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Effects of Temperature on the Emission Rate of Formaldehyde from Medium Density Fiberboard in a Controlled Chamber

William Swankie
University of South Florida, wrswanki@ncsu.edu

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by

William Swankie

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Major Professor: Yehia Hammad, Sc.D.
Steve Mlynarek, Ph.D.
John Smyth, Ph.D.
Foday Jaward, Ph.D.

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List of Abbreviations

ACH .... Air Changes per Hour
ANSI .... American National Standards Institute
ASHRAE........ American Society of Heating, Refrigerating and Air Conditioning Engineers
ATSDR .... Agency for Toxic Substances & Disease Registry
CARB........ California Air Resource Board
CWP........ Composite Wood Product
DNPH........ 2,4-Dinitrophenylhydrazine
EC .... Experiment Chamber
EPA........ Environmental Protection Agency
HP .... Hardwood Plywood
I1 .... Inlet
IARC........ International Agency for Research on Cancer
JAS........ Japanese Agricultural Standards
JIS .... Japanese Industrial Standards
LPH........ Liters Per Hour
LPM .... Liters Per Minute
MBTH........ 3-Methyl-2-Benzothiazolinone Hydrazone
MDF........ Medium Density Fiberboard
MF........ Melamine Formaldehyde
ND........ Non Detect
NIOSH .... National Institute for Occupational Safety and Health
NTP........ National Toxicology Program
O1........ Top Exit Port
O2........ Bottom Exit Port
OSHA........ Occupational Health and Safety Administration
PB........ Particle Board
PF........ Phenol Formaldehyde
PPB .... Parts Per Billion
PPM........ Parts Per Million
PTFE .... Polytetrafluoroethylene
PVC........ Polyvinyl Chloride
RH........ Relative Humidity
SCC........ Standards Council of Canada
SCOEL........ Scientific Committee on Occupational Exposure Limits
TPC .... Third Party Certification
TSCA .... Toxic Substances Control Act
UF .... Urea Formaldehyde
WIEC .... Walk-In Environmental Chamber

Abstract

Formaldehyde is a colorless gas that is found naturally in the environment. It is a popular additive in many consumer products including composite wood products. Composite wood products are engineered wood panels produced from pressing pieces, chips, particles, or fibers of wood together at high temperatures held together with a bonding agent. This bonding agent is often formaldehyde-containing resins that are known to release formaldehyde over time. This is concerning because of the carcinogenic classification of formaldehyde, the wide spread application of composite wood products, and the increasing amount of time spent in the indoor environment.

In a controlled 0.53 m^3 chamber, a panel of medium density fiberboard (MDF) with a surface area of 4.49 m^2 was subjected to multiple temperatures to measure formaldehyde emissions. The panels were allowed to acclimate for 48 hours followed by a 72 hour sample period using passive diffusive monitors at temperatures: 26.1, 29.3, 34.1, and 38.9 ºC. The results of the study found a strong relationship (R^2 = 0.9954) between the emission rate of formaldehyde from MDF and temperature. The emission rate increased 192% between 26.1 ºC and 38.9 ºC. The results of the study indicate that as temperature increases, the amount of formaldehyde emitted from a panel of MDF also increases. This results in higher airborne concentrations of formaldehyde in environments where the panels are present.

Introduction

Formaldehyde

Formaldehyde is a flammable, colorless gas that is found naturally in the environment and has a pungent odor at room temperature (ATSDR, 1999). It is also naturally produced in small amounts in plants, animals, and humans as a method of metabolism. Formaldehyde is a popular product that is used widely in consumer products including resins used to manufacture composite wood products (CWP), building materials and insulation. Formaldehyde is also a common component used in other household products such as glues, paints, lacquers, paper products, preservatives in some medicines, cosmetics, fertilizers, and pesticides (EPA, 2016). Formaldehyde is also a byproduct of combustion from sources including fuel burning appliances, automobiles, gas stoves, and cigarette smoke (EPA 2016). Since formaldehyde is a byproduct of combustion, rural and suburban air typically has a lower concentration than urban air. Formaldehyde is also normally found in higher concentrations indoors compared to outdoor air (ATSDR, 1999). Formaldehyde is known to cause both short term and long term adverse health effects explained in more detail in the Literature Review.

Composite Wood Products

CWPs are a family of engineered wood panels made from pieces, chips, particles, or fibers of wood bonded together with a resin. The wood pieces containing the resin are pressed together at high temperatures to form panels. CWPs are defined as hardwood plywood (HP) made with a veneer or composite core, medium density fiberboard (MDF), and particle board (PB) according to the Environmental Protection Agency (EPA) (EPA, 2016).

MDF is formed from small wood particles that are pressed together with glue under extreme heat and pressure to make a solid surface (Composite Panel Association, n.d.). Wood particles are refined further into smaller particles than particleboard to provide a smooth edge to panels. The American National Standards Institute (ANSI) standard A208.2 defines MDF as a composite panel product composed of mainly of cellulosic fibers and a bonding system cured under heat and pressure (ANSI, 2002). MDF panels usually have a density between 500 kg/m^3 and 1000 kg/m^3 (ANSI, 2002). MDF is widely used in furniture, kitchen cabinets, door parts, moulding, millwork, and laminate flooring (Composite Panel Association, n.d.).

BONDING AGENTS IN COMPOSITE WOOD PRODUCTS

CWPs are bonded together with formaldehyde containing resins which include: urea formaldehyde (UF), phenol-formaldehyde (PF), and melamine formaldehyde (MF). Of these common resins, it has been found that UF emits the most formaldehyde when used in CWPs (EPA, 2016). UF resins have been used since the 1920s and are the most common resin used due to their low costs, a rapid cure rate, and their light color (EPA, 2016). UF resins are also usually used for interior application because they are not water resistant (EPA, 2016). Hydrolysis of formaldehyde can occur from moisture interacting with the UF resin causing depolymerization and the release of formaldehyde (EPA, 2016).

PF resins were developed in the early 20th century and are typically used in exterior applications due to their high water resistance (EPA, 2016). They have some disadvantages though which include a dark color, longer press time, and higher press temperature (EPA, 2016). They do however have more stable reactions involving the phenol formaldehyde resin synthesis compared to UF resins resulting in lower formaldehyde emissions (EPA, 2016). This has been confirmed with studies accepted by the EPA measuring formaldehyde concentrations of different resins used in CWPs (EPA, 2016).

MF resin is resistant to moist conditions and is commonly used for exterior and semi-exterior applications (EPA, 2016). It is also commonly used in decorative laminates, paper treating, and paper coating (EPA, 2016). MF resins are light in color but are expensive compared to UF due to the cost of melamine. MF resins have a similar synthesis as UF resins but melamine is a stronger nucleophile resulting in a quicker and more complete reaction of formaldehyde (EPA, 2016). There are limited data available on MF resins without added urea but previous studies have shown a similar emission rate as UF resins (EPA, 2016).

Public Health Significance

Americans spend an average of 87% of their time indoors in enclosed buildings (EPA, 1989). Indoor air quality is an often overlooked but is an important factor in the overall wellbeing of a person's health. With the significant amount of time spent indoors, a person's exposure to indoor pollutants may be harmful and result in acute and chronic adverse health effects. Some indoor pollutants, such as formaldehyde, are also 2 to 5 times higher in the indoor environment compared to the outdoor concentrations (EPA, 1989). MDF is a known formaldehyde emission source which can contribute to these increased levels. Since MDF is a widely used product found in many residential and commercial buildings, occupants may be exposed to significant concentrations of formaldehyde over an extended period of time.

While occupational exposure standards exist for formaldehyde, there are no regulations regarding formaldehyde concentrations in the indoor environment outside of occupational settings. While some regulations are being created that limit the amount of formaldehyde a product can emit, none regulate the overall concentration in indoor air.

Purpose of Study

This study was designed to measure the relationship of formaldehyde emissions from MDF and temperature. Methods and standards currently exist to test the emission rates of formaldehyde from MDF, but only one temperature is used in these methods as seen in Table 3. It is possible that panels may pass emission standards in one of the standardized methods, but emit over the limit when temperatures increase. Since indoor environments can often have dramatic fluctuations both seasonally and daily, these methods may not be representative of actual emission rates. Information from the effects on temperature could help create a better representation of formaldehyde concentrations in indoor environments from MDF emissions. In order to achieve these goals, this study was designed to answer:

- Do airborne formaldehyde concentrations from MDF increase with temperature?
- Does the emission rate of formaldehyde from MDF increase as temperature increases?
- Are current emission standards of MDF representative of emission rates in a random piece of MDF?
- Can results from the study be extrapolated to represent concentrations that may be found in residential settings?

Study Limitations

A walk-in environmental chamber (WIEC) was used to produce the temperatures desired in this study. The room where the WIEC was located often experienced fluctuations in temperature in accordance to outdoor conditions. To get a better representation of temperature through the whole study, a data logger was used continuously to monitor conditions and the average temperature used for all calculations. Relative humidity (RH) also fluctuated with outdoor conditions and was not possible to be maintained with a reasonable degree of accuracy inside the WIEC.

Due to the high temperatures of the 35 °C and 40 °C experiment runs, the air pumps used to move air through the chamber often did not meet +/- 5% calibration standards. This is not thought to have affected the study however due to air flow only being used to prevent the chamber from being static. Sponge Window Seal was used to seal the panels against the edges of the experiment chamber to channel air over all surfaces of the panels. The Sponge Window Seal contained polyvinyl chloride (PVC) which is known to break down into formaldehyde when it is in air (ATSDR, 2006). The Sponge Window Seal was undisturbed during the course of the study. It is unknown if any off gassing occurred from natural sources or temperature related causes. It is possible some of the formaldehyde concentrations measured are from the byproduct of PVC breakdown in air. This is thought to be a negligible amount however due to the significantly higher surface area of MDF compared to the Sponge Window Seal.

Literature Review

Health Effects of Formaldehyde

The most common health effects from formaldehyde is the irritation of the eyes, nose, and throat due to portal-of-entry health effects, mainly inhalation (ATSDR, 1999). This is due to formaldehyde being a highly reactive molecule that is quickly broken down by the tissues it comes in contact with causing irritation (ATSDR, 1999). The upper respiratory tract including the lining of the nose and throat are the main targets of toxicity in formaldehyde inhalation. This is because up to 90% on inhaled formaldehyde is absorbed and metabolized here (Kimbell et al. 2001). Studies have shown that inhalation of formaldehyde concentrations of 0.1 to 0.5 ppm can produce nasal irritation, increase the risk of asthma or allergies, and produce neurological effects (ATSDR, 1999). At airborne concentrations of 0.6 to 1.9 ppm, changes in pulmonary function may begin to occur (ATSDR, 1999). At airborne concentrations of 6.0 to 10.9 ppm, headaches, nausea and discomfort in breathing and coughing may occur (ATSDR, 1999). Airborne concentrations above 5 ppm also cause irritation to the lower airway including coughing, chest tightness, and wheezing (OSHA, 2012). Airborne concentrations above 50 ppm may cause pulmonary edema, pneumonia, and bronchial irritation within minutes that may cause death (OSHA, 2012). According to the Occupational Health and Safety Administration (OSHA), airborne concentrations of 0.05 ppm to 0.5 ppm have been shown to produce irritation in the eyes characterized by burning, itching, redness and tearing (OSHA, 2012).

Formaldehyde also causes adverse health effects in other exposure routes including dermal contact and ingestion. Dermal contact with formaldehyde mainly causes skin irritation and may cause allergic contact dermatitis. Previous studies have shown that formaldehyde concentrations in air of 0.6 to 1.9 ppm may cause eczema (ATSDR, 1999). Airborne concentrations above 2.0 ppm have been shown to cause skin irritation (ATSDR, 1999). Symptoms of irritation are characterized by erythema, edema, vesiculation or hives (OSHA, 2012). Ingestion of formaldehyde causes gastrointestinal toxicity that is most severe in the stomach. Symptoms of ingestion include: nausea, severe abdominal pain, and vomiting (OSHA, 2012). Acute responses to the ingestion of formaldehyde may also damage the liver, kidney, spleen, pancreas, brain, and central nervous system (OSHA, 2012).

Chronic effects of formaldehyde exposures have been shown to increase the risk of cancer of the nose and accessory sinuses as well as cause oropharyngeal, nasopharyngeal, and lung cancers (OSHA, 2012). Numerous studies and agencies have concluded that formaldehyde is a cancer causing agent. Formaldehyde was classified a Group 1 carcinogen in 2004 by the International Agency for Research on Cancer (IARC). The IARC classified formaldehyde as a known human carcinogen that has sufficient evidence of causing nasopharyngeal cancer and leukemia (IARC, 2012). Formaldehyde is categorized as a known human carcinogen by the U.S. National Toxicology Program (ATSDR, 1999). The National Institute for Occupational Safety and Health (NIOSH) has placed formaldehyde on its carcinogen list. The EPA considers formaldehyde a probable human carcinogen and has been ranked in Group B1 (EPA, 1999). EPA Group B1 classifies a substance as a probable human carcinogen based on limited evidence in humans and sufficient evidence in animals. The National Toxicology Program (NTP) classifies formaldehyde as known to be a human carcinogen (NTP, 2016). Although it is agreed upon that formaldehyde is a carcinogen, there is no generally agreed upon exposure level which causes cancer.

Exposure Limits and Guidelines of Formaldehyde

There are currently no agreed upon standards that regulate the concentration of formaldehyde in the indoor environment in the United States. There are existing occupational exposure limits for formaldehyde, but these are not applicable to residential settings. A few agencies have published guidelines which list recommended concentrations limits based on health effects, but they are not enforceable. Some international guidelines do exist for formaldehyde concentrations in the indoor environment.

