			
	2 Hour	Error	24 Hour	Error	PES Rate	Error	2 Hour	Error	24 Hour	Error	2 Hour	Error	24 Hour	Error
C1	(-)	n/a	(-)	n/a	30.01	11.11	16.79	7.11	27.41	0.20	0.00	0.00	0.00	0.00
C2	(-)	n/a	(-)	n/a	66.97	12.06	28.56	14.22	29.25	0.22	0.00	0.00	0.00	0.00
C3	(-)	n/a	LOD	n/a	13.43	5.08	LOD	n/a	15.82	0.07	0.00	0.00	0.00	0.00
C4	(-)	n/a	LOD	n/a	10.32	3.93	10.21	0.96	11.87	0.10	0.00	0.00	0.00	0.00
C5	LOD	n/a	(-)	n/a	11.83	4.85	13.74	4.93	LOD	n/a	0.00	0.00	0.00	0.00
C6	0.04	0.00	LOD	n/a	LOD	n/a	106.53	4.89	79.74	1.47	86.00	2.44	59.21	0.73
C7	LOD	n/a	LOD	n/a	LOD	n/a	33.67	5.43	20.03	5.05	32.71	2.71	19.08	2.53
C8	LOD	n/a	LOD	n/a	14.60	4.38	29.54	9.69	18.72	2.18	14.94	7.04	0.00	0.00
C9	0.04	0.00	0.02	0.00	15.57	0.64	134.84	4.46	92.30	18.42	119.27	2.55	76.74	9.53
C10	0.02	0.00	0.01	0.00	17.68	7.21	98.72	25.16	69.04	0.15	81.04	16.19	51.35	3.68
C11	LOD	n/a	LOD	n/a	LOD	n/a	20.24	0.80	22.63	0.03	0.00	0.00	0.00	0.00
C12	LOD	n/a	LOD	n/a	LOD	n/a	15.81	3.82	23.50	1.75	11.88	1.91	19.57	0.87
Acetone	(-)	n/a	LOD	n/a	22.83	6.85	22.26	3.80	26.82	5.44	0.00	0.00	0.00	0.00

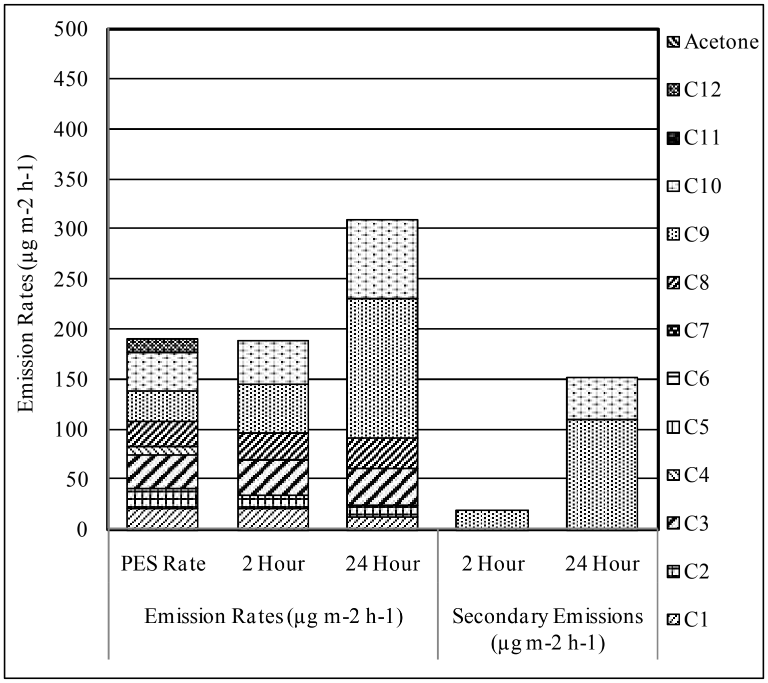




40. Eurostone - First Experiment

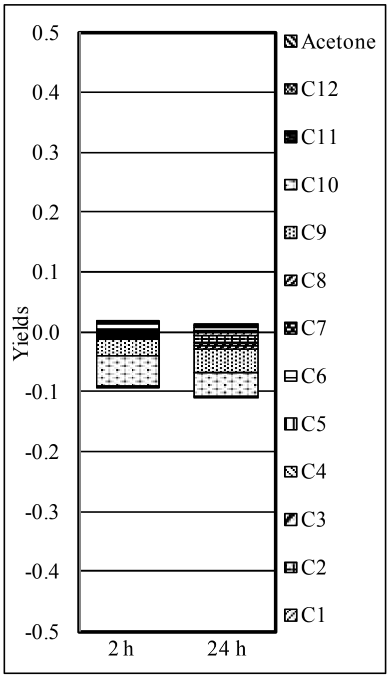
	Yields				Emission Rates (μg m^{-2} h^{-1})						Secondary Emissions (μg m^{-2} h^{-1})			
	2 Hour	Error	24 Hour	Error	PES Rate	Error	2 Hour	Error	24 Hour	Error	2 Hour	Error	24 Hour	Error
C1	LOD	n/a	(-)	n/a	20.63	7.88	21.73	0.00	12.98	0.00	0.00	0.00	0.00	0.00
C2	(-)	n/a	(-)	n/a	20.12	2.01	13.14	0.66	11.94	0.01	0.00	0.00	0.00	0.00
C3	LOD	n/a	LOD	n/a	33.59	2.00	34.98	0.30	35.80	0.01	0.00	0.00	0.00	0.00
C4	(-)	n/a	(-)	n/a	8.77	1.07	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C5	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C6	(-)	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C7	(-)	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C8	LOD	n/a	LOD	n/a	25.53	3.13	26.92	8.08	30.87	2.61	0.00	0.00	0.00	0.00
C9	LOD	n/a	0.07	0.00	29.40	2.11	48.99	2.83	139.78	47.45	19.60	2.47	110.38	24.78
C10	LOD	n/a	0.02	0.01	38.20	12.05	43.26	6.17	78.94	21.29	0.00	0.00	40.74	16.67
C11	(-)	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C12	(-)	n/a	(-)	n/a	14.04	6.39	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
Acetone	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00

