BAY AREA AIR QUALITY MANAGEMENT DISTRICT

Compliance Advisory

February 2, 2012

Wood Products Coatings: Formaldehyde Emissions Estimates

This Advisory is provided to inform you about activities of the Air District which may affect your operation. It is intended to assist you in your effort to achieve and maintain compliance with applicable air pollution regulations.

ATTENTION: WOOD PRODUCTS COATINGS MANUFACTURERS

SUBJECT: FORMALDEHYDE EMISSIONS ESTIMATES AND REPORTING REQUIREMENTS FOR WOOD PRODUCTS COATINGS (REGULATION 8, RULE 32)

On August 5, 2009, the Bay Area Air Quality Management District ("Air District") amended Regulation 8, Rule 32 (Reg 8-32). Reg 8-32 applies to the in-shop coating of wood products including kitchen cabinetry, furniture, wooden picture frames, speaker cabinets, architectural millwork and other wood products. The amendments reduced Volatile Organic Compound (VOC) emissions from wood products coatings by incorporating lower VOC limits. The amendments also limited the VOC content of cleanup solvents to 25 grams/liter (g/l) unless certain operational standards are met. Changes were also required for labeling of wood coatings and for compliance information in product material safety data sheets (MSDS). In addition, the rule requires that manufacturers report formaldehyde emissions from wood coatings by July 1, 2012. Staff worked with manufacturers and resin suppliers to develop the emissions calculations approach below.

Formaldehyde Emissions Reporting Requirement

Based on sales for 2011, each wood products coating manufacturer that sells more than 1000 gallons of product within the Air District is required to estimate formaldehyde emissions that are generated by drying or curing of their wood coatings. *The information submitted must include the following:*

- Estimated volume of each wood coating sold or distributed in the Air District, in gallons.
- Estimated formaldehyde emissions from each coating, in pounds.
- Formaldehyde emission factor may be estimated by the following equation:

  $$EF = 10 \times FF + 1.3438 \times [UF + 0.1871 \times (MF + PF)] + 0.248$$

  EF= Formaldehyde Emission Factor in milligrams/gram of wood coating
  FF= Weight % free formaldehyde in the coating
  UF= Weight % urea formaldehyde polymers in the coating
  MF= Weight % melamine formaldehyde polymers in the coating
  PF= Weight % phenol/cyclohexanone formaldehyde polymers in the coating (if any)

- Basis for the formaldehyde emissions estimation (if the above equation is not used).

Please note that this requirement only affects coatings subject to Reg 8- 32. Architectural coatings are not subject to this requirement.

A report explaining the derivation of the formaldehyde estimating equation with the spreadsheet to calculate emissions is attached. In addition, the spreadsheet to calculate Formaldehyde Emissions is available on our website; see http://www.baaqmd.gov/advisories and scroll down to "Coatings."

See Attachment: ***"Formaldehyde Emissions from Wood Coatings"*** *with* ***"Regulation 8, Rule 32: Wood Product Coatings" Calculation Spreadsheet and example.***

The formaldehyde emissions report must be submitted no later than July 1, 2012 to:

Bay Area Air Quality Management District
939 Ellis Street
San Francisco, CA 94109
Attention: Guy Gimlen

If you have any further questions, please call the District at the following numbers:

- ☎ For further questions on estimating formaldehyde emissions, contact Guy Gimlen, Senior Air Quality Engineer at ggimlen@baaqmd.gov or (415) 749-4734.
- ☎ For further questions on this Advisory or the Air District Regulation, contact Jeannette Lim, Supervising Air Quality Inspector at jlim@baaqmd.gov or (415) 749-4981.
- ☎ For a copy of the rule, see www.baaqmd.gov/Divisions/Planning and Research/Rules and Regulations.aspx.
- ☎ For compliance assistance, call the Compliance Counselor Hotline at: (415) 749-4999.

Brian Bateman
Director of Enforcement

Formaldehyde Emissions from Wood Coatings

Bay Area Air Quality Management District
Regulation 8: Volatile Organic Compounds, Rule 32: Wood Product Coatings

Introduction:

This report summarizes the current science readily available, and the testing work done to quantify formaldehyde emissions from wood coatings as they cure. This report also proposes a method to estimate formaldehyde emissions. Coating suppliers that sell or distribute more than 1000 gallons of wood coatings into the Bay Area, subject to Regulation 8, Rule 32, must provide estimates of formaldehyde emissions from these wood coatings. Formaldehyde emissions estimates must be based on the coating volumes sold or distributed into the Bay Area during calendar year 2011 and must be reported to the District by July, 2012.

Background:

On August 5, 2009, the BAAQMD Board of Directors amended District Regulation 8, Rule 32: Wood Products Coatings (Rule 8-32). Rule 8-32 regulates volatile organic compound (VOC) emissions from the wood products manufacturing industry by setting standards for application techniques and the amount of VOC in coatings that can be used in surface preparation, coatings application, and cleanup for the manufacture of wood products. The amendments to Rule 8-32 reduce VOC limits for some types of coatings used on the three types of wood products subject to VOC limitations in the rule: general wood products; wood furniture, custom cabinetry and custom architectural millwork; and custom furniture. The more stringent VOC limits went into effect July 1, 2010.

As part of the 2009 amendments, Rule 8-32 included a provision, §8-32-408, requiring each manufacturer of wood coatings that sells or distributes at least 1000 gallons of wood coatings into the Bay Area Air Quality Management District to provide the volumes of each wood coating sold or distributed into the District in calendar year 2011, and to provide estimates of formaldehyde emissions during drying or curing from these wood coatings. The specific requirements of this provision are shown in Attachment 1. This information will enable the District to estimate the scope of formaldehyde emissions from wood coatings, and to determine whether any additional work is necessary to reduce formaldehyde emissions from wood coatings to protect public health.