Table 1 – Summary of Current United States Formaldehyde Guidelines

Source	Concentration	Time	Source
OSHA Permissible Exposure Limit	750 ppb	8 Hour	1
OSHA Short Term Exposure Limit	2000 ppb	15 Min	1
NIOSH Recommended Exposure Limit	16 ppb	8 Hour	1
NIOSH Recommended Exposure Limit	100 ppb	15 Min	1
ATSDR Minimal Risk Level	40 ppb	1 – 14 days	2
ATSDR Minimal Risk Level	30 ppb	15 – 365 days	2
ATSDR Minimal Risk Level	8 ppb	> 365 days	2

Notes:
OSHA – Occupational Safety and Health Administration
NIOSH – National Institute for Occupational Safety and Health
ATSDR – Agency for Toxic Substances & Disease Registry

Sources:
1. "Formaldehyde" (OSHA, 2012)
2. "Minimal Risk Level" (ATSDR, 2016)

Table 2 – Summary of Current International Formaldehyde Guidelines

Source	Concentration	Time	Reference
World Health Organization	81 ppb	30 Min	1
Health Canada / World Health Organization	100 ppb	1 Hour/Long Term	1,2
Health Canada	40 ppb	8 Hour	2
Scientific Committee on Occupational Exposure Limits	20 ppb	8 Hour	3
Scientific Committee on Occupational Exposure Limits	40 ppb	30 Min	3

References:

1. "WHO Guidelines for Indoor Air Quality: Selected Pollutants" (Kaden, 2010)
2. "Formaldehyde in Indoor Air" (Health Canada, 2012)
3. "Recommendation from the Scientific Committee on Occupational Exposure Limits for Formaldehyde" (SCOEL, 2008)

<u>Composite Wood Product Emission Standards and Guidelines</u>

In recent years, more countries have begun to implement programs which set allowable emission rates for CWPs that contain formaldehyde adhesives. Most recently, the United States EPA and the Standards Council of Canada (SCC) have both implemented standards for CWPs in their respective countries. The new standards place limits on the amount formaldehyde allowed to be emitted from a CWP sold or produced in each country. This joins a host of preexisting countries and organizations that have standards in place which include: The California Air Resource Board (CARB), Japanese Industrial Standard (JIS)/ Japanese Agricultural Standards (JAS), the European Union, and the American National Standards Institution (ANSI).

Table 3 – Emission Standards of Formaldehyde in Medium Density Fiberboard

Country	Standard	Emission Limit	Test Method	Temperature	Duration of Test	Source
United States	CARB-P1	0.21 ppm	ASTM E1333	25 °C +/- 1.0 °C	16 – 20 Hours	1
	CARB-P2	0.11 ppm	ASTM E1333	25 °C +/- 1.0 °C	16 – 20 Hours	1
	ANSI A208.2	0.30 ppm	ASTM E1333	25 °C +/- 1.0 °C	16 – 20 Hours	1
Canada	CAN/CAS - 0160	0.13 ppm	ASTM E1333	25 °C +/- 1.0 °C	16 – 20 Hours	1
European Union	E1	< 0.10 ppm	EN 717-1	23 °C +/- 0.5 °C	Up to 28 Days	2
	E2	> 0.10 ppm	EN 717-1	23 °C +/- 0.5 °C	Up to 28 Days	2
Japan	F* (Type 1)	> 0.10 ppm	JIS A-1460	20 °C +/- 1.0 °C	24 Hours	3
	F** (Type 2)	0.10 ppm	JIS A-1460	20 °C +/- 1.0 °C	24 Hours	3
	F*** (Type 3)	0.07 ppm	JIS A-1460	20 °C +/- 1.0 °C	24 Hours	3
	F**** (Type 4)	0.04 ppm	JIS A-1460	20 °C +/- 1.0 °C	24 Hours	3

References:

1. “Method E1333-14” (ASTM, 2014)
2. “Method EN 717-1” (CEN, 2004)
3. “Method JIS A-1460” (JAS, 2001)

FORMALDEHYDE STANDARDS FOR COMPOSITE WOOD PRODUCTS

On December 12, 2016 the EPA published the final rule of the Formaldehyde Standards for Composite Wood Products Act. This rule which went into effect February 10, 2017 added Title VI to the Toxic Substances Control Act (TSCA). In the rule, formaldehyde emission standards have been created for applicable CWPs including: HP, MDF, PB, and finished goods containing these products that are sold, supplied, offered for sale or manufactured in the United States (Formaldehyde Standards for Composite Wood Products Act, 2016). The new statute establishes emission standards that are identical to the existing California Air Resource Board (CARB) Air Toxic Control Measure (ATCM) Phase 2 Standards for formaldehyde.

Table 4 –Formaldehyde Standards for Composite Wood Products Act Emission Standards

Composite Wood Product	**Emission Standard**
Hardwood Plywood (made with veneer core or a composite core)	0.05 ppm
Particleboard	0.09 ppm
Medium Density Fiberboard	0.11 ppm
Thin Medium Density Fiberboard	0.13 ppm

Products that meet the criteria of regulated composite wood products must comply with the emission standards seen in Table 4 on December 12, 2017. After this date, all boards that are sold, supplied, manufactured, or imported in the United States must be labeled TSCA Title VI complaint. In the rule, an EPA TSCA Title VI Third-Party Certification (TPC) program was established to ensure compliance of composite wood panel producers. These TPC's are accredited from the EPA and certify compliance that all CWPs meet the new EPA emission standards. In order for a panel producer to have a CWP certified, the product would have to have been demonstrated to have emissions below the standards in Title VI shown in Table 4. The demonstration can be through a combination of testing performed at an accredited TPC laboratory repeated on a quarterly basis and more frequent quality control testing (Formaldehyde Standard for Composite Wood Products Act, 2016).

In order for a panel to become approved, it must be measured every three months by an approved TPC using test method ASTM E1333-96 or ASTM D6007-02. In order for testing to be conducted using ASTM D6007-02 however, equivalence must be shown to ASTM E1333-96 results. Quality control tests must also be conducted using test method ASTM D6007-02, ASTM D-5582, EN 717-2, DMC, EN 120 or JIS A 1460 if a positive correlation is shown to ASTM E1333-96 (Formaldehyde Standard for Composite Wood Products Act, 2016).

In ASTM E1333-96, a large chamber at least 22 m^3 must be used. The ratio of the MDF panel surface area to the volume of the chamber, called loading ratio, must be 0.26 m^2/m^3. Boards are first pre-conditioned for 7 days +/- 3 hours at 50% relative humidity +/- 5% and 24 °C +/- 3 °C (ASTM, 2014). The chamber must have an air change rate of 0.5 +/- 0.05 air changes per hour (ACH) (ASTM, 2014). During testing, the environmental conditions inside the chamber must be 50% +/- 4% RH and 25 °C +/- 1 °C (ASTM, 2014). The samples are kept in the chamber for 16 to 20 hours before an air sample can be taken. Air samples are then taken using a modified version of NIOSH Method 3500 in impingers containing a 1% solution of sodium bisulfite (ASTM, 2014). Many of the conditions and methods are the same in ASTM D6007 except the chamber is only 0.02 – 1.0 m^3 (ASTM, 2014). ASTM D6007 is often used in place of ASTM E1333 when a correlation has been shown to make testing results valid.

Previous Experiments and Studies

In 2000, Wiglusz et al. measured formaldehyde emissions from two types of laminate flooring in relation to temperature in an environmental chamber located at ATS Stratus, Poland. Type A featured a bonded laminate on top with a particleboard substrate, Type B featured thermofused saturated papers on top with a high density fibre substrate. Air samples were taken at a flow rate of 20 liters per hour (LPH) for 4 hours using 2 washers connected in a series containing 10 ml of water each (Wiglusz, 2000). A colorimetric method with p-rosaniline was used to measure formaldehyde concentrations which had an analytical detection limit of 0.006 mg/m^3 (4.18 ppb). Three temperatures were tested at 23, 29, and 50 ºC. All three temperature events occurred with an air exchange ratio of 0.50 air changes per hour. Both types of laminate flooring did not produce formaldehyde emissions at temperatures 23 ºC and 29 ºC. At 50 ºC Type A had a formaldehyde emission of 0.415 mg*m*h and Type B had a formaldehyde emission of 0.030 mg*m*h.

Xiong and Zhang measured the impact of temperature on the initial emittable concentration of formaldehyde in MDF in a report published in 2010. A 30 L cylindrical static chamber was used with a real-time gas Volatile Organic Compound analyzer to measure the concentrations of formaldehyde in the chamber. A multi-emission/flush regression method was used which involves flushing the chamber once it reaches equilibrium inside a static chamber (Xiong and Zhang, 2010). Four temperatures were tested which included 25.2, 33.3, 41.4, and 50.6 °C. For temperatures 25.2 and 33.3 °C, a 100 x 200 x 2.8 mm (L x H x W) board was used. For temperatures 44.1 and 50.6 °C, a 100 x 100 x 2.8 mm (L x H x W) board was used. The results of the experiment showed a 507% increase in the initial emittable concentration of formaldehyde between the lowest temperature of 25.2 °C and the highest temperature of 50.6 °C (Xiong and Zhang, 2010).

Huang et al. determined the impact of temperature on the ratio of initial emittable concentration and the total concentration of formaldehyde in 2014. Prior to this study, temperatures above 50 °C had not been tested to examine potential formaldehyde emission levels of building materials. Formaldehyde molecules are bonded by adsorption to the material surface and become emittable when the kinetic energy of the molecule is high enough to overcome an energy barrier (Huang et al., 2015). The released formaldehyde molecules add up which is known as the initial emittable concentration. Temperature is a known factor which increases the kinetic energy of a molecule, therefor in theory increasing the emittable concentration of formaldehyde from building materials. To test this, a piece of widely used MDF used for decoration was placed inside an environmentally controlled 30 L stainless steel chamber (Huang et al., 2015). The piece of MDF measured 10 cm x 10 cm x 0.3 cm (L x H x W) and had the sides and edges taped off. An air pump operating at 0.2 Liters per minute (LPM) was connected to a tube containing a 3-methyl-2-benzothiazolinone hydrazone (MBTH) aqueous solution. A sample time of 5 minutes was used for all samples and then analyzed using a Chinese national standard called the MBTH spectrophotometer method. Samples were allowed to equilibrate in the chamber for 36 hours at each temperature being tested. Eight temperatures were tested which included: 25, 29, 35, 42, 50, 60, 70, and 80 °C all at 50% RH. The results of the study found that formaldehyde emission rates increased about 14-fold between the initial test at 25 °C and the final test at 80°C (Huang et al., 2015).

Liang et al. measured the formaldehyde emissions from MDF over the course of 29 months in an experimental room in a report published in 2015. The room located in a rural district of Beijing, China, measured 4 m x 3 m x 3 m (L x W x H). The room was built two years prior to the study beginning. The tile floors and latex walls were deemed negligible for formaldehyde emissions at the time of the experiment. Temperature and humidity were allowed to vary naturally in the room with a fan operating to mix air. Three full size MDF boards measuring 2.44 m x 1.2 m x 0.012 m (L x W x H) and one small board measuring 0.18 m x 1.2 m x 0.012 m (L x W x H) were purchased directly from the manufacturer. This resulted in a loading ratio of 0.5 m^2/m^3 (Liang et al., 2015). A sampling portal was created in the door of the room 1.2 m high. Formaldehyde was measured using the MBTH spectrophotometric method. Sample times ranged from 5 – 30 minutes and samples were taken frequently at times ranging from a few days to a few weeks. The maximum concentration measured occurred in summer 2013 and measured 4.78 mg/m^3 (3.89 ppm) (Liang et al., 2015). In the study it was measured that the initial emission rate of from the MDF was 0.93 mg/m^2-h. The highest rate measured in the summer of 2013 was 2.76 mg/m^2-h and 1.84 mg/m^2-h in summer 2014 (Liang et al., 2015). The Pearson correlation coefficient between formaldehyde concentration and temperature was 0.84 (Liang et al., 2015). Absolute humidity was also compared to formaldehyde emissions and a Pearson correlation coefficient was found to be 0.89 (Liang et al., 2015). It was concluded that formaldehyde emissions were much higher in the summer temperatures and that temperature was likely one of the key factors influencing seasonal formaldehyde concentration differences.

Pierce et al. measured formaldehyde concentrations of two types of HDF laminate flooring products in both an experimental room and a small chamber test in a report published in 2016. Two separate rooms were used to test the two different flooring products. Room 1 was 26.64 m^3 and room 2 was 27.62 m^3 (Pierce et al., 2016). The building ventilation was on from approximately 8:00 am to 6:00 pm on weekdays and 8:00 am to 1:00 pm on Saturdays. The system was turned off during the rest of the time. An air exchange rate of 5.2 hr^{-1} with the system on and 0.76 hr^{-1} with the system off was measured in Room 1 (Pierce et al., 2016). An air exchange rate of 5.1 hr^{-1} with the system on and 0.52 hr^{-1} with the system off was measured in Room 2 (Pierce et al., 2016). A total of 79 ChemDisk 571 Aldehyde Passive Monitors were used with a sample time of 24 hours per monitor. In total, a sample period of 63 days was used which included background samples, acclimation samples, post-installation samples, and post-removal samples. The test resulted in an average of 0.038 ppm in room 1 and 0.022 ppm in room 2 post-installation. (Pierce et al., 2016). Post removal resulted in an average of 0.025 ppm in room 1 and 0.021 ppm in room 2 (Pierce et al., 2016). A deconstructive and non-deconstructive chamber test commonly called CARB Deconstructive Testing using ASTM D6007 guidelines was also conducted on the flooring products. In deconstructive testing, the surface layer of the panel is removed to expose the core. These panels are then tested using ASTM D6007 guidelines. In non-deconstructive testing the panel is tested using ASTM D6007 without removing any surface off of the panels. The standardized formaldehyde concentrations of product 1 resulted in 0.420 ppm in the deconstructive test and 0.018 ppm in the non-deconstructive test (Pierce et al., 2016). The standardized formaldehyde concentrations of product 2 resulted in 0.106 ppm in the deconstructive test and 0.012 ppm in the non-deconstructive test (Pierce et al., 2016).

Methods

Material Selection

MDF was chosen as the CWP for this experiment due to having the highest emission rate of formaldehyde (Godish, 1989). This is due to a higher resin-to-wood ratio than any other CWP (EPA, 1991). At a common nationwide home improvement store, a panel of 0.75" x 49" x 8.083' (W x H x L) MDF was selected. The 0.75 in thickness was chosen because store employees said it was the most popular. The panel was untreated and unfinished and was listed as CARB compliant. No non-CARB compliant panels could be located at the local home improvement stores. Using dimensions from the experiment chamber (EC), the panel was cut into 5 pieces measuring 38" x 18.325" (H x L). This resulted in a total exposed MDF surface area of 4.49 m^2.