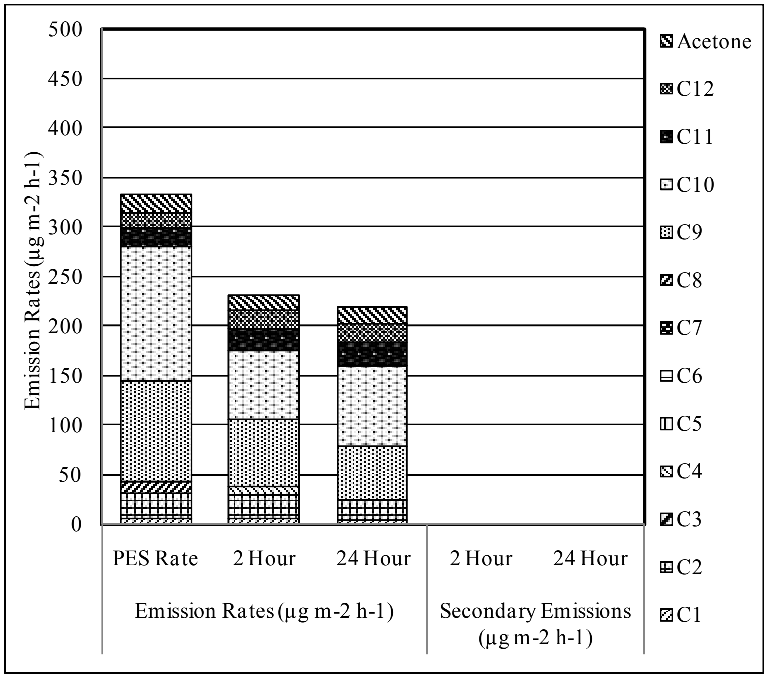




41. Eurostone - Replicate Experiment

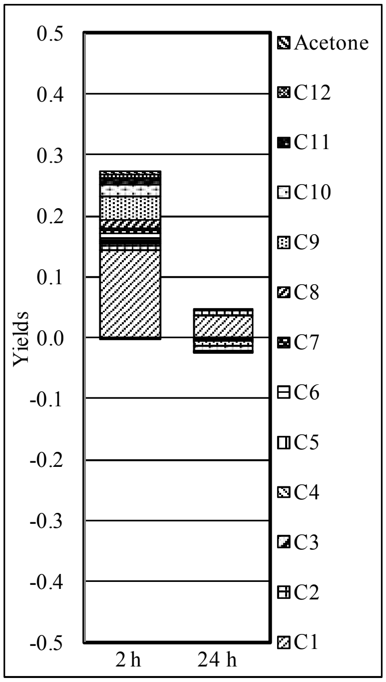
	Yields				Emission Rates ($\mu g\ m^{-2}\ h^{-1}$)						Secondary Emissions ($\mu g\ m^{-2}\ h^{-1}$)			
	2 Hour	Error	24 Hour	Error	PES Rate	Error	2 Hour	Error	24 Hour	Error	2 Hour	Error	24 Hour	Error
C1	(-)	n/a	(-)	n/a	5.77	2.43	5.19	0.09	4.57	0.00	0.00	0.00	0.00	0.00
C2	(-)	n/a	(-)	n/a	25.23	3.21	24.28	3.34	20.33	0.01	0.00	0.00	0.00	0.00
C3	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C4	LOD	n/a	LOD	n/a	LOD	n/a	8.71	0.45	LOD	n/a	0.00	0.00	0.00	0.00
C5	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C6	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C7	(-)	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C8	(-)	n/a	(-)	n/a	12.17	3.65	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C9	(-)	n/a	(-)	n/a	101.53	31.28	67.77	19.18	54.11	16.32	0.00	0.00	0.00	0.00
C10	(-)	n/a	(-)	n/a	135.29	8.86	70.27	4.65	81.90	17.91	0.00	0.00	0.00	0.00
C11	LOD	n/a	LOD	n/a	19.82	1.81	20.38	4.06	23.00	3.19	0.00	0.00	0.00	0.00
C12	LOD	n/a	LOD	n/a	15.24	2.95	19.06	0.51	18.35	0.76	0.00	0.00	0.00	0.00
Acetone	(-)	n/a	(-)	n/a	17.65	0.34	16.23	1.25	16.60	1.69	0.00	0.00	0.00	0.00