At the public hearing, the National Paint and Coatings Association commented on behalf of its members that formaldehyde emissions cannot easily be determined, and would require significant and costly testing. District staff committed to work with wood coating resin suppliers and coating manufacturers to determine a method for estimating formaldehyde emissions based on current science, and to provide guidelines for estimating formaldehyde emissions.

District staff has conducted an extensive literature search, as well as e-mail and telephone research with wood coatings suppliers and with formaldehyde based polymer resin manufacturers. All acknowledged that available information on formaldehyde emissions is scarce. Each contact pointed out that formaldehyde emissions are a natural and expected by-product of formaldehyde resin chemistry. The amount of formaldehyde emissions is influenced by the type of formaldehyde resin, the amount of excess resin in the coating mixture, and curing temperature and humidity.

Formaldehyde Emissions Chemistry:

Formaldehyde emissions can occur during application of wood coatings that contain small amounts of free formaldehyde, and can continue to occur during curing of wood coatings comprised of polymer resins that are (typically) made from:

- Melamine formaldehyde polymers, and
- Urea formaldehyde polymers.

The coatings that typically contain these polymers are known as conversion varnishes and pre-catalyzed lacquers, and can serve as both sealers and topcoats.

A third formaldehyde polymer, phenol/cyclohexanone formaldehyde polymer, can potentially be used in wood coating mixtures. However, staff was not able to locate any coating containing phenol/cyclohexanone formaldehyde polymer for testing, so it was not included in this pilot testing program. For estimation of formaldehyde emissions, phenol/cyclohexanone formaldehyde polymers are assumed to generate formaldehyde emissions in the same order of magnitude as the melamine formaldehyde polymers tested.

The normal reaction of formaldehyde based polymer resins is to cross-link with each other. This reaction produces alcohols, and the alcohols vaporize and are emitted during the curing process. However, formaldehyde is also emitted from coatings containing formaldehyde based polymer resins for two reasons: 1) there is typically excess polymer resin added to the formulation, allowing the excess resin reaction sites to hydrolyze with water (from humidity in the air) to form formaldehyde; and 2) not all of the polymer resin reaction sites are able to cross-link with each other to form polymers, allowing the un-linked reaction sites to hydrolyze with water to form formaldehyde.. High humidity during curing can encourage these undesired side-reactions that produce formaldehyde.

Much of a polymer's ability to cross-link depends on the spatial structure of the molecules – i.e. can one reaction site "reach" the next polymer molecule's reaction site hydroxyl groups so they can cross-link with each other?

- Example – a polymer molecule with 6 available reaction sites, only 2 or 3 may actually cross-link. That leaves the other 3 or 4 reaction sites exposed and vulnerable to side-reactions. In addition, some of the reaction sites may not react at all because they are hindered by the spatial arrangement of the atoms in the polymer molecule.

Higher humidity encourages side-reactions that create formaldehyde. Higher temperatures may increase the initial formaldehyde release, but the total formaldehyde emissions over the extended curing period may be no different.

The worst case formaldehyde emissions scenario would be the situation where all the reaction sites have the side-reactions to create formaldehyde. However, that scenario isn't realistic because if none of the polymers were able to cross-link, there would be no polymerized coatings. Empirical data provided by the polymer resin manufacturers suggest that 4-5% of the formaldehyde polymer (by weight) is released as formaldehyde. This calculation is complicated, however, by the fact that the coating formulations have other components that can also supply hydroxyl groups.

EPA Study on Interior Air Quality

EPA conducted a study(4) on indoor emissions from Acid-Catalyzed Varnishes. Free formaldehyde content was determined using quantitative liberation of sodium hydroxide when formaldehyde reacts with sodium sulfite. Free formaldehyde content ranged from 1.46 – 5.35 mg/g varnish for the three varnishes they tested. Chamber tests were conducted to determine total formaldehyde emissions during curing, and they were found to be 2 to 8 times higher than the amount of free formaldehyde. This provides a range of formaldehyde emission factors from 2.9 to 42.8 mg/g of varnish. They found that even 3000 hours after application, the formaldehyde emissions rates were greater than 0.1 mg/m^2/hour, slightly higher than the HUD standard for plywood at the time of the study.

Formaldehyde Emissions Factor Test Data:

Given the acute lack of quantitative information available, and the wide range of potential formaldehyde emission factors that can result from a coating formulation, the District decided to conduct pilot testing of wood coatings with a Bay Area laboratory capable of doing chamber tests. Staff, in consultation with the contractor lab personnel, decided to conduct small chamber tests (ASTM D5116-10), and measure formaldehyde emissions using ASTM D5197-09. Small chamber tests were selected rather than large chamber tests to limit costs. Large chamber tests may have the advantage of better ability to measure formaldehyde emissions during initial application of the coating to the test substrate. However, since the objective of this study is to determine reasonable estimates of formaldehyde emissions during curing, staff decided the large chamber tests were not warranted.

Coating samples were applied to a stainless steel substrate, rather than wood. Stainless steel was used to prevent possible formaldehyde contribution from wood products. Stainless steel is not reactive or absorbent and is likely to provide best emission estimates. Staff was concerned that use of any particular wood as a test substrate would introduce an additional degree of variation that was unnecessary for the purposes of this study.