MDF Preparation

The panels were wiped down using a damp paper towel to remove excess dust from cutting. Ten 1" wide pieces were cut from excess MDF left over from the same panel. Two pieces were then attached to the top of each panel using Epoxy Adhesive (JB Weld, Sulphur Springs) approximately 1 inch from each side and allowed to dry overnight. Each panel was then fitted with Sponge Window Seal (MD Building Products, Oklahoma City) along the three inner perimeter edges of the panel surface. The surface edge of the panel with the two 1 in pieces was not fitted with Sponge Window Seal. A piece of Sponge Window Seal was also placed along the entirety of the top of the panel opposite of the side with the two 1" pieces.

Experiment Chamber Design

A Plexiglas box measuring 18.5” x 38.75” x 45.25” (W x H x L) with an internal volume of 0.53 m^3 was used as the EC. A 21” x 48” (W x L) Plexiglas lid covered the box and was closed via PTFE screws with metal washers and nuts. The top of the Plexiglas box was lined with Sponge Window Seal to create a seal with the lid. On one side of the chamber, a 1.5” PVC pipe had previously been fitted through the Plexiglas side. A North Defender Multi-Gases/Vapors/P100 Respirator Cartridge (Honeywell, Morris Plains) was secured onto the end of a 1.5” PVC pipe using Epoxy Adhesive. The cartridge was positioned so that air would be filtered as it flowed into the EC. This PVC pipe was connected to the existing PVC pipe in the chamber with a 1.5” PVC elbow to form the inlet as seen in Figure 1.

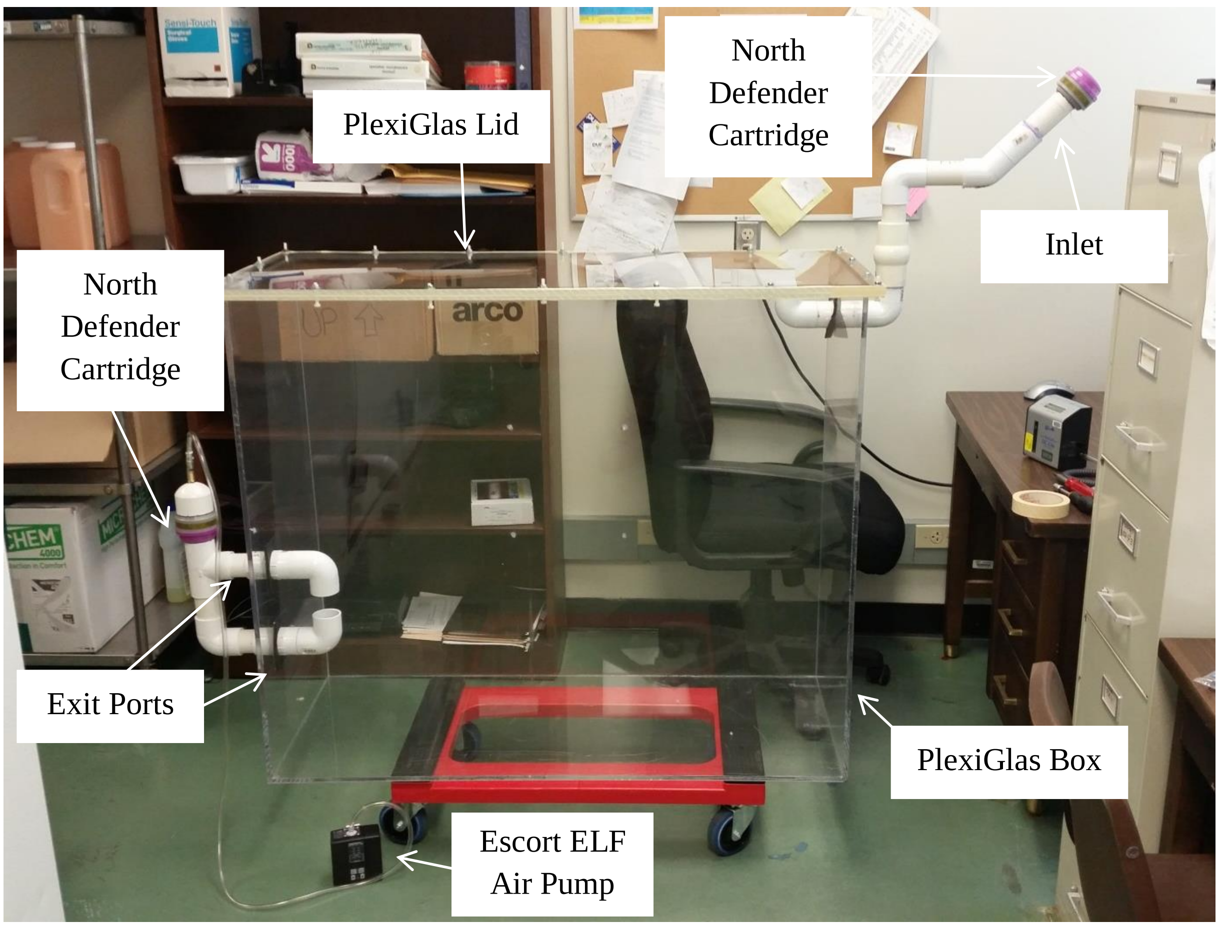

Figure 1. Completed EC during the background test period.

The opposite side of the chamber featured two 1.5” PVC pipes which had been previously fitted through the Plexiglas side. A series of 1.5” PVC pipes and elbows were used to connect the two outlet pipes together to form the exit port. Two outlets were used to account for errors and improve the accuracy of measurements. At the top of the connection, a North Defender Multi-Gas/Vapors/P100 Respirator Cartridge was secured using Epoxy Adhesive to filter air as it flowed out of the chamber. On the opposite side of the cartridge, a 1.5” PVC cap with a metal fitting was secured using Epoxy Adhesive. Approximately 3’ of Tygon 3603 tubing (US Plastics, Lima) was connected to the metal fitting.

Sample Media and Method Selection

The monitors chosen for this experiment were 571 Aldehyde Monitors (Assay Technology, Livermore). The monitors feature a sampling media of fiberglass coated with 2,4-dinitrophenylhydrazine (DNPH) and had a sampling flowrate of 0.0162 LPM (Assay Technology, 2014). The monitors were chosen because of previous studies similar in nature having success, minimal maintenance, and their low detection limit. The monitors have a detection limit of 0.0012 ppm when used at the 72 hour functional range. The monitors meet or exceed the OSHA requirements for +/- 25% accuracy (Assay Technology, 2014). Assay Technology uses a modified version of OSHA 1007 to analyze samples.

Experiment Design

BACKGROUND TEST

The empty EC was placed in a room and fully sealed as seen in Figure 1. This was done by connecting the lid to the box and then using Scotch Sealing Tape (3M, St. Paul) to seal the edges. A calibrated Escort ELF (Zefon International, Ocala) air pump was connected to the EC via Tygon tubing at the exit port. Three monitor packages were removed from a refrigerator and brought to the experiment room. The inlet PVC pipe was then removed from the EC. A monitor package was opened and then the cover was opened on the monitor and placed inside the PVC pipe, (I1). The time was recorded and the inlet PVC pipe was then reattached to the chamber. The exit PVC pipes were then removed from the EC. Two monitor packages were opened and the covers opened. One was placed in the top exit port (O1) and the other was placed in the bottom exit port (O2). The time was recorded and the exit PVC pipe was reattached to the EC.

a.) Monitor placement in Inlet (I1)

b.) Monitor placement in top exit port (O1)

c.) Monitor placement in bottom exit port (O2)

Figure 2. Monitor placements inside the EC. a.) Monitor placement in Inlet (I1) b.) Monitor placement in top exit port (O1) c.) Monitor placement in bottom exit port (O2).

A total sampling time of 72 hours was desired in order to have the lowest detection limit possible in the functional range of the monitors. The air pump was replaced daily with another calibrated Escort ELF air pump for the duration of the sampling period. At the end of the 72 hour sampling period, the inlet PVC pipe was removed from the EC and the monitor removed and lid closed. The exit PVC pipe was then removed and both monitors removed and lids closed. Each monitor was then sealed in an individual lab bag provided from Assay Technology and placed in another bag containing the chain of custody. The monitors were then placed back into the refrigerator. An additional monitor package was removed from the refrigerator and package opened. This monitor was not opened and placed directly into the provided lab bag. Once sealed, the monitor was put into another bag with the chain of custody and placed back into the refrigerator. The first following business day, the samples were taken out of the refrigerator and shipped back to Assay Technology via FedEx two day air for analysis.

ACCLIMATION PERIOD

Four temperatures which included: 25, 30, 35, and 40 °C were tested in this study. In order to measure a representative concentration at each temperature, an acclimation period was calculated for the EC to reach a steady state formaldehyde concentration. The time needed for the EC to reach equilibrium was calculated using Equilibrium Time Calculation, Equation 1.

$$\frac{C}{C_o} = e\wedge\frac{-Qt}{V} \quad (1)$$

Where;

C = Initial concentration
C_o = Final concentration
Q = Air Flow (m^3/hour)
t = Time (hour)
V = Volume of Chamber (m^3)

The equilibrium time to reach a steady state inside the EC was calculated to be 40.7 hours. This is using a desired flowrate of 1 LPM (0.060 m^3/hr) divided by the EC volume of 0.53 m^3 to reach a 99% concentration. Thus, a 48 hour acclimation was adopted for convenience and to give ample time for the chamber to reach a steady state.

The EC was placed inside a walk-in environmental chamber (WIEC) (American Panel, Ocala) located in a university laboratory in Florida. The tape was removed from the EC and the Plexiglas cover was removed from the Plexiglas box. The five MDF panels were placed inside the chamber approximately 4-5 inches apart. They were positioned so air would flow over every exposed surface area of every panel. This was done by placing panels in positions 1, 3, and 5 with the air channels down and panels in positions 2 and 4 with the air channels up as seen in Figure 3. Once the panels were in the EC, the Plexiglas cover was bolted back onto the Plexiglas box and the edge sealed with Scotch Sealing Tape.

Once the EC was sealed, the WIEC was turned on and the desired temperature was programmed into the F4 master controller (Watlow Electric Manufacturing Company, St. Louis). Once the master controller displayed that the WIEC reached the desired temperature, a thermometer inside the WIEC was used to confirm the correct temperature. After the WEIC was at the correct temperature, a calibrated Escort ELF air pump was connected to the EC via the Tygon tubing attached to the exit port. A HOBO Temperature/Relative Humidity/Light/External Data Logger (Onset Computer, Bourne) was placed on top of the Plexiglas lid in the center of the EC. The HOBO was connected to a laptop loaded with HOBOware software. The data logger was then turned on in HOBOware to record temperature and relative humidity. The start time of the data logging event was used as the official start time of each acclimation period. The EC was checked upon daily to ensure the temperature was stable inside the WIEC. Some adjustments were made to the chamber to maintain stable temperatures. This included opening the door of the WIEC various degrees and adjusting the exhaust fan speed. The air pump was changed daily with another calibrated Escort ELF at each daily check in. After 48 hours since the data logger start time, the sample period began which is explained in the next section. This method was repeated for all four temperature testing events, minus positioning the panels and removing the Plexiglas lid. Once the first temperature event began the EC was not moved or opened. The EC remained sealed and the Plexiglas lid was never removed for the duration of all four temperature tests.

a.) Panel positioning inside EC.

b.) Panel positioning order.

Figure 3. Overview of panel positions inside the EC. a.) Panel positioning inside EC. b.) Panel positioning order.

SAMPLING PERIOD

After the 48 hour acclimation period had finished, the sampling period for each temperature test began. A calibrated Escort ELF air pump replaced the existing air pump connected to the EC. Three 571 Aldehyde monitor packages were removed from a refrigerator and brought to the experiment room. The inlet PVC pipe was removed from the EC and the monitor package was opened. The cover was then opened on the monitor and the monitor was then placed inside the inlet PVC pipe. The time was recorded and the inlet PVC pipe was then reattached to the EC. The exit PVC pipes were then removed from the EC. Two monitor packages were opened and the covers opened. One was placed in the top exit port (O1) and the other was placed in the bottom exit port (O2). The time was recorded and the exit PVC pipe was reattached to the EC.

The experiment chamber was checked daily and a calibrated Escort ELF pump replaced the existing air pump connected to the chamber each day. In order to not exceed the functional range of the monitors, they were retrieved from the EC approximately 71.5 hours into sampling, ending the sampling period. This was done by removing the inlet PVC pipe from the EC. The monitor was then retrieved and the monitor lid closed. The exit PVC pipe was then removed and both monitors retrieved and lids closed. The time that the lid of each monitor was closed was recorded. The HOBO was then connected to a laptop computer and the data logging event stopped in HOBOware. Each monitor was then sealed individually in a lab bag provided from Assay Technology and placed in another bag containing the chain of custody. The monitors were then placed back into the refrigerator. An additional monitor package was removed from the refrigerator and package opened. This monitor was not opened and was placed directly into the provided lab bag. Once sealed, the monitor was put into another bag with the chain of custody and placed back into the refrigerator. The WIEC was then turned off and allowed to cool back to room temperature with the door open. The first following weekday the samples were taken out of the refrigerator and shipped back to Assay Technology via FedEx two day air for analysis. This procedure was repeated for every temperature test directly following each acclimation period.