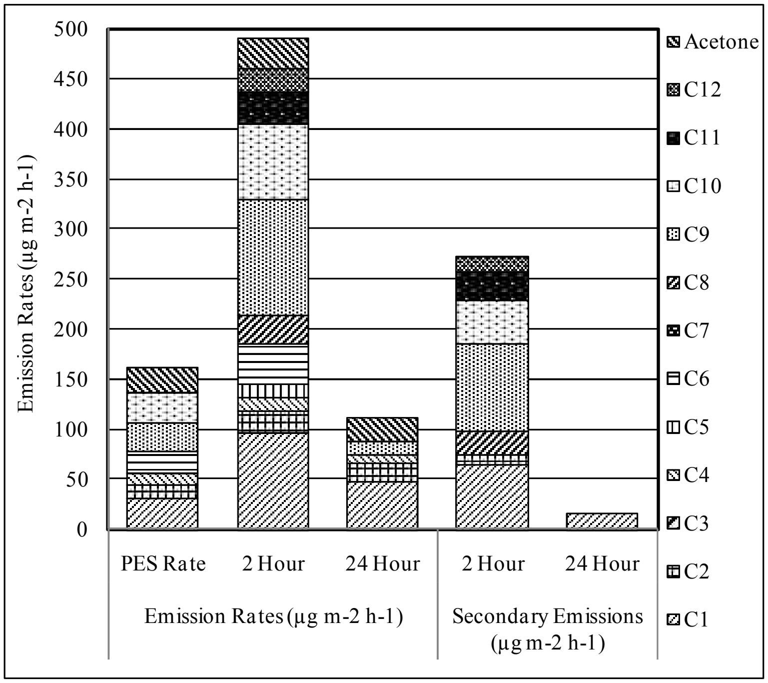




42. Certainteed - First Experiment

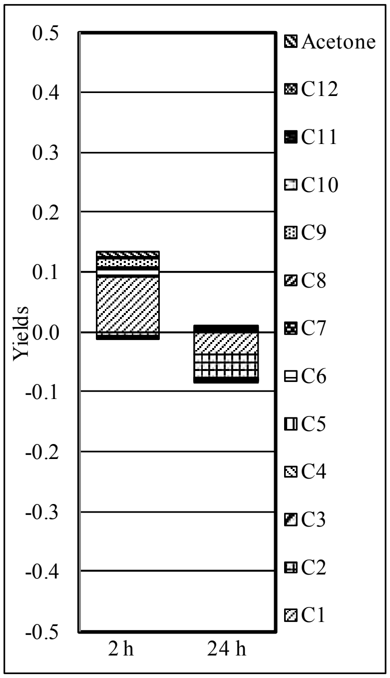
	Yields				Emission Rates (µg m^{-2} h^{-1})						Secondary Emissions (µg m^{-2} h^{-1})			
	2 Hour	Error	24 Hour	Error	PES Rate	Error	2 Hour	Error	24 Hour	Error	2 Hour	Error	24 Hour	Error
C1	0.14	0.01	0.03	0.00	31.35	8.74	96.59	28.98	47.28	0.29	65.24	4.51	15.93	4.51
C2	LOD	n/a	LOD	n/a	13.25	3.49	22.19	5.99	18.30	0.08	8.93	3.57	0.00	0.00
C3	(-)	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C4	LOD	n/a	(-)	n/a	11.18	2.33	13.56	1.65	9.54	0.04	0.00	0.00	0.00	0.00
C5	LOD	n/a	(-)	n/a	LOD	n/a	12.45	4.12	LOD	n/a	0.00	0.00	0.00	0.00
C6	LOD	n/a	(-)	n/a	21.46	1.32	40.81	6.26	LOD	n/a	0.00	0.00	0.00	0.00
C7	LOD	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C8	LOD	n/a	LOD	n/a	LOD	n/a	27.84	8.35	LOD	n/a	23.87	4.18	0.00	0.00
C9	0.04	0.00	(-)	n/a	29.95	8.99	116.92	40.71	13.71	4.11	86.97	24.85	0.00	0.00
C10	0.02	0.00	(-)	n/a	30.12	9.04	74.58	22.37	LOD	n/a	44.46	15.70	0.00	0.00
C11	LOD	n/a	(-)	n/a	LOD	n/a	32.44	9.73	LOD	n/a	27.22	4.87	0.00	0.00
C12	LOD	n/a	(-)	n/a	LOD	n/a	23.00	6.90	LOD	n/a	15.22	3.45	0.00	0.00
Acetone	LOD	n/a	(-)	n/a	23.86	6.78	30.23	10.18	22.61	5.28	0.00	0.00	0.00	0.00

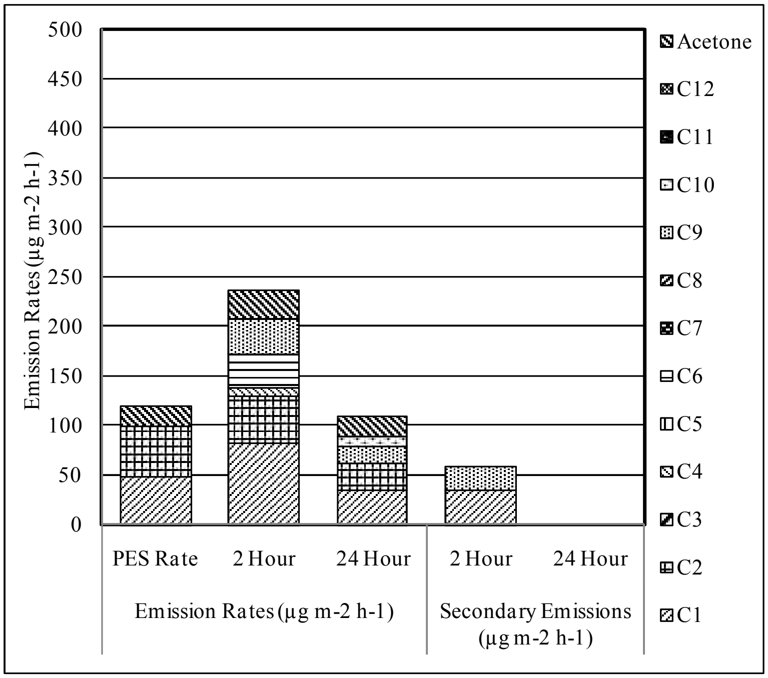




43. Certainteed - Replicate Experiment

	Yields				Emission Rates (µg m^{-2} h^{-1})						Secondary Emissions (µg m^{-2} h^{-1})			
	2 Hour	Error	24 Hour	Error	PES Rate	Error	2 Hour	Error	24 Hour	Error	2 Hour	Error	24 Hour	Error
C1	0.09	0.01	(-)	n/a	47.56	17.77	82.34	38.59	33.94	0.39	34.78	0.00	0.00	0.00
C2	(-)	n/a	(-)	n/a	50.86	3.64	47.33	12.00	28.36	0.29	0.00	0.00	0.00	0.00
C3	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C4	LOD	n/a	(-)	n/a	LOD	n/a	8.82	0.34	LOD	n/a	0.00	0.00	0.00	0.00
C5	(-)	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C6	LOD	n/a	(-)	n/a	LOD	n/a	33.37	2.42	LOD	n/a	0.00	0.00	0.00	0.00
C7	LOD	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C8	(-)	n/a	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C9	LOD	n/a	LOD	n/a	LOD	n/a	36.52	5.39	16.42	4.93	24.13	2.69	0.00	0.00
C10	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	10.66	3.25	0.00	0.00	0.00	0.00
C11	(-)	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
C12	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	LOD	n/a	0.00	0.00	0.00	0.00
Acetone	LOD	n/a	(-)	n/a	21.42	2.61	27.92	8.09	19.37	5.24	0.00	0.00	0.00	0.00





APPENDIX C.