During the summer of 2010, two samples with known formaldehyde polymer contents were tested(5). Standard curing conditions were set at 50% humidity (45 – 55%), and 23°C (22 – 24°C).

- Sample 1 with 4.09 wt% butylated melamine formaldehyde polymer emitted 0.75 mg/g of coating from the period of 3 hours after application until 168 hours after application. The formaldehyde emissions decay curve fit the Power Law Curve very well (R^2 = 0.9635).
- Sample 2 with 10.73 wt% butylated melamine formaldehyde polymer, and 4.970 wt% butylated urea formaldehyde polymer emitted 6.93 mg/g of coating from the period of 3 hours after application until 168 hours after application. The formaldehyde emissions decay curve fit the Power Law Curve extremely well (R^2 = 0.9916).

Based on this very limited testing, it appears that coatings with higher formaldehyde polymer content emit more formaldehyde during curing.

Four more wood coating samples were tested during the summer of 2011 using the same test methods and standard curing conditions[6].

* Sample 3 with 2.61 wt% butylated melamine formaldehyde polymer, and 3.46 wt% butylated urea formaldehyde polymer emitted 3.83 mg/g of coating from the period of 3 hours after application until 168 hours after application. The formaldehyde emissions decay curve fit the Power Law Curve extremely well ($R^2 = 0.9926$).
* Sample 4 with 3.40 wt% butylated melamine formaldehyde polymer, and 2.74 wt% isobutylated urea formaldehyde polymer emitted 3.16 mg/g of coating from the period of 3 hours after application until 168 hours after application. The formaldehyde emissions decay curve fit the Power Law Curve very well ($R^2 = 0.9623$).
* Sample 5 with 2.08 wt% butylated melamine formaldehyde polymer emitted 0.39 mg/g of coating from the period of 3 hours after application until 168 hours after application. The formaldehyde emissions decay curve fit the Power Law Curve well ($R^2 = 0.9352$).
* Sample 6 with 3.34 wt% methylated melamine formaldehyde polymer, and 10.24 wt% methylated urea formaldehyde polymer emitted 11.57 mg/g of coating from the period of 3 hours after application until 168 hours after application. The formaldehyde emissions decay curve fit the Power Law Curve extremely well ($R^2 = 0.9953$).

Table 1 shows the results of the testing, the Power law Curve fit equations and estimated mass emissions of formaldehyde over the 3 hour to 168 hour exposure period, calculated as mass of formaldehyde emitted per gram of product. Additional testing could have reduced potential variation in results from the individual test chambers, but cost constraints limited any duplicate testing.

Table 1: Power Law Curve fit equations, and estimated mass emissions

Sample	Power Law Curve Fit - 3 – 168 hours (mg/gram-hour vs. hour)	Σ Mass Emissions (mg/gram)
Sample 1	$Y = 0.2257 X^{-1.064}$	0.747
Sample 2	$Y = 0.9914 X^{-0.829}$	6.93
Sample 3	$Y = 0.8357 X^{-0.9587}$	3.83
Sample 4	$Y = 0.5081 X^{-0.8643}$	3.16
Sample 5	$Y = 0.0137 X^{-0.4396}$	0.387
Sample 6	$Y = 3.524 X^{-1.0664}$	11.6

* mg – milligram

Free Formaldehyde Emissions:

Formaldehyde emissions from these coatings were not measured from initial application of the coating to the test substrate through the first three hours because the sample must be prepared, transferred to the test chamber, then given time for the air in the test chamber to change at least twice before quantitative analysis begins. Information from formaldehyde resin manufacturers indicates that the amount of formaldehyde released during the initial 3 hour period is estimated to be very low, limited to the amount of free formaldehyde in the coating mix. Alcohols and other solvents in these wood coatings generally retard the cross-linking of the formaldehyde polymers until they have evaporated from the coating. Small amounts of free formaldehyde are often used as a biocide to prevent any degradation of the coating in the container. This study assumes the only formaldehyde emissions from the coating during the first three hours originate from the free formaldehyde in the coating.

Formaldehyde Emissions during Curing:

Formaldehyde emissions beyond 168 hours (1 week) can be extrapolated from the emission decay curves because these curves follow the Power Law Curve very well (R^2 ranges from 0.9352 to 0.9953). Comments from a formaldehyde resin supplier indicate their experience is that coatings achieve 99% of their final properties after 28 days. A technical representative from a major wood coating resin supplier indicated they believe there is general consensus among most coating suppliers that most or all of the formaldehyde from curing has evolved after 4 weeks. This study has extrapolated formaldehyde emissions beyond one week out to four weeks using the emission delay curves obtained from the sample analyses. Staff finds that measured and extrapolated formaldehyde emissions from the period of 3.0 hours out to 4 weeks will reasonably estimate the formaldehyde emissions from coatings containing formaldehyde-based polymers during the curing process.

Two samples – Sample 1 and Sample 5 contained only butylated melamine formaldehyde (MF) resin. Based on these samples' formaldehyde emissions, it appears that the MF resins release much less formaldehyde than the urea formaldehyde (UF) resins. The formaldehyde emissions from Sample 1 and Sample 5 were used to estimate the contribution of the MF resins. Using the estimated contribution from the MF resins, staff back-calculated the estimated formaldehyde emissions from the UF resins in the other samples. The results were very consistent for the two MF resins, and for the four UF resins, as shown in Table 2.