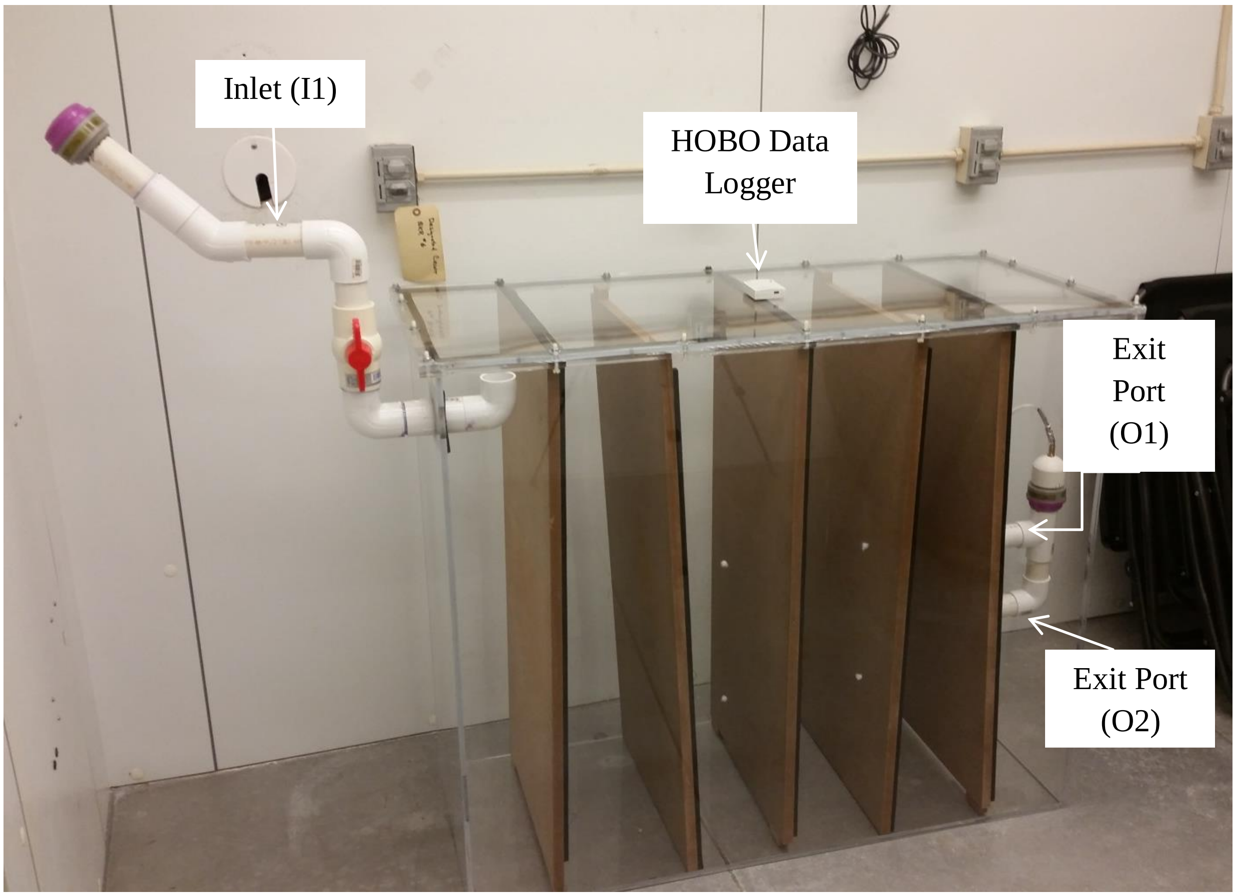

Figure 4. Sealed EC inside of the WIEC.

SAMPLING SCHEDULE OVERVIEW

Table 5 shows the timeframe and number of samples taken over the course of the experiment. In total there were 4 different temperature tests and 20 samples. The background test only consisted of a 72 hour sampling period at room temperature because no MDF was in the

EC. The four temperature tests featured a 48 hour acclimation period followed by a 72 hour sample period.

Table 5 – Sampling Schedule Overview

Temperature (°C)	**Time (hours)**	**Event**	**Number of Samples**	**Control**	**Total Samples**
Background Room Temperature	72	Sample	3	1	4
25	48 72	Acclimation Sample	3	1	8
30	48 72	Acclimation Sample	3	1	12
35	48 72	Acclimation Sample	3	1	16
40	48 72	Acclimation Sample	3	1	20

<u>Calibration and Quality Control</u>

All Escort ELF pumps had pre and post calibrations conducted using a primary standard DryCal DC-Lite (BIOS International, Butler). An air pump was turned on and allowed to run for a few minutes at the desired flowrate of 1.0 LPM. The air pump was then connected to the DryCal DC-Lite. A total of 10 readings were taken and the average used as the pre-calibration flowrate of the pump. The calibrated pump was then taken into the WIEC and connected to the EC at the exit port via Tygon tubing. If an air pump was replacing another air pump, the replaced air pump was taken outside of the WIEC and connected to the DryCal DC-Lite. A total of 10 readings were taken and the average used as the post-calibration flowrate. Air pumps were changed every morning during each temperature test. A total of 5 air pumps were used per temperature test.

At the end of every sampling event, a blank was used as a quality control measure. This was done by removing a 571 Aldehyde Monitor from the package and immediately sealing it in the lab bag provided from Assay Technology. These blanks were shipped along with the three other monitors in every sampling event. A total of 5 blanks were sent over the course of the experiment.

Results

The following tables and figures display the results from the study. The accompanying data is available in Appendixes 1 – 4.

Table 6 – Results of Temperature Tests

Average Temperature (°C)*	Sample ID	Total Sample Time (min)	Concentration (ppm)**	Concentration (µg/m^3)**
23.5 (Background)	012417-CONT-I1	4307	ND	ND
	012417-CONT-O1	4304	0.0069	8.5
	012417-CONT-O2	4305	0.0067	8.2
	012717-CONT-CONT	0	ND	ND
26.1	020817-25-I1	4297	ND	ND
	020817-25-O1	4295	0.48	589.6
	020817-25-O2	4297	0.55	675.5
	021117-25-CONT	0	ND	ND
29.3	021517-30-I1	4266	ND	ND
	021517-30-O1	4268	0.72	884.4
	021517-30-O2	4267	0.75	921.2
	021817-30-CONT	0	ND	ND
34.1	022217-35-I1	4267	ND	ND
	022217-35-O1	4267	1.2	1473.9
	022217-35-O2	4267	1.2	1473.9
	022517-35-CONT	0	ND	ND
38.9	030117-40-I1	3420	0.0097	11.9
	030117-40-O1	3420	1.91***	2346.0
	030117-40-O2	3420	1.26***	1547.6
	030417-40-CONT	0	ND	ND

Notes:

*Average temperature over the entire temperature test. Consists of 48 hour acclimation period and 72 hour sample period. Temperature data available in Appendix 4.
**ND – non detect, results were below the detection limit of 0.0012 ppm of the analytical method.
***The airline during this sampling period became crimped and the pump turned off prematurely. The concentrations were calculated from the weight of the sample divided by the actual time the air pump was functioning. This is explained further in the discussion section.

Table 7 – Formaldehyde Emission Rate Results

Average Temperature (°C)	Sample	Average Flowrate (LPM)*	Q/A Ratio (m/h)	Emission Factor (µg/m²·h)
26.1	O1	1.032	0.0138	8.14
	O2			9.32
29.3	O1	1.019	0.0136	12.03
	O2			12.53
34.1	O1	1.008	0.0135	19.90
	O2			19.90
38.9	O1	0.978	0.0131	30.73
	O2			20.27

Formulas:

Average Flowrate (LPM) = ((Average Pump $Flowrate_1$ * Total Sample $Time_1$) + (Average Pump $Flowrate_n$ * Run $Time_n$)) / (Total Time)
Q/A Ratio (m/h) = Average Flowrate (m^3/hour) / Total MDF Surface Area
Emission Factor (µg/m^2·h) = Concentration (µg/m^3) * Q/A Ratio

Notes:
*Pump flowrate data available in Appendix 1.

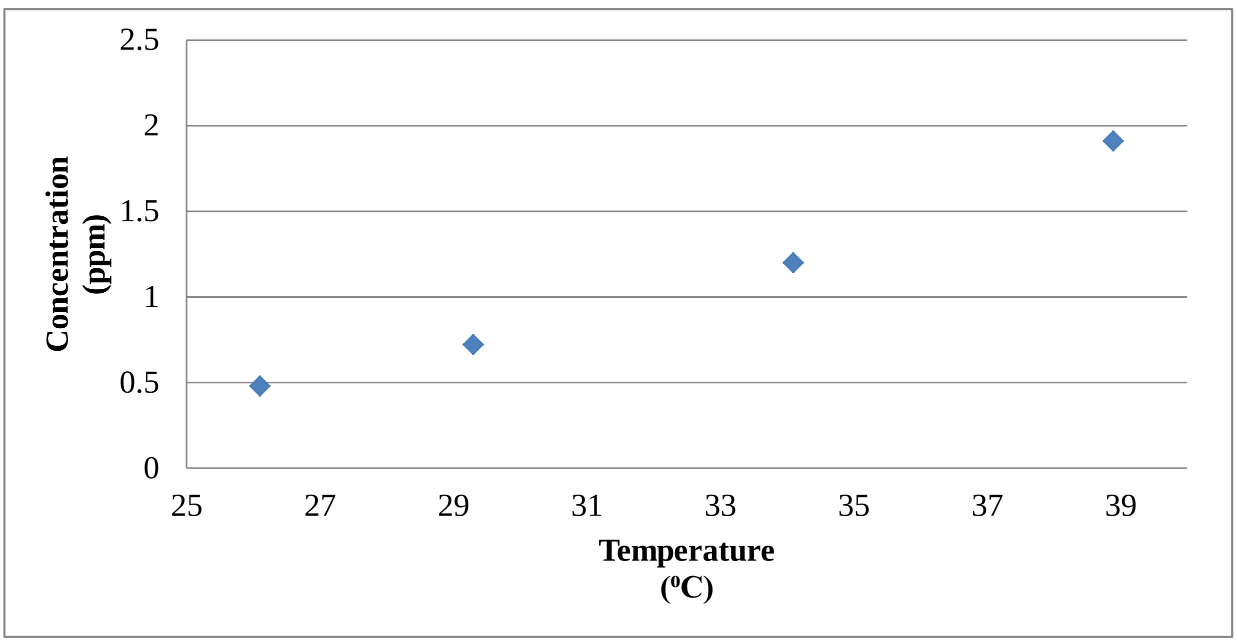

Figure 5. The relationship between the concentrations measured at each temperature test in exit port O1.

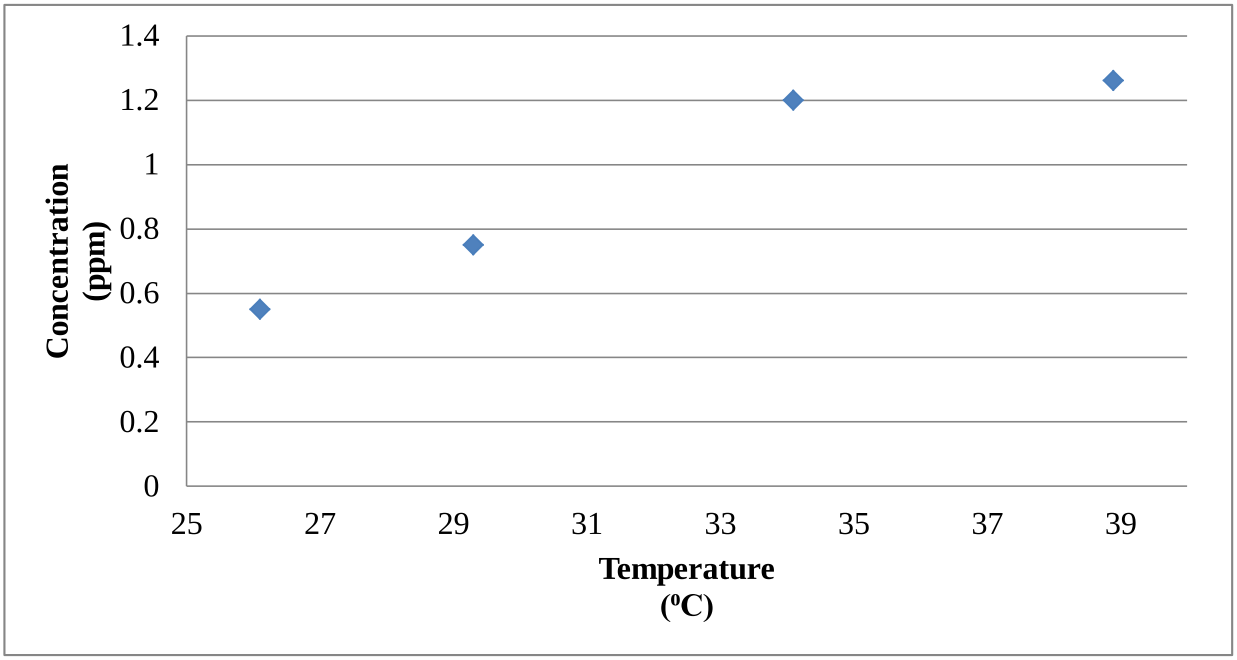

Figure 6. The relationship between the concentrations measured at each temperature test in exit port O2.

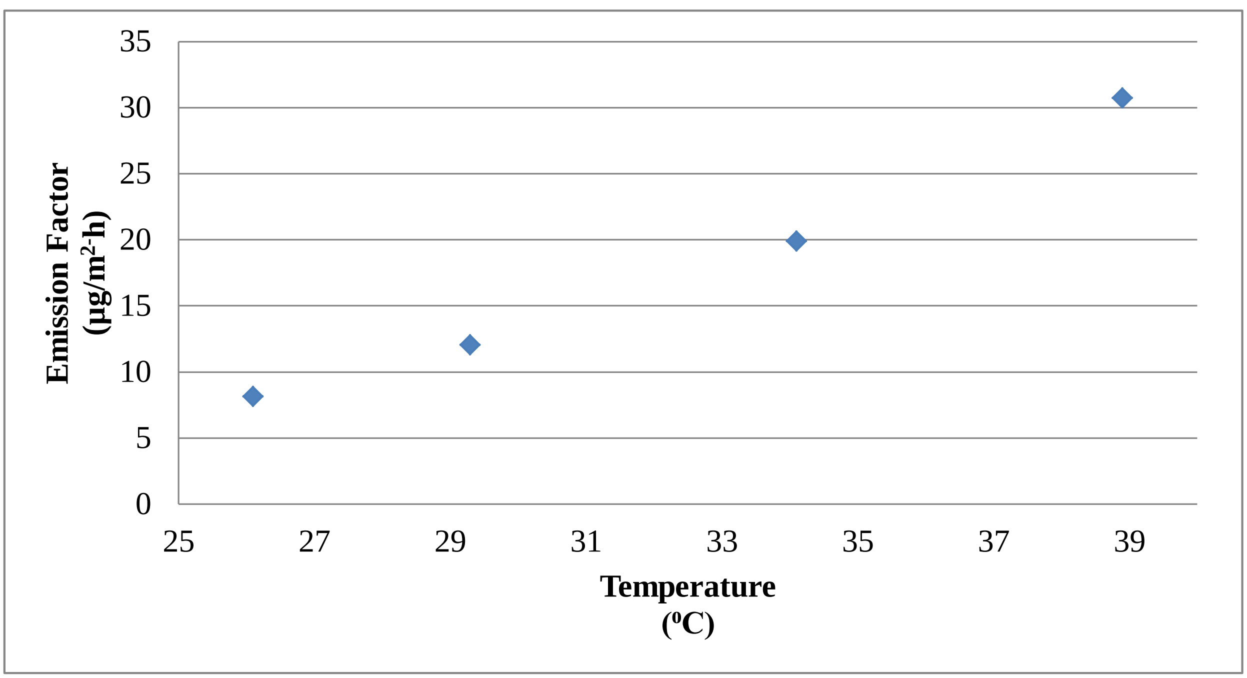

Figure 7. Relationship of emission factors at each temperature in exit port O1.