GC/FID AND HPLC METHOD

Thermal Desorber with Gas Chromatography/Flame Ionization Detector Method

Software: Thermal Desorber: Unity Software
GC/FID: 6890 GC Software
Thermal Desorber: Ultra TD Markes International Limited
GC/FID: Agilent Technologies 6890 N Network GC System (G 1530 N) S/#: US10332028
Method Settings:

Thermal Desorber:

Idle Split: True
StandbyFlow: 20
Purge Time: 1
Minimum Carrier Pressure: 5
Purge Trap In Line: False
Purge Split: True
Flow Pather Temeperature: 120

Purge Flow: 20
ola Split Flow: 20
Oven Temperature: 280
Desorb Time: 10
Desorb Split: True
Desorb Flow: 80
GC Cycle Time: 0

Oven:

Initial Temp: 50 ^{o}C (on)
Initial Time: 5.00 min
Ramps:

#	Rate	Final Temp	Final Time
1	30.0	250	20.00
2	0.0	(Off)	

Post Temp: 0^{o}C
Post Time: 0.00 min
Run Time: 31.67 min
Maximum Temp: 325^{o}C
Equilibration time: 0.50 min

Inlet:

Mode: Splitless
Initial Temp: 150^{o}C (On)
Pressure: 17.97 psi (On)
Purge flow: 0.0 mL/min

Purge time: 999.99 min
Total flow: 7.5 mL/min
Gas saver: Off
Gas type: Nitrogen

Column:

Capillary Column
Model Number: Agilent 19091J-413
HP-5 5% Phenyl Methyl Siloxane
Max temperature: 325^{o}C
Nominal length: 30.0 m
Nominal Diameter: 320 um
Nominal film thickness: 0.25 um

Mode: constant pressure
Pressure: 17.97 psi
Nominal initial flow: 5.0 mL/min
Average velocity: 67 cm/sec
Inlet: Back Inlet
Outlet: Back Detector
Outlet Pressure: Ambient

Detector: FID

Temperature: 250oC (On)
Hydrogen flow: 40.0 mL/min (On)
Air flow: 450 mL/min (On)
Mode: Constant Makeup flow
Makeup flow: 45.0 mL/min (On)

Makeup Gas Type: Nitrogen
Flame: On
Electrometer: On
Lit offset: 2.0

Signal

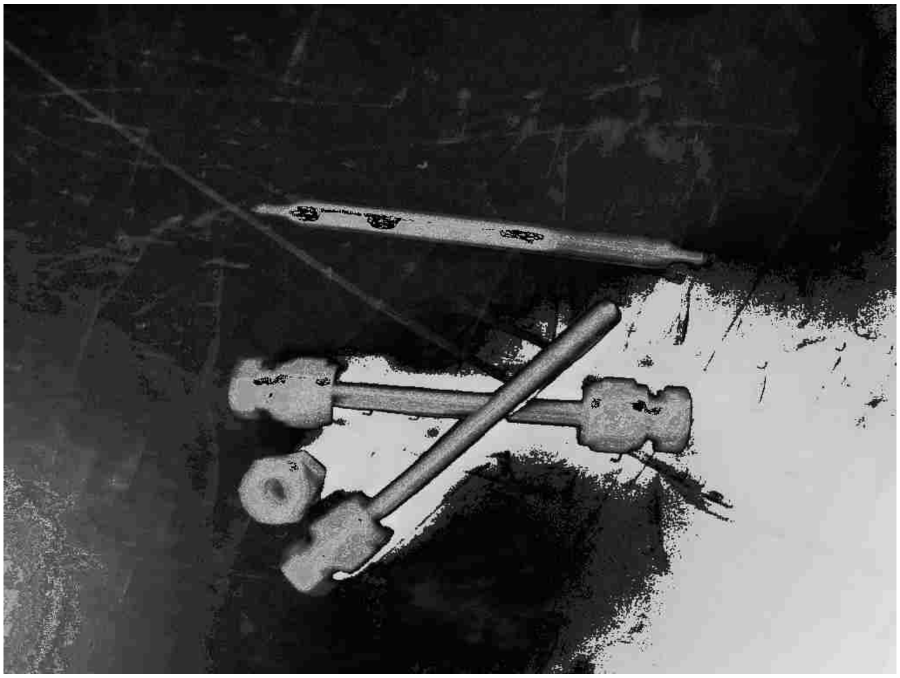
Data rate: 5 Hz
Type: back detector
Save Data: On
Zero: 0.0 (On)

Range: 0
Fast Peaks: Off
Attenuation: 0

Column Comp

  Derive from back detector

  Post Time: 0.00 min



High Pressure Liquid Chromatograph Method
Software: Empower Software
Autosampler: Waters 717plus
Autosampler
HPLC Controller: Waters 600
Controllers
Detector: Waters 996 Photodiode Array
Detector
Column: Phenomenex
P/No 006-4435-E0
Desc: Gemini 5u C18 110A
    Size: 250x4.60 mm 5 micron
    S/No: 294604-18
Method Settings:
996 PAD: general: Starting Wavelength:
210.0
Ending Wavelength: 600.0
Sampling Rate: 0.50
Resolution 1.2
Auto Exposure: On
Interpolate 656 nm Filter Response 1:
On
Analog Channel 1 Enable: On
Analog Channel 2 Enable: Off
Enable Events: Off
Events: Default
Channel 1: Output Mode Absorbance
Bandwidth 4.8
Output Wavelength 360.0
Offset 0.000
Filter Type: Hamming
Filter Response 0.0
Channel 2: Output Mode Off
W600: general: Pump Type 600 E head
volume 100 chart out % A
    Degas: A On B Off C On D Off
Rate: 30
    Channel: Enable Channel: Off
Flow: High Limit: 5000 Low Limit: 0
Pump Mode: Gradient