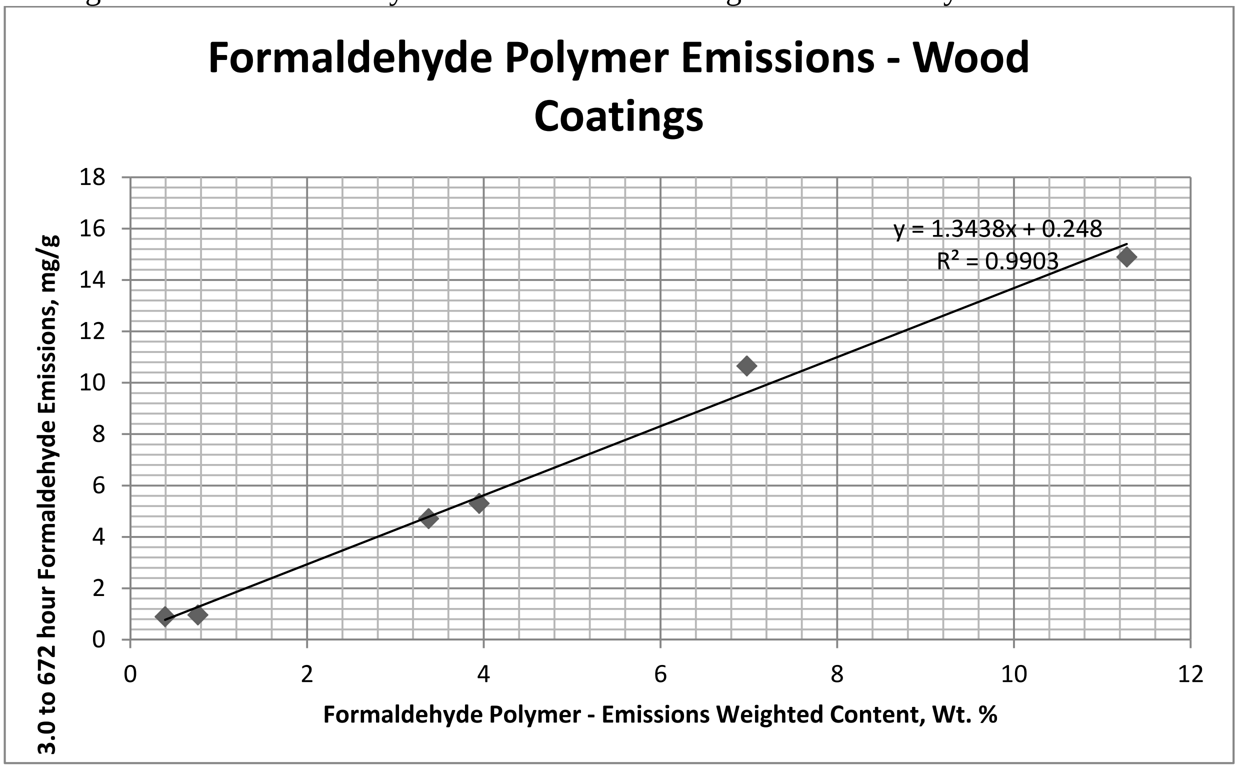
Table 2: Estimated Formaldehyde Emissions from MF and UF Resins

Sample	MF Emissions: 3 – 168 hours (mg/gram of MF resin)	UF Emissions: 3 – 168 hours (mg/gram of UF resin)
Sample 1	18.28	N/A
Sample 2	18.34*	99.81
Sample 3	18.34*	96.85
Sample 4	18.34*	92.52
Sample 5	18.41	N/A
Sample 6	18.34*	102.89

* average of Sample 1 and Sample 5

Taking the average emissions from MF resins and UF resins, it appears that MF resins emit (on average) only 18.71% as much formaldehyde as UF resins. Staff used that proportion to weight the potential to emit formaldehyde based on formaldehyde polymer content, and plotted formaldehyde emissions versus emissions weighted formaldehyde resin content in Figure 1. Figure 1 shows a linear correlation that provides an estimated formaldehyde emissions factor from formaldehyde based polymers in wood coatings during the curing process.

Figure 1. Formaldehyde Emissions versus Weighted Formaldehyde Resin Content



<u>Proposed Formaldehyde Emissions Factor:</u>
The proposed emission factor for wood coatings containing formaldehyde polymers is:

$$EF = 10 \text{ x } FF + 1.3438 \text{ x } [UF + 0.1871 \text{ x } (MF + PF)] + 0.248$$

EF: Formaldehyde Emission Factor in milligrams / gram of wood coating
FF: Weight % free formaldehyde in the coating
UF: Weight % urea formaldehyde polymers in the coating
MF: Weight % melamine formaldehyde polymers in the coating
PF: Weight % phenol/cyclohexanone formaldehyde polymers in the coating (if any)

Phenol/cyclohexanone formaldehyde polymer is assumed to yield formaldehyde emissions in the same order of magnitude as melamine formaldehyde polymers.

Free formaldehyde information is normally available in the MDSD information for each coating. Urea, melamine, and phenol formaldehyde polymer content is normally NOT readily available. Each coating supplier must provide this information in your emissions estimate submittals for product sales into the Bay Area for calendar year 2011.

For those who find the units of milligrams/gram of coating awkward to use, spreadsheet will be supplied with this report to provide ease and consistency in estimating formaldehyde emissions from 2011 wood coating sales into the Bay Area. We have retained the units of milligrams/gram of coating to be consistent with the testing methodology used. An example of how to use this formula to estimate formaldehyde emissions from an coating supplier's sales into the Bay Area is shown in Attachment 2, and included in the spreadsheet.