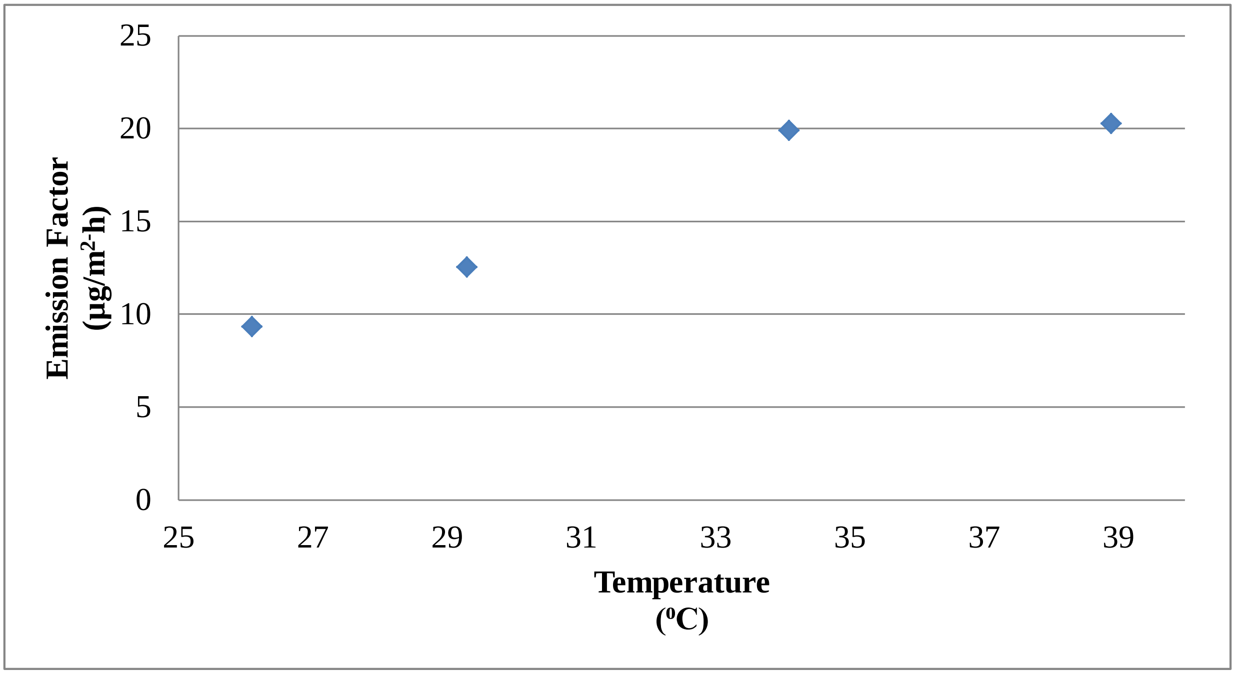

Figure 8. Relationship of emission factors at each temperature in exit port O2.

Table 8 –Linear Correlation Information of Concentration Relationships

Exit Port	R^2	Regression Equation
O1	0.9809	Y = 0.1115x – 2.502
O2	0.9200	Y = 0.0592x – 0.959

Table 9 –Linear Correlation Information of Emission Factor Relationships

Exit Port	R^2	Regression Equation
O1	0.9852	Y = 1.7670x – 39.02
O2	0.8951	Y = 0.9208x – 14.05

Table 10 – Descriptive Statistics of Exit Port Measurements

Average Temperature (°C)	Average Concentration (ppm)	Standard Deviation (ppm)	Average Emission Factor (μg/m^2-h)	Standard Deviation (μg/m^2-h)
26.1	0.52	0.035	8.81	0.590
29.3	0.74	0.015	12.36	0.250
34.1	1.20	0.000	19.90	0.000
38.9	1.59	0.330	25.58	5.215

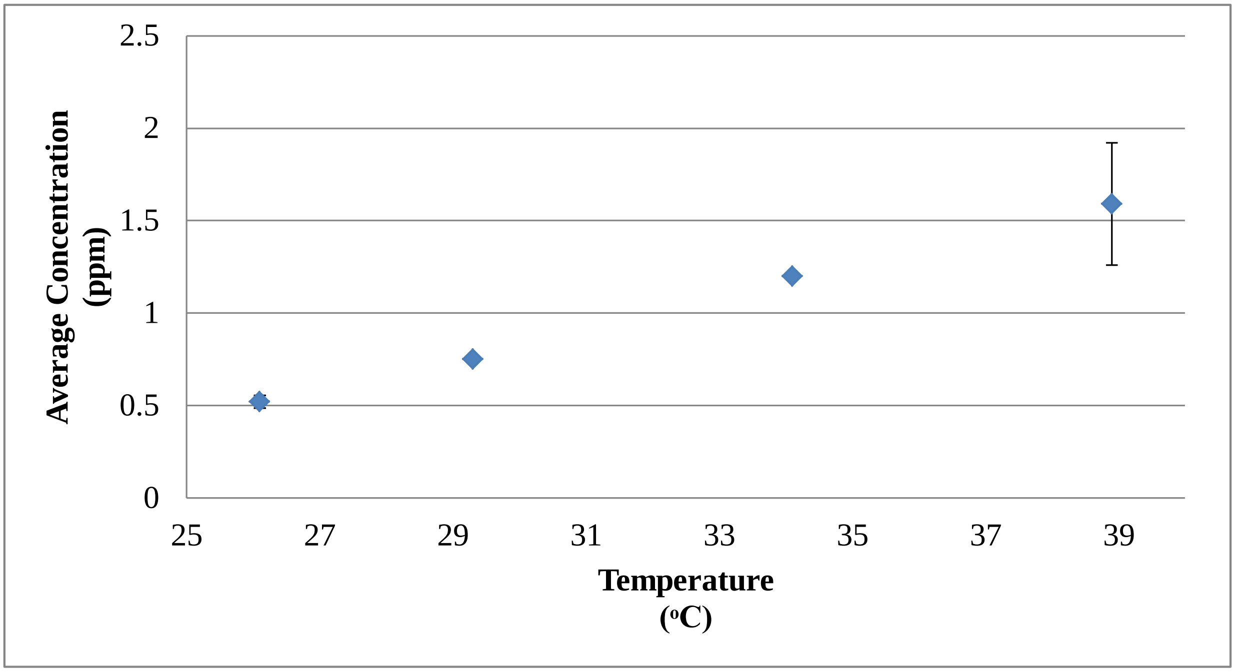

Figure 9. Relationship of the average concentration measured in the exit ports at each temperature test.

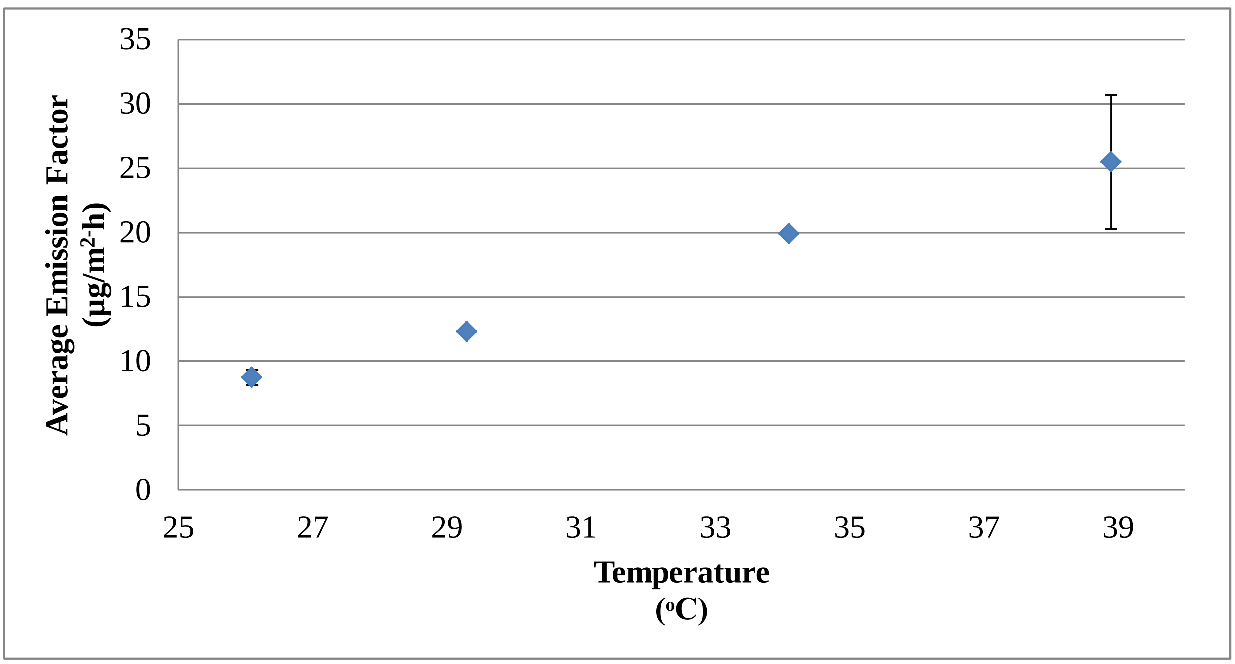

Figure 10. Relationship of the average emission factor calculated from each exit port measurement at each temperature test.

Table 11 – Correlation Information of Average Measurements and Calculations

	Average Concentration	**Average Emission Factor**
Linear R^2	0.9983	0.9954
Linear R	0.9991	0.9977
Linear Regression Equation	$Y = 0.0849x - 1.712$	$Y = 1.3432x - 26.52$
Exponential R^2	0.9938	0.9767
Exponential R	0.9969	0.9883
Exponential Regression Equation	$Y = 0.0557e^{0.0877x}$	$Y = 1.0036e^{0.0848x}$
Logarithmic R^2	0.9812	0.9938
Logarithmic R	0.9905	0.9969
Logarithmic Regression Equation	$Y = 2.7224\ln(x) - 8.398$	$43.097\ln(x) - 132.4$

Discussion

Analysis of Results

In total, 20 passive samples were taken using 20 Aldehyde 571 Monitors. Four temperatures were tested that included a 48 hour acclimation period and a 72 hour sampling period. Every temperature test included one blank used as a quality control measure. One panel of MDF was tested by cutting it into 5 equal pieces and placing them in a sealed chamber. An air pump flowed air through the chamber and over the monitors to capture formaldehyde concentrations in the air. With the results, the goal of this study was to compare the concentrations and emission factors in relation to temperature from the panel of MDF.

Four of the samples taken included a background measurement of the EC. No MDF was present inside the EC at the time of the testing. The background tests resulted in formaldehyde concentrations 0.0069 ppm measured in O1, 0.0067 ppm measured in O2, and < 0.0012 ppm measured in I1. The MDF panels were stored inside the EC with the lid off prior to testing beginning. The concentrations measured in O1 and O2 are believed to be residual formaldehyde left over from the storage of the panels. The non-detectable measurement in I1 of < 0.0012 ppm indicates that no formaldehyde entered the EC from the outside air supplied. The measured background concentrations are considered insignificant and were not subtracted from any other concentration measurements for this reason.

In the study, it was found that the average emission factor increased 191% between the highest temperature tested of 38.9 ^{o}C and the lowest temperature of 26.1 ^{o}C. This is a significant increase between the amount of formaldehyde emitted from the MDF and a 49% increase in temperature. A strong linear relationship with an R^2 of 0.9954 was discovered between the temperature and the emission factor of MDF. As temperature increased, the amount of formaldehyde emitted from the panel also increased. This relationship is further backed by the concentrations measured during the study displayed in Table 10. Formaldehyde concentrations increased 206% between the highest and lowest temperature tested. The concentrations measured also exhibit a strong linear relationship with an R^2 of 0.9983. The strong correlations indicate that as temperature increased, the amount of formaldehyde emitted from the panels increased as well. This resulted in a higher concentration of airborne formaldehyde measured with the monitors during each sampling period.

The EPA's Composite Wood Product Act and CARB-P2 standards both use the ASTM E1333 standard to test CWPs for compliance. ASTM E1333 uses a controlled chamber operated at 25 ºC with an allowable fluctuation of +/- 1 ºC. Emission limits in both standards for this test are 0.11 ppm for MDF. The lowest average concentration measured in this study was 0.52 ppm at 26.1 ºC. This concentration is 373% higher than the allowable concentration in the standards and only 0.1 ºC outside the allowable temperature range in ASTM E1333. The highest average concentration measured at 38.1 ºC was 1.59 ppm which is 1345% higher than allowable by the standard. As seen in Table 6, all of the samples in this study resulted in concentrations much higher than the allowable limits of EPA and CARB-P2 standards.

During the sampling periods, a monitor was placed in the inlet of the EC. The purpose of this monitor was to ensure that no outside formaldehyde would influence measured concentrations. In every sampling event except 38.9 °C, monitors placed in the inlet resulted in non-detectable concentrations. This indicates that the North Defender respirator cartridge that was placed on the inlet successfully filtered any foreign formaldehyde from entering the EC.