	Time	Flow	%A	%B	%C	%D	Curve
1	-	1.00	40.0	0.0	60.0	0.0	-
2	20.0	1.00	30.0	0.0	70.0	0.0	6
3	21	1.00	0.0	0.0	100.0	0.0	6
4	26.0	1.00	0.0	0.0	100.0	0.0	6
5	27.0	1.00	40.0	0.0	60.0	0.0	6
6	32.0	1.0	40.0	0.0	60.0	0.0	6

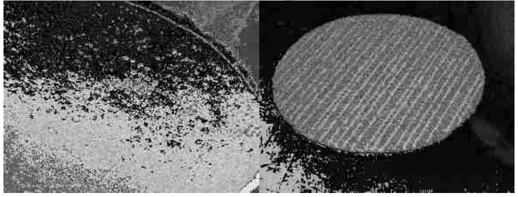
Events: Don’t Change
Solvents: A: H2O C: CAN
Temperature: Temperature Set: 0.0
Temperature High Limit: 25.0
W717: general: Temperature Enable: Off
Processing: Integration peak Width 15.0 Threshold@ 15.0
Min Area 0 Min Height = 0
Purity Start 190.0 Start 0.25
Stop 800 Stop 0.75
Purity Enable: Off
Active Peak Region (%) 100.0
Threshold Criteria Auto Threshold Solvent Angle 1.00
Purity Possess 1
PAD Library Search
None 10.0 None 3
Noise + Solvent 1.00
Component: None 5.00 Never CcalRef 1: Off


Waters 717plus Autosampler
Equipment problems?

APPENDIX D.

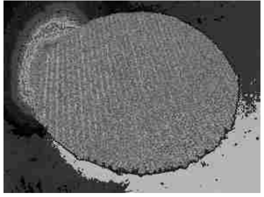
BUILDING MATERIAL DETAILS

1. Interface Carpet



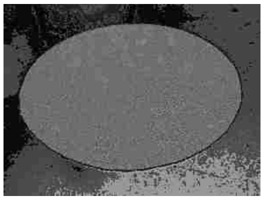
ID Number: FC-1 Carpet
Manufacturer: Interface Flooring
Style/composition: 100% post-consumer content type-6 nylon loop pile of height 0.43 cm supported by recycled vinyl and fiberglass backing. The carpet had a total recycled content of 68%-71%.
Lot Numbers: Unknown
Acquisition Date: 4/12/2009
Receiving Notes: The carpet was shipped in "tiles" of 50 cm x 50 cm x 0.7 cm to the University of Texas, Austin. Tile samples of FC-1 were shipped by UT to S&T.
Green Attribute: Recycled, California High Performance Schools, Low Emitting Materials

2. Shaw Carpet



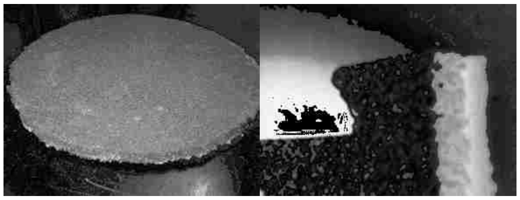
ID Numbers: FC-2
Manufacturer: Shaw
Style/composition: Casual Joy/Alskan Mist
Lot Numbers: Dye Lot V44591, Mill order number 222216
Acquisition Date: 8/18/2009
Receiving Notes: Shaw Carpet was picked up from McCall's Carpeting and transported directly to 207 Butler-Carlton Hall. The carpet consisted of a 20' by 2' section of carpet wrapped in plastic sheeting. The carpet was stored as such until sample preparation and testing could be performed.
Green Attribute: Recycled, California High Performance Schools Low Emitting Materials

3. Forbo



ID Numbers: FRf-1
Manufacturer: Forbo
Style/composition: Marmoleum, Migrations, Natural Biege
Lot Numbers: unknown
Acquisition Date: 8/18/2009
Receiving Notes: Picked up from McCalls Floor-mart, Rolla, MO. They consisted of 1'x1' square tiles. As donated materials directly from the manufacturer, lot number and style were not specified.
Green Attribute: Renewable, California High Performance Schools, Low Emitting Materials

4. Rubber



ID Numbers: FRf-2
Manufacturer: Rubber Products/Rubber Cal
Style/composition: Green Puzzle-lok recycled tire flooring
Lot Numbers: none
Acquisition Date: 4/13/2009
Receiving Notes: The rubber tile was received as 2'X2'X0.5" interlocking tiles, in room 210 Butler-Carlton Hall and transported to room 207 Butler-Carlton Hall. They were left in the original shipping box to await sample preparation and testing.
Green Attribute: Recycled rubber tires

5. Armstrong Floor Tile

ID Numbers: FRf-3
Manufacturer: Armstrong Floor Tile
Style/composition: Green grass, migrations
Lot Numbers: 99991 207638
Acquisition Date: 8.18.2009
Receiving Notes: Armstrong bio-based tile was picked up from McCall's Carpeting in Rolla, MO and transported directly to room 207 Butler-Carlton Hall. The 1'x1' tiles came in a standard shipping box of tile sheets
Green Attribute: Renewable, California High Performance Schools, Low Emitting Materials

6. Clay Tile

ID Numbers: FCf-1
Manufacturer: American Olean
Style/composition: Red, unglazed porcelain
Lot Numbers: SS033220
Acquisition Date: 4/24/2009
Receiving Notes: The 0.5'X0.5" clay tiles were picked up directly from McCalls Flooring in Rolla, MO. The clay tiles were received in a cardboard box, where they were left until preparation.
Green Attribute: Likely low emitting