Conclusion:

The purpose of this study is to propose an emission factor for use by wood coating manufacturers to estimate formaldehyde emissions from their products in order to comply with §8-32-408. The proposed emission factor is somewhat consistent with resin manufacturer guidance that 4-5% of the formaldehyde polymer (by weight) is released as formaldehyde. In this case, melamine formadehyhde polymers released 1.8 weight % of the formaldehyde polymer as formaldehyde, and the urea formaldehyde polymers released 9.3 – 10.3 weight % of formaldehyde polymer as formaldehyde. Alternately, any manufacturer can propose some other basis for estimating formaldehyde emissions, along with testing information and data needed to provide technical support for their proposal.

Coating composition data, coating sales volumes and estimated emissions are due to the District by July 1, 2012. Coatings that contain no formaldehyde based polymers do not need to be reported, with any free formaldehyde in these coatings considered to be de-minimis.

Air District staff will consider hosting a meeting or workshop facilitate implementation of this formaldehyde estimating procedure if needed.

Please address comments and questions to:
Guy Gimlen
Bay Area Air Quality Management District
939 Ellis Street
San Francisco, CA 94109
415-749-4734
ggimlen@baaqmd.gov

References

1. BAAQMD Regulation 8, Organic Compounds; Rule 32, Wood Product Coatings
2. Characterization of Manufacturing Processes and Emissions and Pollution Prevention Options for the Composite Wood Industry, EPA-600/R-96-066, NTIS PB96-183892, June 1996
3. Sources and Factors Affecting Indoor Emissions from Engineered Wood Products: Summary and Evaluation of Current Literature, EPA-600/R-96-067, NTIS PB96-183876, June 1996
4. The Application of Pollution Prevention Techniques to Reduce Indoor Air Emissions from Engineered Wood Products, EPA-600/R-98-146, NTIS PB99-118309, November 1998
5. Formaldehyde Emissions from Wood Coatings (redacted), Berkeley Analytical, September 13, 2010
6. Formaldehyde Emissions from Wood Coatings (redacted), Berkeley Analytical, September 2, 2011

Attachment 1

Regulation 8, Rule 32: Wood Products Coatings

8-32-408 Formaldehyde Emissions Information Requirement: By July 1, 2012, each manufacturer with at least 1000 gallons of wood coatings sold or distributed into the District shall submit the following information for each of the wood coatings based on 2011 sales:

408.1 The estimated volumes of each wood coating sold or distributed into the Bay Area.

408.2 The estimated formaldehyde emitted during drying or curing (in grams) from each of the wood coatings sold or distributed into the Bay Area.

408.3 The basis for the formaldehyde emissions estimate for each of the wood coatings sold or distributed into the Bay Area.

Regulation 8, Organic Compounds; Rule 32, Wood Product Coatings can be found at:
http://www.baaqmd.gov/Divisions/Planning-and-Research/Rules-and-Regulations.aspx

Attachment 2

Example – Wood Coatings formaldehyde emissions calculation

XYZ Coating Company
Product Sales into the Greater San Francisco Bay Area

Product	Volume (gallons)	Density (lbs/gallon)	FF (wt %)	UF (wt %)	MF (wt %)	PF (wt %)
Low Solids Stain 1	700	7.5	0.003	0	0	0
High Solids Stain 2	1300	8.3	0.005	0	0	0
Filler 3	500	12.2	0.002	0	0	0
Sealer 4	1800	8.1	0.010	1.9	2.4	0
Topcoat 5	2000	8.6	0.016	3.1	8.7	2.6
Topcoat 6	1400	8.5	0.063	10.7	3.7	0

Volume: in gallons sold into the 9 counties of the Greater Bay Area in 2011*
Density: in pounds (lbs.) per gallon
FF: Weight % free formaldehyde in coating mixture**
UF: Weight % urea formaldehyde in coating mixture**
MF: Weight % melamine formaldehyde in coating mixture**
PF: Weight % phenol / cyclohexanone formaldehyde in coating mixture**

Note: * - Southern Sonoma County and Southwestern portion of Solano county are within the Bay Area Air Quality Management District Jurisdiction.
Note: ** - coating mixture as sold, excluding any recommended catalyst or thinner

Example Calculations:

EF = 10 x FF + 1.3438 x [UF + 0.1871 x (MF + PF)] + 0.248
EF: Formaldehyde Emission Factor in milligrams / gram of wood coating

Low Solids Stain 1

EF = 10 X 0.003 + 1.3438 x [0 + 0.1871 x (0 + 0) +0.248

However, since this coating contains no formaldehyde based polymers, no formaldehyde emissions estimates are required for this coating.

High Solids Stain 2

EF = 10 X 0.005 + 1.3438 x [0 + 0.1871 x (0 + 0) +0.248

However, since this coating contains no formaldehyde based polymers, no formaldehyde emissions estimates are required for this coating.

Filler 3

EF = 10 X 0.002 + 1.3438 x [0 + 0.1871 x (0 + 0) +0.248

However, since this coating contains no formaldehyde based polymers, no formaldehyde emissions estimates are required for this coating.

Sealer 4

EF = 10 X 0.010 + 1.3438 x [1.9 + 0.1871 x (2.4 + 0) +0.248
EF = 0.1 + 1.3438 x (1.9 + 0.4490) + 0.248
EF = 0.1 + 1.3438 x (2.3490) + 0.248
EF = 0.1 + 3.1566 + 0.248

EF = 3.5046 mg/g of coating

Density =8.1 lbs/gallon
Grams sold in Bay Area =1800 gallons X 8.1 lbs/gallon X 453.59 grams/lb = 6,613,342.2 grams
Grams Formaldehyde emission in Bay Area = EF x grams sold / 1000
= 3.5046 x 6,613,342.2 / 1000
23,177 grams = 51.10 lbs.