The results also suggest that the EC was successfully sealed and a negative pressure created with the air pump. The negative pressure inside the EC only allowed formaldehyde to flow through the exit ports.

During the last day of the sampling period of the 38.9 °C temperature test, the Tygon tubing connected to the air pump folded in half. The fold blocked air from being pulled by the pump and the pump turned itself off. It is thought that the high temperature softened the Tygon tubing and caused a loss of rigidity. Due to the position of the tubing coming directly up out of the EC connection, gravity and the heated material allowed for the folding to occur. The shortened sampling time was accounted for and corrected in the results displayed in Table 6. This was done by using the total run time of 574 minutes which was displayed on the pump when it was discovered. This was added to the pump start time and then added to the total sample time from the previous days. In total, monitors 030117-40-I1, 030117-40-O1, and 030117-40-O2 all had sample times of 3420 minutes. The monitor sample rate was determined to be 0.0162 LPM from dividing the total volume and total time used in the laboratory report from Assay Technology. The Total Air Volume Equation, Equation 2, shows the calculation of the corrected total volume of air sampled.

$$V = F * T \tag{2}$$

Where;

V = Volume (m^3)
F = Flowrate (m^3/minute)
T = Time (minute)

The total volume of air sampled was calculated to be 0.0554 m^3 using a flowrate of 0.0000162 m^3/min multiplied by a time of 3420 minutes.

The weight of formaldehyde reported for each monitor provided by the lab report was then divided by the total volume of air sampled. Results were converted into $\mu g/m^3$ and ppm respectively. These final calculated results are displayed in Table 6.

Extrapolation of Chamber Results to Residential Concentrations

The results of the study provided significantly higher concentrations than allowable by current emission standards. Although these results were in a small controlled chamber, it was questioned if these results were comparable to concentrations that would be found in a residential environment. According to the United State Census Bureau, in 2015 the median floor area of a completed single-family home was 2467 ft^2 and 47% had 4+ bedrooms. Using this information, a representative calculation can be conducted to compare the results found in this study.

Using the Total Ventilation Rate Equation 4.1a from the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) Standard 62.1 – 2016, a representative emission rate can be calculated as shown in Equation 3.

$$Q_{tot} = 0.03*A_{floor} + 7.5(N_{br} + 1) \quad (3)$$

Where;

Q_{tot} = Total required ventilation rate (cfm)
A_{floor} = Dwelling-unit floor area (ft^2)
N_{br} = number of bedrooms

Using the data from the United States Census Bureau, a home with 2467 ft^2 dwelling-unit floor area and 4 bedrooms requires 111.5 cfm, or 189.5 m^3/hr, total ventilation rate. Using the data presented in Table 10, an extrapolated concentration of formaldehyde can be calculated to estimate what formaldehyde concentrations would be if the boards tested were present in the residence with an average floor area of 2467 ft^2.

Table 12 – Extrapolated Concentrations from Study Results

Average Temperature (°C)	Average Concentration* (μg/m^3)	Average Flowrate (m^3/h)	Q/A Ratio** (m/h)	Emission Rate (μg/h)	Extrapolated Concentration (μg/m^3)
26.1	638.7	0.06192	0.0138	39.2	0.21
29.3	908.7	0.06114	0.0136	55.5	0.29
34.1	1473.9	0.06048	0.0135	89.4	0.47
38.9	1952.9	0.05868	0.0131	114.9	0.61

Formulas:

Average Flowrate (m^3/h) = Average Flowrate in Table 7 (lpm) * (60 min) * (1 m^3/ 1000 L)

Q/A Ratio (m/h) = Average Flowrate (m^3/h) / Total Surface Area of MDF (m^2)

Emission Rate (μg/h) = Total Surface Area of MDF (m^2) * Average Emission Factor in Table 10 (μg/m^{2-}h)

Extrapolated Concentration (μg/m^3) = Emission Rate (μg/h) / Total Ventilation Rate Required from Equation 3 (m^3/hr)

Notes:

*Values from Table 10 converted from ppm to μg/m^3
**Ratio of the flowrate of the chamber and the total surface area of the MDF panels

Using the extrapolated concentrations in Table 12, comparisons can be made to existing recommendations of formaldehyde concentrations. Converting the extrapolated concentrations from μg/m^3 to ppb result in concentrations of 0.17 ppb, 0.20 ppb, 0.38 ppb, and 0.50 ppb from the lowest temperature to highest temperature. The concentrations in ppb can then be compared to the recommendations found in Table 1. The extrapolated concentrations are below all of the existing recommendations on acceptable formaldehyde concentrations. The highest concentration of 0.50 ppb is well below the ATSDR Minimum Risk Level of 8 ppb for long term exposure. However, it is important to remember that there are no current agreed upon standards for formaldehyde concentrations in residential settings. The extrapolated result also represents the concentration found in an average residence with a 2467 ft^2 floor area, which does not take into account individual rooms. Some rooms such as kitchens could have much greater quantities of MDF than other rooms. The concentrations found in these rooms could be significantly higher than rooms which do not contain as much or any MDF.

Extrapolation of Chamber Results using Hypothetical ASTM E1333 Specifications

ASTM E1333 is the standardized method to test the emission rate of formaldehyde in CWP for compliance (EPA, 2016). In ASTM E1333, a minimum chamber of 22 m^3 must be used with 0.5 ACH (ASTM, 2014). Using this information, a new flowrate can be determined and Equation 4 used to calculate a new hypothetical emission factor using the concentrations found in the study.

$$ACH = Q / V \tag{4}$$

Where;

ACH = Air Changes per Hour
Q = Flowrate (m^3/h)
V = Volume of Chamber (m^3)

Using the required ACH of 0.5 and the minimum chamber volume of 22 m^3, a flowrate of 11 m^3/h is required.

Table 13 – Hypothetical Extrapolated Concentrations using ASTM E1333

Average Temperature (°C)	Average Concentration (μg/m^3)	Q/A Ratio (m/h)	Emission Factor (μg/m^{2}-h)	Emission Rate (μg/h)	Extrapolated Concentration (μg/m^3)
26.1	638.7	2.45	1564.8	7025.0	37.1
29.3	908.7	2.45	2226.8	9998.3	58.8
34.1	1473.9	2.45	3611.1	16213.8	85.6
39.9	1952.9	2.45	4784.6	21482.9	113.4

The extrapolated concentrations in Table 13 represent a hypothetical situation where the concentrations found in the study are used with the much higher flowrate of ASTM E1333. Thus, the results represent a hypothetical extrapolated concentration if the same concentrations were measured using ASTM E1333 methodology. As seen in Table 13, increasing the ventilation rate of the study drastically increases the emission factor. The higher emission factor also results in a higher emission rate and ultimately a higher extrapolated concentration. In order to be compliant with the 25°C temperature requirement of ASTM E1333, only results at average temperature 26.1°C were looked at for comparison. Converting the extrapolated concentration of 37.1 $\mu g/m^3$ to ppb results in a concentration of 30.21 ppb. This concentration is above the ATSDR Minimum Risk Level of 8 ppb for greater than 365 days of exposure and 30 ppb for 15 to 365 days. The concentration is also above the 8 hour NIOSH REL of 16 ppb. If ASTM E1333 methodology resulted in the concentrations found in the study, these levels of formaldehyde would be concerning based the exposure limits in Table 1.

Conclusion

The resins used in the creation of MDF are known to emit formaldehyde into the environment. With new regulations, the amount of formaldehyde allowed to be emitted from MDF panels is limited. However the standard test methods used to determine the emission rate for compliance only include one temperature. As seen in the study, formaldehyde emission factors increased as temperature also increased. This relationship had a strong linear correlation (R^2 = 0.9954). As the formaldehyde emission factor increased, the resulting formaldehyde concentration in air also increased. The relationship between formaldehyde concentration and temperature also showed as strong linear correlation (R^2 = 0.9983). These results indicate that MDF panels which pass emission tests may emit formaldehyde over emission limits when subjected to higher temperatures. Since no agreed upon formaldehyde standards exist for residential buildings, it is hard to determine the extent of danger formaldehyde emissions from MDF pose in the indoor environment. Further study is recommended to examine the relationship between temperature and emission rates in residential settings.

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Appendices

Appendix 1 – Air Pump Calibration Data

Table 14 – Air Pump Calibration Data

Pump Serial Number	Dates of Use	Beginning Flowrate (LPM)	Ending Flowrate (LPM)	Average Flowrate (LPM)	Percent Difference	Total Time (min)
A4-17338	1/24-1/25	1.027	1.026	1.027	0.1%	1419
A4-17337	1/25-1/26	1.019	0.996	1.007	2.3%	1372
A4-17338	1/26-1/27	1.045	1.002	1.024	4.1%	1375
A4-17339	2/6-2/7	1.024	1.023	1.024	0.1%	1356
A4-17336	2/7-2/8	1.051	1.019	1.035	3.0%	1496
A4-17337	2/8-2/9	1.032	1.049	1.041	1.6%	1395
A4-17338	2/9-2/10	1.048	1.018	1.033	2.9%	1423
A4-17336	2/10-2/11	1.038	1.010	1.024	2.7%	1510
A4-17336	2/13	1.065	1.023	1.044	3.9%	38
A4-17339	2/13-2/14	1.062	0.980	1.021	7.7%	1424
A4-17336	2/14-2/15	1.038	1.006	1.022	3.1%	1441
A4-17338	2/15-2/16	1.058	1.000	1.029	5.5%	1408
A4-17336	2/16-2/17	1.039	0.994	1.017	4.3%	1437
A4-17338	2/17-2/18	1.022	1.003	1.013	1.9%	1425
A4-17336	2/20-2/21	1.066	0.949	1.008	10.9%	1434
A4-17338	2/21-2/22	1.052	0.960	1.006	8.7%	1456
A4-17336	2/22-2/23	1.054	0.934	0.994	11.4%	1426
A4-17338	2/23-2/24	1.064	0.965	1.015	9.3%	1444
A4-17336	2/24-2/25	1.053	0.976	1.015	7.3%	1411
A4-17338	2/27-2/28	1.043	0.892	0.968	14.4%	1404
A4-17336	2/28-3/1	1.049	0.938	0.994	10.6%	1459
A4-17339	3/1-3/2	1.016	0.908	0.962	10.6%	1426
A4-17338	3/2-3/3	1.029	0.912	0.971	11.4%	1449
A4-17336	3/3-3/4	1.045	1.033	1.039	1.1%	574

Appendix 2 – Equipment List

Table 15 – Equipment List

Equipment Name	**Equipment Manufacturer**	**Part Number**	**Serial Number**	**Manufacturer Location**
Escort ELF	Zefon International	N/A	A4-17336	Ocala, FL
			A4-17337	
			A4-17338	
			A4-17339	
571 Aldehyde Monitor	Assay Technology	X571	MB2476	Livermore, CA
			MB2155	
			MB1745	
			MB2323	
			MB1774	
			MB1708	
			MB2525	
			MB1202	
			MB3692	
			MB0041	
			MB0985	
			MB4124	
			MB4374	
			MB3744	
			MB3725	
			MB3981	
			MB2065	
			MB4233	
			MB2732	
			MB2444	
DryCal DC-Lite	BIOS International	N/A	DC-L 631	Butler, NJ
Tygon Tubing	US Plastics	R3603	N/A	Lima, OH
HOBO Temperature/Relative Humidity/Light/External Data Logger	Onset Computer	U12-012	N/A	Bourne, MA
HOBOware Graphing & Analysis Software	Onset Computer	N/A	N/A	Bourne, MA
Sponge Window Seal	MD	6619	N/A	Oklahoma City, OK
North Defender Multi-Gases/Vapors/P100 Respirator Cartridge	Honeywell	75SCP100L	N/A	Morris Plains, NJ
1.5” PVC Piping	Unknown	N/A	N/A	N/A

Appendix 3 – Data Logger Environmental Data

25ºC:

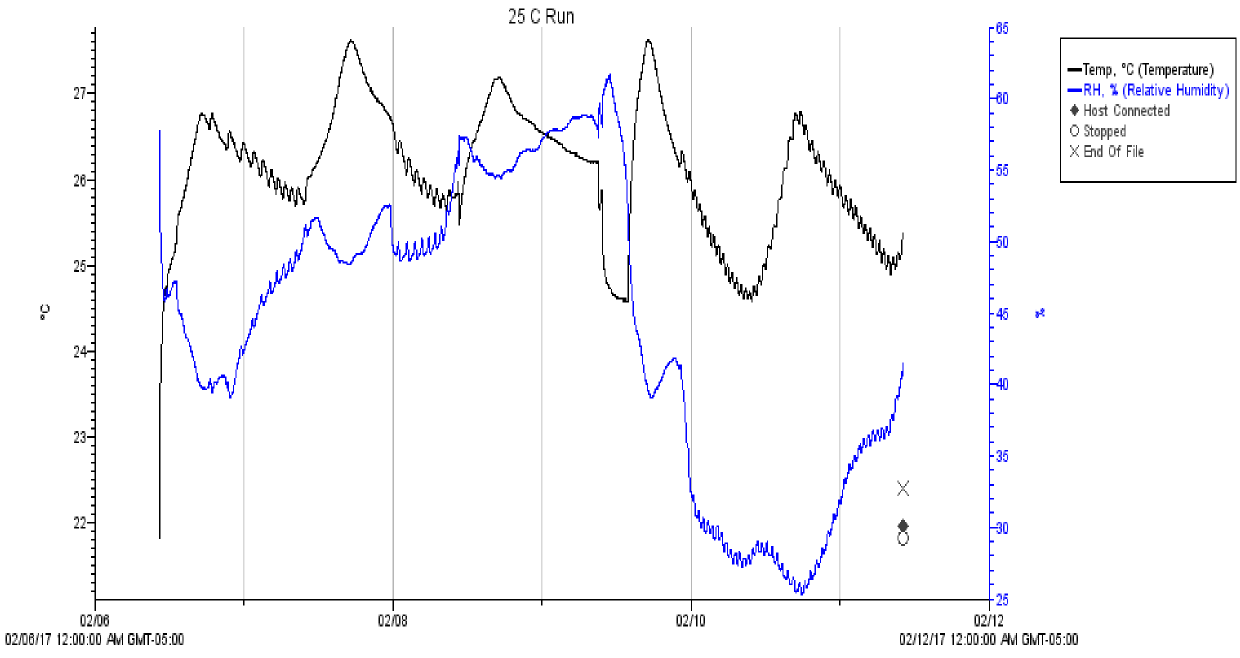

Figure 11. Environmental Data from 25ºC Temperature Test

Table 16 - 25ºC Environmental Data

Data Logger Information	
Start Time	02/06/17 10:28 AM
Stop Time	02/11/17 10:08 AM
Logging Interval	1 Min
Temperature Statistics	
Samples	7181
Maximum Temperature	27.63 ºC
Minimum Temperature	21.82 ºC
Average Temperature	26.08 ºC
Standard Deviation	0.748 ºC
Relative Humidity Statistics	
Samples	7181
Maximum Relative Humidity	61.70%
Minimum Relative Humidity	25.25%
Average Relative Humidity	44.26%
Standard Deviation	10.37%