7. Ecotimbers

ID Numbers: FWf-1
Manufacturer: Green Floors
Style/composition: Mocha Hickory, finished
Lot Numbers: HEDM001
Acquisition Date: 2/24/2010
Receiving Notes: A 4' box of Ecotimber wood flooring was received via UPS, which consisted of 12 pices, 4" wide, 4' long. The box was received in room 210 Butler-Carlton Hall and moved to room 207 Butler-Carlton Hall to await sample preparation and testing.
Green Attribute: Renewable
Other Product Specifications:
Dimensions

- Thickness: ½"
- Face Width: 5"
- Lengths: Random (12"-42")

Hardness

- 1820 per Janka scale
- 141% as hard as Red Oak

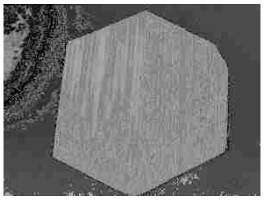
Construction

- Engineered 5-ply, kiln-dried, tongues & groove all four sides, beveled edges

Finish

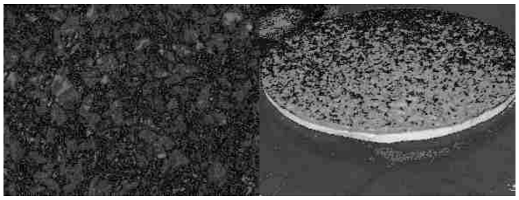
- Satin sheen Aluminum-oxide enhanced UV-cured urethane finish
- Scratch-resistant hardened acrylic top-coat

8. Bamboo



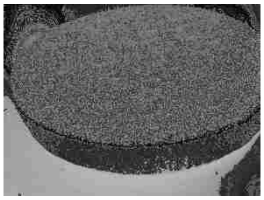
ID Numbers: FWf-2
Manufacturer: Smith & Fong
Style/composition: Plyboo, edge-grain, flooring, "Natural" pre finished FL-V5872PA-NAF
Lot Numbers: 0654 Roll B223
Acquisition Date: 8/18/2009
Receiving Notes: Picked up from McCalls flooring. Received as 5/8 x 3 5/8 x 72" pieces in a cardboard shipping box.
Green Attribute: Renewable

9. Cork



ID Numbers: WC-1
Manufacturer: Unknown (purchased from EcoChoices Natural Living Store, Portugese manufacturer name not provided)
Style/composition: Granito, pre-glued
Lot Numbers: Corboard: ACP PL1505
Contact cement: Unknown
Acquisition Date: 4/15/2009
Receiving Notes: The corkboard was received as a box of 1'x2' corboard sheets, and a second box containing a paint roller and a one gallon bucket of the contact cement to use with the corkboard. The box, bucket and roller were all stored in room 207 Butler-Carlton Hall after being retrieved from room 210 Butler-Carlton Hall after delivery, until sample preparation and testing could be performed.
Green Attribute: Renewable

10. Acoustic

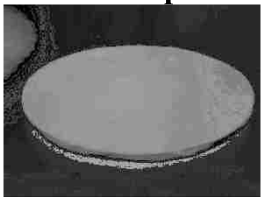


ID Numbers: WC-2
Manufacturer: Golterman & Sabo (made on contract with Missouri S&T)
Style/composition: ecoCoustic Fiberglass core, Guilford 2100 finish, 402 green neutral, 100% polyester
Lot Numbers: M-38044
Acquisition Date: 2/2/2010
Receiving Notes: The wall paneling was received in a shipping box containing 6 pieces of circular 8.5” diameter, 1.5” thick panels to 210 Butler-Carlton Hall, where they were then transported to 207 Butler-Carlton Hall until testing could be performed.
Green Attribute: 35% post-consumer recycled content

11. Rayon

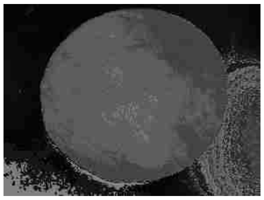
ID Numbers: WC-3
Manufacturer: Carnegie Fabrics
Style/composition: Corel monofilament polyethylene fabric
Lot Numbers: Wall covering: THOM-4798 Adhesive: 907805-1
Acquisition Date: 4/23/2009
Receiving Notes: The Rayon Wall Covering was received via UPS in room 210 Butler-Carlton Hall, as a roll of wall covering 6’ wide and 20’ long. The roll of wall covering was stored in room 207 Butler-Carlton Hall to await sample preparation and testing.
Green Attribute: Renewable

12. Ecospec



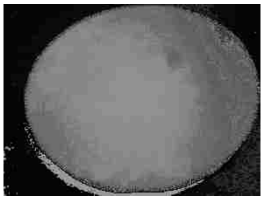
ID Numbers: WP-1a
Manufacturer: Benjamin Moore
Style/composition: 100% acrylic, flat finish (light blue). The paint contained a maximum of 25% titanium dioxide, 15% limestone, 5% silica and 5% diatomaceous earth. The primer contained water, acrylic resin, a maximum of 15% titanium dioxide and a maximum of 6% hydrous aluminum silicate.
Lot Numbers:
Acquisition Date: Transported from UT Austin to Missouri S&T on 3/23/2009, received at UT Austin on xxx.
Receiving Notes: Transported from UT Austin to Missouri S&T on 3/23/2009, received at UT Austin on xxx.
Green Attribute: Low VOC