<u>Topcoat 5</u>

EF = 10 X 0.016 + 1.3438 x [3.1 + 0.1871 x (8.7 + 2.6) +0.248
EF = 0.16 + 1.3438 x (3.1 + 2.1142) + 0.248
EF = 0.16 + 1.3438 x (5.2142) + 0.248
EF = 0.16 + 7.0069 + 0.248
EF = 7.4149 mg/g of coating

Density =8.6 lbs/gallon
Grams sold in Bay Area =2000 gallons X 8.6 lbs/gallon X 453.59 grams/lb = 7,801,748 grams
Grams Formaldehyde emission in Bay Area = EF x grams sold / 1000
= 7.4149 x 7,801,748 / 1000
57,849 grams = 127.54 lbs.

<u>Topcoat 6</u>

EF = 10 X 0.063 + 1.3438 x [10.7 + 0.1871 x (3.7 + 0) +0.248
EF = 0.63 + 1.3438 x (10.7 + 0.6923) + 0.248
EF = 0.63 + 1.3438 x (11.3923) + 0.248
EF = 0.63 + 15.3089 + 0.248
EF = 16.1869 mg/g of coating

Density =8.5 lbs/gallon
Grams sold in Bay Area =1400 gallons X 8.5 lbs/gallon X 453.59 grams/lb = 5,397,721 grams
Grams Formaldehyde emission in Bay Area = EF x grams sold / 1000
= 16.1869 x 5,397,721 / 1000
87,373 grams = 192.62 lbs.

Total formaldehyde emissions to report: 0+0+0+51.10 + 127.54 + 192.62 = 371.26 lbs

Use reporting format as follows:

XYZ Coating Company

Product Sales into the Greater San Francisco Bay Area

Product	**Volume (gallons)**	**Density (lbs/gallon)**	**FF (wt %)**	**UF (wt %)**	**MF (wt %)**	**PF (wt %)**	**HCHO lbs/year**
Low Solids Stain 1	700	7.5	0.003	0	0	0	N/A
High Solids Stain 2	1300	8.3	0.005	0	0	0	N/A
Filler 3	500	12.2	0.002	0	0	0	N/A
Sealer 4	1800	8.1	0.010	1.9	2.4	0	51.10
Topcoat 5	2000	8.6	0.016	3.1	8.7	2.6	127.54
Topcoat 6	1400	8.5	0.063	10.7	3.7	0	192.62
Total							**371.26**

Regulation 8-32: Wood Product Coatings Calculation Spreadsheet with Example

Product Sales into the Greater San Francisco Bay Area*

Insert product sales volumes and technical information into the cells highlighted in yellow.

	Coating Company

Product	Volume (gallons)	Density (lbs/gallon)	FF (wt %)	UF (wt %)	MF (wt %)	PF (wt %)	EF (mg/gram)	Coating Sold (grams)	Formaldehyde Emissions (grams/year)	Formaldehyde Emissions (pounds/year)
Coating 1							0.0000	0	0	0.00
Coating 2							0.0000	0	0	0.00
Coating 3							0.0000	0	0	0.00
Coating 4							0.0000	0	0	0.00
Coating 5							0.0000	0	0	0.00
Coating 6							0.0000	0	0	0.00
Coating 7							0.0000	0	0	0.00
Coating 8							0.0000	0	0	0.00
Coating 9							0.0000	0	0	0.00
Coating 10							0.0000	0	0	0.00
Coating 11							0.0000	0	0	0.00
Coating 12							0.0000	0	0	0.00
Coating 13							0.0000	0	0	0.00
Coating 14							0.0000	0	0	0.00
Coating 15							0.0000	0	0	0.00
Coating 16							0.0000	0	0	0.00
Coating 17							0.0000	0	0	0.00
Coating 18							0.0000	0	0	0.00
Coating 19							0.0000	0	0	0.00
Coating 20							0.0000	0	0	0.00
									Total	**0.00**

Formaldehyde Emissions during Curing: EF = Emission Factor in mg/gram of coating

EF = 10 x FF + 1.3438 x [UF + 0.1871 x (MF + PF)] + 0.248

Volume: in gallons sold into the 9 counties of the Greater Bay Area in 2011*
Density: in pounds (lbs.) per gallon
FF: Weight % Free Formaldehyde in the coating mixture**
UF: Weight % Urea Formaldehyde polymer resins in the coating mixture**
MF: Weight % Melamine Formaldehyde polymer resins in the coating mixture**
PF: Weight % Phenol / Cyclohexanone Formaldehyde polymer resins in the coating mixture**

Note: * - Southern Sonoma County and Southwest portion of Solano county are within the Bay Area Air Quality Management District Jurisdiction.
Note: ** - coating mixture as sold, excluding any recommended catalyst or thinner

Send formaldehyde emissions report no later than July 1, 2012 to: Bay Area Air Quality Management District, Attention: Guy Gimlen; 939 Ellis Street, San Francisco, CA 94109.