30^{o}C:

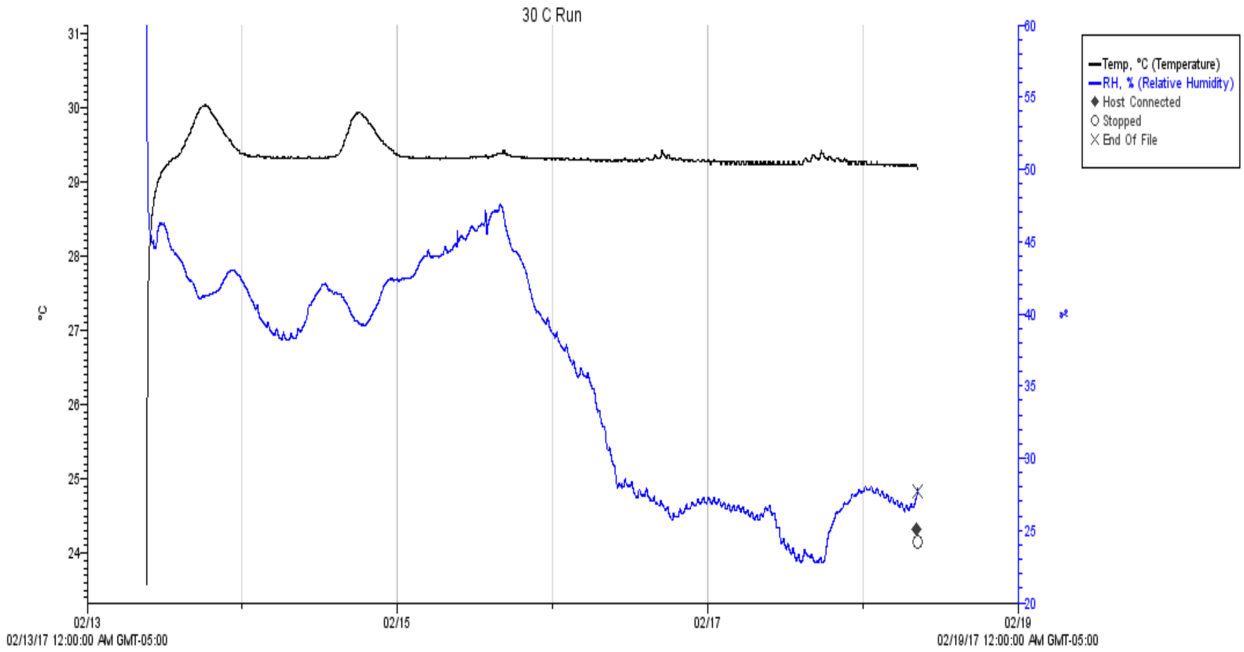

Figure 12. Environmental Data from 30^{o}C Temperature Test

Table 17 - 30^{o}C Environmental Data

Data Logger Information	
Start Time	02/13/17 9:13 AM
Stop Time	02/18/17 8:24 AM
Logging Interval	1 Min
Temperature Statistics	
Samples	7152
Maximum Temperature	30.04 ^{o}C
Minimum Temperature	23.57 ^{o}C
Average Temperature	29.34 ^{o}C
Standard Deviation	0.249 ^{o}C
Relative Humidity Statistics	
Samples	7152
Maximum Relative Humidity	59.92%
Minimum Relative Humidity	22.73%
Average Relative Humidity	35.49%
Standard Deviation	7.927%

35ºC:

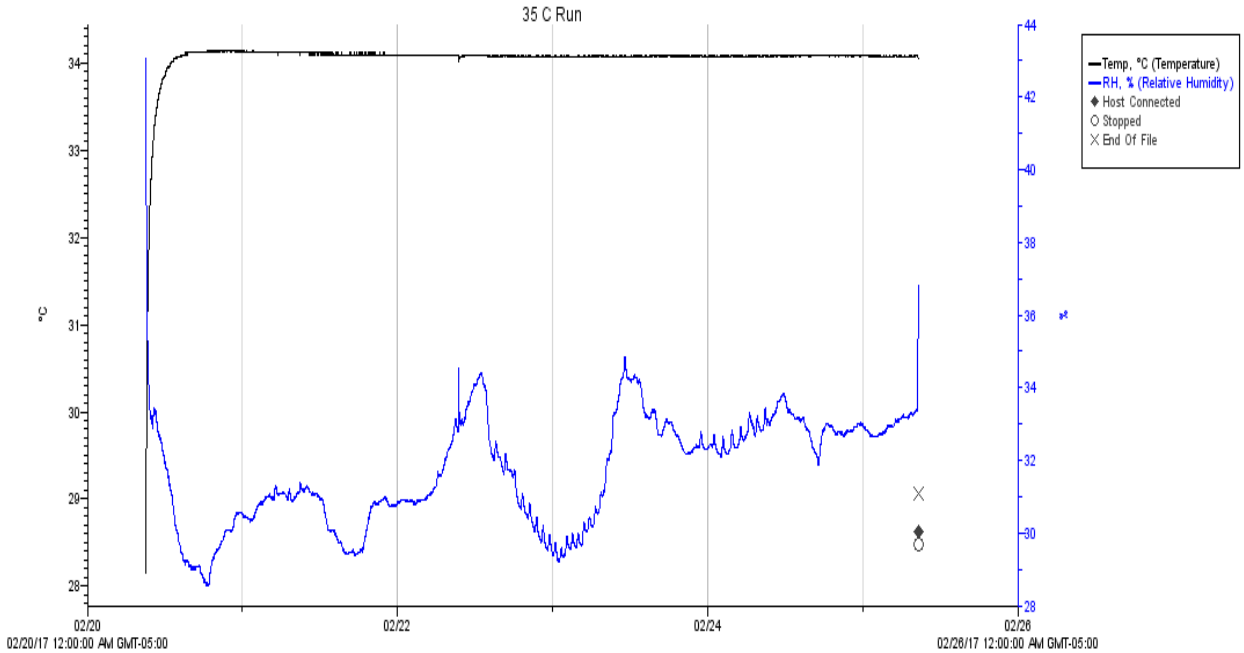

Figure 13. Environmental Data Table from 35ºC Temperature Test

Table 18 - 35ºC Environmental Data

Data Logger Information	
Start Time	02/20/17 9:03 AM
Stop Time	02/25/17 8:34 AM
Logging Interval	1 Min
Temperature Statistics	
Samples	7172
Maximum Temperature	34.15 ºC
Minimum Temperature	28.15 ºC
Average Temperature	34.06 ºC
Standard Deviation	0.259 ºC
Relative Humidity Statistics	
Samples	7172
Maximum Relative Humidity	43.06%
Minimum Relative Humidity	28.53%
Average Relative Humidity	31.70%
Standard Deviation	1.488%

40^{o}C:

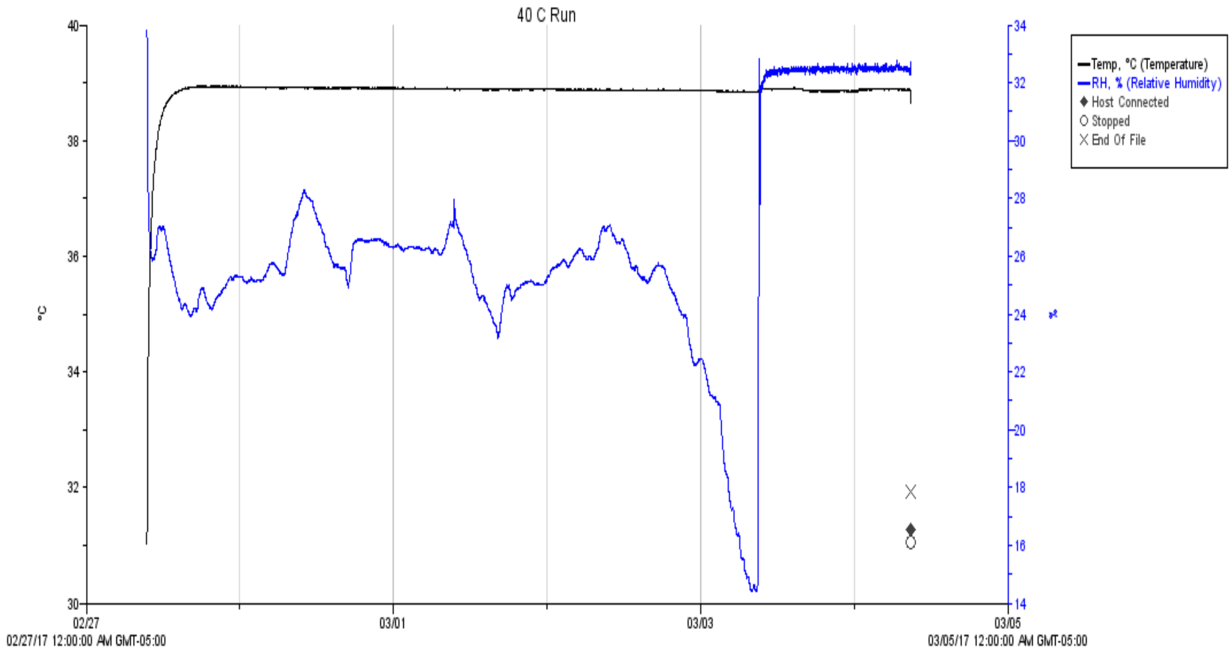

Figure 14. Environmental Data Table from 40^{o}C Temperature Test

Table 19 - 40^{o}C Environmental Data

Data Logger Information	
Start Time	02/27/17 9:29 AM
Stop Time	03/04/17 8:48 AM
Logging Interval	1 Min
Temperature Statistics	
Samples	7160
Maximum Temperature	38.95 ^{o}C
Minimum Temperature	31.03 ^{o}C
Average Temperature	38.85 ^{o}C
Standard Deviation	0.356 ^{o}C
Relative Humidity Statistics	
Samples	7160
Maximum Relative Humidity	33.80%
Minimum Relative Humidity	14.42%
Average Relative Humidity	26.42%
Standard Deviation	3.776%

Appendix 4 – Assay Technology Lab Analyses

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Lab Report

The Innovation & Value Leader in Occupational Hygiene Analysis

Lab Work Order: 2017020189

Customer: USF
Attention: BILLY SWANKIE
Address: 5694 BAYWATER DRIVE
TAMPA, FL 33615
USA

Customer No.: 60115
Received Date: February 08, 2017
Date Reported: February 10, 2017

Project ID:
PO No.:

Phone No.: (252) 202-3686
Fax No.:

Exposure results are the average concentration for the period of time monitored. RptLmt = Reporting Limit. ND = None Detected at or above the reporting limit. The results relate only to the items tested. Unless noted below, samples were received in acceptable condition, all applicable quality control were within method specifications, lab blanks were subtracted before a result was reported, and any customer supplied field blanks were not subtracted from sample results. The molar volume at 25 C (24.45 L/mole) was used to calculate parts per million, ppm. Air concentrations reported are based upon field sampling information provided by the customer. For assistance with the content of this report, please visit the Customer Support section of our web site at http://www.assaytech.com or contact Technical Support at 1-800-833-1258. For details of significant method modifications go to www.assaytech.com/methmod.html.

Lab Sample ID	Lab Code	Date Sampled	Client Sample ID	Media	Media Lot / Serial #	Analytes Requested	Quantity Found Total	Quantity Found RptLmt	Quantity Found Units	Sample Vol. (L)	Sample Time	Concentration Found	Concentration RptLmt	Concentration Units
17004078	ATOH	01/24/2017	012417-CONT-02	571A	9B16 - MB2155	FORMALDEHYDE	0.57	0.10	UG	69.3	4275	0.0067	0.0012	PPM
Analyzed By: JZATCHOK			Analyzed On: 2/9/2017		Approved By: MWAGNER	Approved On: 2/10/2017								
17004079	ATOH	01/24/2017	012417-CONT-01	571A	9B16 - MB2476	FORMALDEHYDE	0.59	0.10	UG	69.3	4276	0.0069	0.0012	PPM
Analyzed By: JZATCHOK			Analyzed On: 2/9/2017		Approved By: MWAGNER	Approved On: 2/10/2017								
17004080	ATOH	01/27/2017	012717-CONT-CONT BLANK	571A	9B16 - MB2323	FORMALDEHYDE	ND	0.10	UG					
Analyzed By: JZATCHOK			Analyzed On: 2/9/2017		Approved By: MWAGNER	Approved On: 2/10/2017								
17004081	ATOH	01/24/2017	012417-CONT-I1	571A	9B16 - MB1745	FORMALDEHYDE	ND	0.10	UG	69.2	4273	ND	0.0012	PPM
Analyzed By: JZATCHOK			Analyzed On: 2/9/2017		Approved By: MWAGNER	Approved On: 2/10/2017								

Method References:

TestCode	Analytes Requested	Method Reference	Regulatory Agency	TWA Limit	STEL Limit	Exposure Units
50000A	FORMALDEHYDE	MOD OSHA 1007	OSHA	0.75	2	PPM

Applicable OSHA PELs, ACGIH TLVs, or NIOSH RELS have been included in this lab report for guidance, but may not be sufficient for regulatory compliance. Clients should be aware that more stringent international, state, local, or organizational exposure limits may supersede the limits included with this report. Visit www.OSHA.gov/dsg/annotated-pels for detailed information on exposure limits and OSHA policies.