13. Bioshield



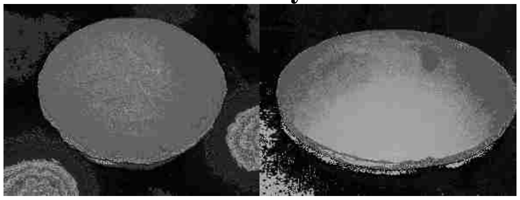
ID Numbers: WP-2
Manufacturer: Bioshield
Style/composition: Clay bright-Burnt Orange 14. Water, clay, chalk, porcelain clay, cellulose, alcohol ester (binder), titanium dioxide pigment, Ecotints, preservative.
Lot Numbers: unknown
Acquisition Date: 1/10/2010
Receiving Notes: The clay paint was received in a one pint container, directly to 210 Butler-Carlton Hall where it was moved to 207 Butler-Carlton Hall.
Green Attribute: Zer*o* VOC

14. Ecotrend



ID Numbers: WP-3
Manufacturer: EcoTrend
Style/composition: Color 14-0216 (light green), eggshell, water, titanium (di)oxide, naterual amino-acrylic emulsion, talc, hydrolyzed collagen, calcium carbonate.
Lot Numbers: Paint: 14-0216 Primer: 260948
Acquisition Date: 4/22/2009
Receiving Notes: EcoTrend paint was received in a one gallon paint bucket via UPS in room 210 Butler-Carlton Hall and then transported to 207 Butler-Carlton Hall to await sample preparation and testing.
Green Attribute: Green Guard Certified

15. American Clay



ID Numbers: WCP-1
Manufacturer: American Clay
Style/composition: Loma Original Finish, Pigment: Santa Fe Tan
Lot Numbers: Clay 57080-00131; Primer 57080-00144; Pigment 57080-00115
Acquisition Date: 4/17/2009
Receiving Notes: American Clay was picked up directly from Negwer Materials in Colombia, MO and transported directly to 207 Butler-Carlton Hall on 4/17/2009. The primary clay substrate consisted of a 50 lb of dry clay powder with a label reading "Loma Original Finish." The primer consisted of a 1 gallon bucket of primer labeled "Sanded Primer." The pigment was a 1 pint container of dry pigment powder labeled "Plastic Color Pack" and was the "Santa Fe Tan" colo.
Green Attribute: Likely Low Emitting

16. USG Drywall

ID Numbers: WD-1
Manufacturer: United States Gypsum
Style/composition: recycled content gypsum wall board
Lot Numbers:
Acquisition Date: 4/12/2009
Receiving Notes: Recycled drywall was purchased from a local distributor in Austin, TX. The drywall sheets contained recycled paper backing covering reclaimed gypsum wallboard, and had dimensions of 121.9 cm x 243.8 cm x 0.635 cm. Samples were received via shipping company in Missouri S&T from UT Austin in a shipping box of pieces of approximated 60 cm x 60 cm, where they were left until preparation and testing could be performed.
Green Attribute: Recycled

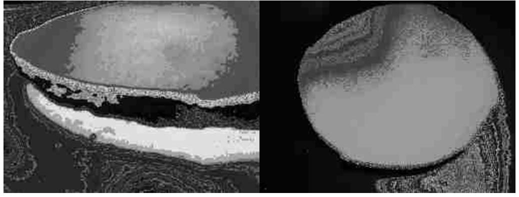
17. Armstrong Ceiling Tile

ID Numbers: CP-1
Manufacturer: Armstrong
Style/composition: Baltic 1132, Home style ceilings, Fine fissured. Mineral fiber content.
Lot Numbers: R3407
Acquisition Date: 2/7/2010
Receiving Notes: Armstrong ceiling tile was delivered, as a standard box of tiles, to Butler-Carlton Hall and dropped off at the loading dock for Butler-Carlton Hall. The box was then transported to room 207 to await preparation and testing.
Green Attribute: California High Performance Schools, Low Emitting Materials, contains recycled post-consumer and post-industrial products.

18. Eurostone Ceiling Tile

ID Numbers: CP-2
Manufacturer: Chicago Metallic
Style/composition: Eurostone, 50-70% by weight expanded perlite, 15-30% by weight sodium silicate, and 5-15% by weight kaolin. Cyrstalline quartz may have been present as an impurity at less than 0.5% by weight. The ceiling tile density was 0.36 g cm^{-3}.
Lot Numbers: unknown
Acquisition Date: 3/23/2009
Receiving Notes: Picked up from Dallas, TX. Ceiling tiles are 60.9 cm x 60.9 cm x 2.22 cm.
Green Attribute: Likely low emitting

19. Certainteed Ceiling Tile



ID Numbers: CP-3
Manufacturer: Certainteed
Style/composition: Cirrus 584 HRC line, Fiberglass composition
Lot Numbers: E35421560
Acquisition Date: 2/11/2010
Receiving Notes: Certainteed ceiling tile was delivered, as a standard box of tiles, to Butler-Carlton Hall and dropped off at the loading dock for Butler-Carlton Hall. The box was then transported to room 207 to await sample preparation and testing.
Green Attribute: California High Performance Schools, Low Emitting Materials

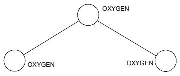
20. Latex Drywall Primer

(Primer was used for WP-2 and WP-3 but not tested separately, no primer was recommended nor provided by these manufacturers)
ID Numbers: none
Manufacturer: Valspar
Style/composition: White 260948
Lot Numbers: 9339055926
Acquisition Date: 4/30/09
Receiving Notes: Purchased directly from Lowes, Rolla, MO.
Green Attribute: Low Odor

APPENDIX E.

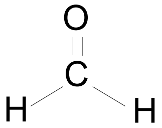
CHEMICALS TESTED AND UTILIZED

Ozone
Short Hand Name: O_3
Chemical Formula: O_3
Chemical Structure Diagram:



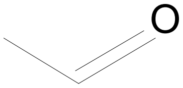
Tested For:Yes
Use:
Health Effects:

Formaldehyde, Methanal
Short Hand Name: C1
Chemical Formula: CH_2O
Chemical Structure Diagram:



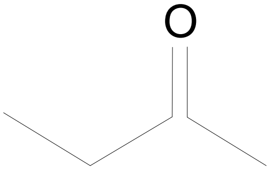
Tested For: Yes
Use: Tissue fixative, embalming agent, disinfectant, biocide, wood production
Health Effects: Highly toxic and volatile, probable human carcinogen.