Product Sales into the Greater San Francisco Bay Area*

XYZ Coating Company
Example

Product	Volume (gallons)	Density (lbs/gallon)	FF (wt %)	UF (wt %)	MF (wt %)	PF (wt %)	EF (mg/gram)	Coating Sold (grams)	Formaldehyde Emissions (grams/year)	Formaldehyde Emissions (pounds/year)
Low Solids Stain 1	700	7.5	0.003	0	0	0	0.0000	2,381,348	0	0.00
High Solids Stain 2	1300	8.3	0.005	0	0	0	0.0000	4,894,236	0	0.00
Filler 3	500	12.2	0.002	0	0	0	0.0000	2,766,899	0	0.00
Sealer 4	1800	8.1	0.01	1.9	2.4	0	3.5046	6,613,342	23,177	51.10
Topcoat 5	2000	8.6	0.016	3.1	8.7	2.6	7.4149	7,801,748	57,849	127.54
Topcoat 6	1400	8.5	0.063	10.7	3.7	0	16.1869	5,397,721	87,373	192.62
									Total	371.26

Formaldehyde Emissions during Curing: EF = Emission Factor in mg/gram of coating
EF = 10 x FF + 1.3438 x [UF + 0.1871 x (MF + PF)] + 0.248

Volume: in gallons sold into the 9 counties of the Greater Bay Area in 2011*
Density: in pounds (lbs.) per gallon
FF: Weight % Free Formaldehyde in the coating mixture**
UF: Weight % Urea Formaldehyde polymer resins in the coating mixture**
MF: Weight % Melamine Formaldehyde polymer resins in the coating mixture**
PF: Weight % Phenol / Cyclohexanone Formaldehyde polymer resins in the coating mixture**

Note: * - Southern Sonoma County and Southwest portion of Solano county are within the Bay Area Air Quality Management District Jurisdiction.
Note: ** - coating mixture as sold, excluding any recommended catalyst or thinner

Send formaldehyde emissions report no later than July 1, 2012 to: Bay Area Air Quality Management District, Attention: Guy Gimlen; 939 Ellis Street, San Francisco, CA 94109.

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Formaldehyde Emissions from Wood Coatings

Customer and Project Information

Report Certification	
Report number	509-001-IH-Sep1310
Report date	September 13, 2010
Certified by (Name/Title)	Alfred T. Hodgson, Research Director
Signature	
Date	*January 31, 2012*

Methods	
ASTM D 5116-10	Standard Guide for Small-Scale Environmental Chamber…
ASTM D 5197-09	Determination of Formaldehyde and Other Carbonyl Compounds in Air…

Customer Information	
Customer:	Bay Area Air Quality Management District
City/State/Country	San Francisco, CA, USA
Contact name/Title	Guy A. Gimlen, Senior Air Quality Engineer
Phone number	415-749-4734

Project Information	
Project number	None given
Project description	Small-scale, pilot testing of wood coatings for emissions of formaldehyde
Project location	Not given
Project date	Not given

Laboratory Receiving Information	
Date samples received by lab	August 10, 2010 and August 27, 2010
Condition of samples	No observed problems
Lab tracking numbers	509-001-03A and 509-001-04A

Product Information and Chamber Test Parameters

Table 1. Coating Product Descriptions

Product Name	System Type	Manufacturer
Sample 1	Pre-catalyzed	Manufacturer 1
Sample 2	Two-component	Manufacturer 2

Table 2. Test parameters for Sample 1

Parameter	Symbol	Units	Value
Mass of applied product	M	g	4.17
Area of applied product	A	m^2	0.0313
Chamber volume	V_C	m^3	0.067
Inlet gas flow rate	Q_C	m^3/h	0.067
Ventilation rate	a_C	h^{-1}	1 ± 0.03
Avg Temperature & Range		^oC	22.7 (22-24)
Avg Relative humidity & Range		%	50 (45-55)
Start date			Aug 31, 2010
Duration		h	168

Table 3. Test parameters for Sample 2

Parameter	Symbol	Units	Value
Mass of applied product	M	g	2.33
Area of applied product	A	m^2	0.0313
Chamber volume	V_C	m^3	0.067
Inlet gas flow rate	Q_C	m^3/h	0.067
Ventilation rate	a_C	h^{-1}	1 ± 0.03
Avg Temperature & Range		^oC	22.9 (22-24)
Avg Relative humidity & Range		%	50 (45-55)
Start date			Aug 31, 2010
Duration		h	168

Chamber Air Sample Information

Table 4. Chamber air sample data

Product	Sample Name	Sample No.	Date Collected	Description	Vol. (L)	Analysis Type	Specified Method
Sample 1	3-Hour	SA020666	Aug 31, 2010	3-h Chamber	2.0	Formaldehyde	ASTM D 5197
Sample 1	5-Hour	SA020667	Aug 31, 2010	5-h Chamber	5.0	Formaldehyde	ASTM D 5197
Sample 1	8-Hour	SA020668	Aug 31, 2010	8-h Chamber	5.0	Formaldehyde	ASTM D 5197
Sample 1	24-Hour	SA020687	Sept 1, 2010	24-h Chamber	20.0	Formaldehyde	ASTM D 5197
Sample 1	48-Hour	SA020689	Sept 2, 2010	48-h Chamber	54.0	Formaldehyde	ASTM D 5197
Sample 1	72-Hour	SA020719	Sept 3, 2010	72-h Chamber	54.0	Formaldehyde	ASTM D 5197
Sample 1	168-Hour	SA020730	Sept 7, 2010	168-h Chamber	54.0	Formaldehyde	ASTM D 5197
Sample 2	3-Hour	SA020669	Aug 31, 2010	3-h Chamber	1.0	Formaldehyde	ASTM D 5197
Sample 2	5-Hour	SA020670	Aug 31, 2010	5-h Chamber	1.0	Formaldehyde	ASTM D 5197
Sample 2	8-Hour	SA020671	Aug 31, 2010	8-h Chamber	2.0	Formaldehyde	ASTM D 5197
Sample 2	24-Hour	SA020688	Sept 1, 2010	24-h Chamber	5.0	Formaldehyde	ASTM D 5197
Sample 2	48-Hour	SA020690	Sept 2, 2010	48-h Chamber	10.0	Formaldehyde	ASTM D 5197
Sample 2	72-Hour	SA020720	Sept 3, 2010	72-h Chamber	10.0	Formaldehyde	ASTM D 5197
Sample 2	168-Hour	SA020731	Sept 7, 2010	168-h Chamber	10.0	Formaldehyde	ASTM D 5197