AIHA Accredited Lab #101728 (ATCA)
AIHA Accredited Lab #100903 (ATOH)
1382 Stealth Street • Livermore, CA 94551 • (800) 833-1258 • FAX: (925) 461-7149
250 DeBartolo Place #2525 • Boardman, OH 44512 • (800) 833-1258 • FAX: (330) 758-1245

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Lab Report

The Innovation & Value Leader in Occupational Hygiene Analysis

Lab Work Order: 2017020296

Customer: USF
Attention: BILLY SWANKIE
Address: 5694 BAYWATER DRIVE
TAMPA, FL 33615
USA

Customer No.: 60115
Received Date: February 15, 2017
Date Reported: February 24, 2017

Project ID:

Phone No.: (252) 202-3686
PO No.:
Fax No.:

Exposure results are the average concentration for the period of time monitored. RptLmt = Reporting Limit. ND = None Detected at or above the reporting limit. The results relate only to the items tested. Unless noted below, samples were received in acceptable condition, all applicable quality control were within method specifications, lab blanks were subtracted before a result was reported, and any customer supplied field blanks were not subtracted from sample results. The molar volume at 25 C (24.45 L/mole) was used to calculate parts per million, ppm. Air concentrations reported are based upon field sampling information provided by the customer. For assistance with the content of this report, please visit the Customer Support section of our web site at http://www.assaytech.com or contact Technical Support at 1-800-833-1258. For details of significant method modifications go to www.assaytech.com/methmod.html.

Lab Sample ID	Lab Code	Date Sampled	Client Sample ID	Media	Media Lot / Serial #	Analytes Requested	Quantity Found Total	Quantity Found RptLmt	Quantity Found Units	Sample Vol. (L)	Sample Time	Concentration Found	Concentration RptLmt	Concentration Units
17004641	ATOH	02/11/2017	021117-25-CONT	571A	9B16 - MB1202	FORMALDEHYDE	ND	0.10	UG					
Analyzed By: JZATCHOK			Analyzed On: 2/17/2017		Approved By: BEWING	Approved On: 2/21/2017								
17004642	ATOH	02/08/2017	020817-25-I1	571A	9B16 - MB2525	FORMALDEHYDE	ND	0.10	UG	69.6	4297	ND	0.0012	PPM
Analyzed By: JZATCHOK			Analyzed On: 2/17/2017		Approved By: BEWING	Approved On: 2/21/2017								
17004643	ATOH	02/08/2017	020817-25-01	571A	9B16 - MB1774	FORMALDEHYDE	41	0.10	UG	69.6	4295	0.48	0.0012	PPM
Analyzed By: JZATCHOK			Analyzed On: 2/24/2017		Approved By: BEWING	Approved On: 2/24/2017								
17004644	ATOH	02/08/2017	020817-25-02	571A	9B16 - MB1708	FORMALDEHYDE	47	0.10	UG	69.6	4297	0.55	0.0012	PPM
Analyzed By: JZATCHOK			Analyzed On: 2/24/2017		Approved By: BEWING	Approved On: 2/24/2017								

Method References:

TestCode	Analytes Requested	Method Reference	Regulatory Agency	TWA Limit	STEL Limit	Exposure Units
50000A	FORMALDEHYDE	MOD OSHA 1007	OSHA	0.75	2	PPM

Applicable OSHA PELs, ACGIH TLVs, or NIOSH RELS have been included in this lab report for guidance, but may not be sufficient for regulatory compliance. Clients should be aware that more stringent international, state, local, or organizational exposure limits may supersede the limits included with this report. Visit www.OSHA.gov/dsg/annotated-pels for detailed information on exposure limits and OSHA policies.

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250 DeBartolo Place #2525 • Boardman, OH 44512 • (800) 833-1258 • FAX: (330) 758-1245

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Lab Report

The Innovation & Value Leader in Occupational Hygiene Analysis

Lab Work Order: 2017020479

Customer:	USF	*Customer No.:*	60115
Attention:	BILLY SWANKIE	*Received Date:*	February 23, 2017
Address:	5694 BAYWATER DRIVE TAMPA, FL 33615 USA	*Date Reported:*	March 02, 2017

Project ID:

Phone No.: (252) 202-3686 *PO No.:*

Fax No.:

Exposure results are the average concentration for the period of time monitored. RptLmt = Reporting Limit. ND = None Detected at or above the reporting limit. The results relate only to the items tested. Unless noted below, samples were received in acceptable condition, all applicable quality control were within method specifications, lab blanks were subtracted before a result was reported, and any customer supplied field blanks were not subtracted from sample results. The molar volume at 25 C (24.45 L/mole) was used to calculate parts per million, ppm. Air concentrations reported are based upon field sampling information provided by the customer. For assistance with the content of this report, please visit the Customer Support section of our web site at http://www.assaytech.com or contact Technical Support at 1-800-833-1258. For details of significant method modifications go to www.assaytech.com/methmod.html.

Lab Sample ID	Lab Code	Date Sampled	Client Sample ID	Media	Media Lot / Serial #	Analytes Requested	Quantity Found Total	Quantity Found RptLmt	Quantity Found Units	Sample Vol. (L)	Sample Time	Concentration Found	Concentration RptLmt	Concentration Units
17005524	ATOH	02/15/2017	021517-30-01	571A	9B16 - MB3692	FORMALDEHYDE	61	0.10	UG	69.1	4268	0.72	0.0012	PPM
Analyzed By: JZATCHOK			Analyzed On: 3/1/2017		Approved By: BEWING	Approved On: 3/2/2017								
17005525	ATOH	02/18/2017	021817-30-CONT	571A	9B16 - MB4124	FORMALDEHYDE	0.12	0.10	UG					
Analyzed By: JZATCHOK			Analyzed On: 3/1/2017		Approved By: BEWING	Approved On: 3/2/2017								
17005526	ATOH	02/15/2017	021517-30-02	571A	9B16 - MB0041	FORMALDEHYDE	64	0.10	UG	69.1	4267	0.75	0.0012	PPM
Analyzed By: JZATCHOK			Analyzed On: 3/1/2017		Approved By: BEWING	Approved On: 3/2/2017								
17005527	ATOH	02/15/2017	021517-30-I1	571A	9B16 - MB0985	FORMALDEHYDE	ND	0.10	UG	69.1	4266	ND	0.0012	PPM
Analyzed By: JZATCHOK			Analyzed On: 3/1/2017		Approved By: BEWING	Approved On: 3/2/2017								

Method References:

TestCode	Analytes Requested	Method Reference	Regulatory Agency	TWA Limit	STEL Limit	Exposure Units
50000A	FORMALDEHYDE	MOD OSHA 1007	OSHA	0.75	2	PPM

Applicable OSHA PELs, ACGIH TLVs, or NIOSH RELS have been included in this lab report for guidance, but may not be sufficient for regulatory compliance. Clients should be aware that more stringent international, state, local, or organizational exposure limits may supersede the limits included with this report. Visit www.OSHA.gov/dsg/annotated-pels for detailed information on exposure limits and OSHA policies.

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AIHA Accredited Lab #100903 (ATOH)

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250 DeBartolo Place #2525 • Boardman, OH 44512 • (800) 833-1258 • FAX: (330) 758-1245

assay technology

Lab Report

The Innovation & Value Leader in Occupational Hygiene Analysis

Lab Work Order: 2017030015

Customer: USF
Attention: BILLY SWANKIE
Address: 5694 BAYWATER DRIVE
TAMPA, FL 33615
USA

Phone No.: (252) 202-3686
Fax No.:

Project ID:
PO No.:

Customer No.: 60115
Received Date: March 01, 2017
Date Reported: March 07, 2017

Exposure results are the average concentration for the period of time monitored. RptLmt = Reporting Limit. ND = None Detected at or above the reporting limit. The results relate only to the items tested. Unless noted below, samples were received in acceptable condition, all applicable quality control were within method specifications, lab blanks were subtracted before a result was reported, and any customer supplied field blanks were not subtracted from sample results. The molar volume at 25 C (24.45 L/mole) was used to calculate parts per million, ppm. Air concentrations reported are based upon field sampling information provided by the customer. For assistance with the content of this report, please visit the Customer Support section of our web site at http://www.assaytech.com or contact Technical Support at 1-800-833-1258. For details of significant method modifications go to www.assaytech.com/methmod.html.

Lab Sample ID	Lab Code	Date Sampled	Client Sample ID	Media	Media Lot / Serial #	Analytes Requested	Quantity Found Total	Quantity Found RptLmt	Quantity Found Units	Sample Vol. (L)	Sample Time	Concentration Found	Concentration RptLmt	Concentration Units
17006273	ATOH	02/25/2017	022517-35-CONT	571A	9B16 - MB3981	FORMALDEHYDE	ND	0.10	UG					
Analyzed By: JZATCHOK			Analyzed On: 3/3/2017		Approved By: BEWING	Approved On: 3/6/2017								
17006274	ATOH	02/22/2017	022217-35-02	571A	9B16 - MB3744	FORMALDEHYDE	100	0.10	UG	69.1	4267	1.2	0.0012	PPM
Analyzed By: JZATCHOK			Analyzed On: 3/7/2017		Approved By: BEWING	Approved On: 3/7/2017								
17006275	ATOH	02/22/2017	022217-35-I1	571A	9B16 - MB3725	FORMALDEHYDE	ND	0.10	UG	69.1	4267	ND	0.0012	PPM
Analyzed By: JZATCHOK			Analyzed On: 3/3/2017		Approved By: BEWING	Approved On: 3/6/2017								
17006276	ATOH	02/22/2017	022217-35-01	571A	9B16 - MB4374	FORMALDEHYDE	100	0.10	UG	69.1	4267	1.2	0.0012	PPM
Analyzed By: JZATCHOK			Analyzed On: 3/7/2017		Approved By: BEWING	Approved On: 3/7/2017								

Method References:

TestCode	Analytes Requested	Method Reference	Regulatory Agency	TWA Limit	STEL Limit	Exposure Units
50000A	FORMALDEHYDE	MOD OSHA 1007	OSHA	0.75	2	PPM

Applicable OSHA PELs, ACGIH TLVs, or NIOSH RELS have been included in this lab report for guidance, but may not be sufficient for regulatory compliance. Clients should be aware that more stringent international, state, local, or organizational exposure limits may supersede the limits included with this report. Visit www.OSHA.gov/dsg/annotated-pels for detailed information on exposure limits and OSHA policies.

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AIHA Accredited Lab #100903 (ATOH)
1382 Stealth Street • Livermore, CA 94551 • (800) 833-1258 • FAX: (925) 461-7149
250 DeBartolo Place #2525 • Boardman, OH 44512 • (800) 833-1258 • FAX: (330) 758-1245

assay technology

Lab Report

The Innovation & Value Leader in Occupational Hygiene Analysis

Lab Work Order: 2017030200

Customer: USF
Attention: BILLY SWANKIE
Address: 5694 BAYWATER DRIVE
TAMPA, FL 33615
USA

Customer No.: 60115
Received Date: March 08, 2017
Date Reported: March 15, 2017

Project ID:

Phone No.: (252) 202-3686
PO No.:
Fax No.:

Exposure results are the average concentration for the period of time monitored. RptLmt = Reporting Limit. ND = None Detected at or above the reporting limit. The results relate only to the items tested. Unless noted below, samples were received in acceptable condition, all applicable quality control were within method specifications, lab blanks were subtracted before a result was reported, and any customer supplied field blanks were not subtracted from sample results. The molar volume at 25 C (24.45 L/mole) was used to calculate parts per million, ppm. Air concentrations reported are based upon field sampling information provided by the customer. For assistance with the content of this report, please visit the Customer Support section of our web site at http://www.assaytech.com or contact Technical Support at 1-800-833-1258. For details of significant method modifications go to www.assaytech.com/methmod.html.

Lab Sample ID	Lab Code	Date Sampled	Client Sample ID	Media	Media Lot / Serial #	Analytes Requested	Quantity Found Total	Quantity Found RptLmt	Quantity Found Units	Sample Vol. (L)	Sample Time	Concentration Found	Concentration RptLmt	Concentration Units
17007558	ATOH	03/01/2017	030117-40-I1	571A	9B16 - MB2732	FORMALDEHYDE	0.66	0.10	UG	69.3	4277	0.0077	0.0012	PPM
Analyzed By: JZATCHOK			Analyzed On: 3/14/2017		Approved By: BEWING	Approved On: 3/15/2017								
17007559	ATOH	03/04/2017	030417-40-CONT	571A	9B16 - MB2444	FORMALDEHYDE	ND	0.10	UG					
Analyzed By: JZATCHOK			Analyzed On: 3/14/2017		Approved By: BEWING	Approved On: 3/15/2017								
17007560	ATOH	03/01/2017	030117-40-01	571A	9B16 - MB2065	FORMALDEHYDE	130	0.10	UG	69.3	4277	1.5	0.0012	PPM
Analyzed By: JZATCHOK			Analyzed On: 3/14/2017		Approved By: BEWING	Approved On: 3/15/2017								
17007561	ATOH	03/01/2017	030117-40-02	571A	9B16 - MB4233	FORMALDEHYDE	86	0.10	UG	69.3	4277	1.0	0.0012	PPM
Analyzed By: JZATCHOK			Analyzed On: 3/14/2017		Approved By: BEWING	Approved On: 3/15/2017								

Method References:

TestCode	Analytes Requested	Method Reference	Regulatory Agency	TWA Limit	STEL Limit	Exposure Units
50000A	FORMALDEHYDE	MOD OSHA 1007	OSHA	0.75	2	PPM

Applicable OSHA PELs, ACGIH TLVs, or NIOSH RELS have been included in this lab report for guidance, but may not be sufficient for regulatory compliance. Clients should be aware that more stringent international, state, local, or organizational exposure limits may supersede the limits included with this report. Visit www.OSHA.gov/dsg/annotated-pels for detailed information on exposure limits and OSHA policies.

AIHA Accredited Lab #101728 (ATCA)
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