Acetaldehyde, ethanal
Short Hand Name: C2
Chemical Formula: C_2H_4O
Chemical Structure Diagram:



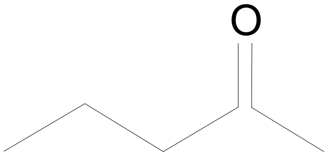
Tested For:
Use: Used as a precursor to acetic acid, used to as a precursor for various derivatives and resins.
Health Effects: Works with nicotine to create tobacco addiction, toxic, probable carcinogen.

Propionaldehyde
Short Hand Name: C3
Chemical Formula: C_3H_6O
Chemical Structure Diagram:



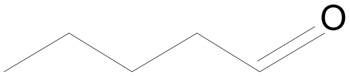
Tested For: Yes
Use: Used to condense out other chemicals.
Health Effects: No information

Butyraldehyde, Butanal
Short Hand Name: C4
Chemical Formula: C_4H_8O
Chemical Structure Diagram:



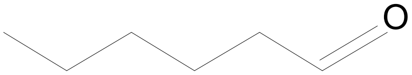
Tested For: Yes
Use: No information
Health Effects: Flammable

Valeraldehyde, Pentanal
Short Hand Name: C5
Chemical Formula: $C_5H_{10}O$
Chemical Structure Diagram:



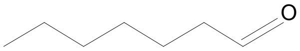
Tested For: Yes
Use: Use in flavorings, resin chemistry and rubber accelerators.
Health Effects: Butanal

Hexanal
Short Hand Name: C6
Chemical Formula: $C_6H_{12}O$
Chemical Structure Diagram:



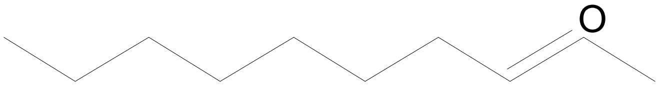
Tested For: Yes
Use: Flavoring
Health Effects: No information

Heptaldehyde, Heptanal
Short Hand Name: C7
Chemical Formula: C7H14O
Chemical Structure Diagram:



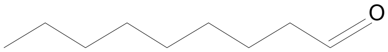
Tested For: Yes
Use: Ingredient in cosmetics, perfumes and flavoring.
Health Effects: No information

Octanal
Short Hand Name: C8
Chemical Formula: $C_8H_{16}O$
Chemical Structure Diagram:



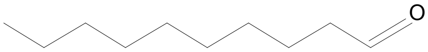
Tested For: Yes
Use: Component of perfumes and flavoring
Health Effects: No information

Nonanal
Short Hand Name: C9
Chemical Formula: $C_9H_{18}O$
Chemical Structure Diagram:



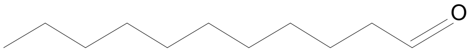
Tested For: Yes
Use: Used in flavoring and perfumes, produced naturally by the human body.
Health Effects: No information

Decanal
Short Hand Name: C10
Chemical Formula: $C_{10}H_{20}O$
Chemical Structure Diagram:



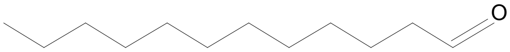
Tested For: Yes
Use: Additive in cosmetics, and flavoring
Health Effects: No information

2-Undecanal
Short Hand Name: C11
Chemical Formula: $C_{11}H_{22}O$
Chemical Structure Diagram:



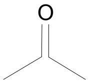
Tested For: Yes
Use: Additive in cosmetics and cigarettes
Health Effects: no information

Dodecanal
Short Hand Name: C12
Chemical Formula: $C_{12}H_{24}O$
Chemical Structure Diagram:



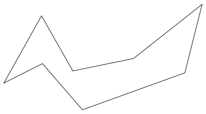
Tested For: Yes
Use: Additive in cosmetics
Health Effects: No information

Acetone
Short Hand Name: Acetone
Chemical Formula: C_3H_6O
Chemical Structure Diagram:



Tested For: Yes
Use: Solvent
Health Effects: Extremely flammable and has low acute and chronic toxicity effects on humans.

Cylooctane
Short Hand Name:Cylooctane
Chemical Formula: C_8H_{16}
Chemical Structure Diagram:



Tested For: No
Use: Internal Standard

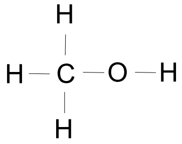
Health Effects: Very stable being a part of the alkane family

Potassium Iodide
Short Hand Name: KI
Chemical Formula: KI
Chemical Structure Diagram:

$K-I$

Tested For: No
Use: Calculate the transport limited deposition velocity
Health Effects: Mild irritant with constant exposure to large doses having the potential of causing thyroid problems.

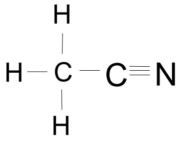
Methanol
Short Hand Name: Methanol
Chemical Formula: CH_4O
Chemical Structure Diagram:



$H-\underset{H}{\overset{H}{C}}-O-H$

Tested For: No
Use: Solvent for GC/FID standards
Health Effects: Toxic with potential to cause blindness and fatality when injested.

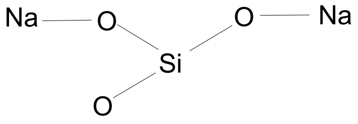
Acetonitrile
Short Hand Name: ACN
Chemical Formula: C_2H_3N
Chemical Structure Diagram:



$H-\underset{H}{\overset{H}{C}}-C\equiv N$

Tested For: No
Use: Solvent for samples and standards tested via HPLC
Health Effects: Can be metabolized to produced hydrogen cyanide to cause modest toxicity. (International Program on Chemical Safety

Sodium Silicate
Short Hand Name: Sodium Silicate
Chemical Formula: Na_2SiO_3
Chemical Structure Diagram:



Tested For: No
Use: Seal non-tested parts of building materials
Health Effects: No significant human health hazard issues.

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