Table 5. Air sample analysis data

Product	Sample Name	Sample No.	Method	Date Analyzed	Analyst	Data File
Sample 1	3-Hour	SA020666	ASTM D 5197	Sept 2, 2010	R. Gill	100902-A\002-0201
Sample 1	5-Hour	SA020667	ASTM D 5197	Sept 2, 2010	R. Gill	100902-A\004-0401
Sample 1	8-Hour	SA020668	ASTM D 5197	Sept 1, 2010	R. Gill	100901-A\006-0601
Sample 1	24-Hour	SA020687	ASTM D 5197	Sept 1, 2010	R. Gill	100901-A\009-0901
Sample 1	48-Hour	SA020689	ASTM D 5197	Sept 2, 2010	R. Gill	100902-A\009-0901
Sample 1	72-Hour	SA020719	ASTM D 5197	Sept 3, 2010	R. Gill	100903-A\007-0701
Sample 1	168-Hour	SA020730	ASTM D 5197	Sept 7, 2010	R. Gill	100907-A\002-0201
Sample 2	3-Hour	SA020669	ASTM D 5197	Sept 2, 2010	R. Gill	100902-A\003-0301
Sample 2	5-Hour	SA020670	ASTM D 5197	Sept 2, 2010	R. Gill	100902-A\005-0501
Sample 2	8-Hour	SA020671	ASTM D 5197	Sept 2, 2010	R. Gill	100902-A\006-0601
Sample 2	24-Hour	SA020688	ASTM D 5197	Sept 2, 2010	R. Gill	100902-A\007-0701
Sample 2	48-Hour	SA020690	ASTM D 5197	Sept 2, 2010	R. Gill	100902-B\004-0401
Sample 2	72-Hour	SA020720	ASTM D 5197	Sept 3, 2010	R. Gill	100903-A\006-0601
Sample 2	168-Hour	SA020731	ASTM D 5197	Sept 7, 2010	R. Gill	100907-A\003-0301

Project Specific Information

The customer delivered two wood coating product samples to the laboratory. The two products are identified in Table 1. The Sample 1, delivered on August 10, 2010, was pre-catalyzed and was within the specified pot life at the time of the test. The Sample 2, delivered on August 27, 2010, was a two-component product. The Sample 2 components were mixed in the manufacturer's specified ratio immediately prior to the test. The products were individually applied by brush to a stainless steel plate. The coated area was 17.5 cm x 17.5 cm (0.313 m^2). The target product loadings were determined based on the manufacturers' specifications. For the Sample 1 product, the manufacturer specified an approximately 5-mil thick wet layer (4-mil to 6-mil) and the product density was given as 1,040 g/L. This produced a target value of 4.1 g. For the Sample 2 product, the manufacturer specified a coverage of 572±20 square feet per gallon and a product density of 8.22 lb/gal. This produced a target value of 2.2 g. The test specimen data is presented in Tables 2 and 3, respectively for the Sample 1and Sample 2 products.

The chamber tests were conducted in small-scale chambers (0.067 m^3) following ASTM standard D 5116-10 at conditions of 1 air change rate per hour, 23^o C average temperature, and 50% relative humidity (Tables 2 and 3). Air samples for the analysis of formaldehyde were periodically collected from the chamber exhausts over an interval of 3-h (three full chamber air changes) to 168-h elapsed time. Sampling flow rates were regulated by electronic mass-flow controllers. Sampling volumes were adjusted to match anticipated chamber concentrations. The sampling information is given in Table 4. The samples were collected on XpoSure Aldehyde Samplers (Waters Corp.). The samples were analyzed for formaldehyde by high-performance liquid chromatography (HPLC) following ASTM standard D 5197-09. The sample analysis information is given in Table 5.

The chamber formaldehyde concentrations and calculated instantaneous emission factors (see Equation 1 below) are presented in Table 6. The emission factor data are plotted versus elapsed time in hours in Figures 1 – 4. A power-law curve function was fit to the emission factor data using the MS Excel 2003 power-law function. The coefficient of determination (r^2) for the curve fitting routine was 0.96 or better, demonstrating an excellent fit to the data. The definite integral (see Equation 2 below) was used to find the area between the curve and the 'x' axis bounded by the two given 'x' values, 3 h and 168 h. This area is called the 'area under the curve', which is the formaldehyde mass emission per gram of product (mg/g) or per square meter of applied surface area (mg/m^2). The results are presented in Table 7.

Equations Used in Calculations – An area-specific emission factor (EF_A) in mg/m^2-h at steady-state conditions for a chemical emitted by a building product in a chamber test is calculated using Equation 1:

$$EF_A = (Q_c\,(C - C_o)) / A_S \qquad (1)$$

where Q_c is the chamber inlet air flow rate (m^3/h), C is the VOC chamber concentration (mg/m^3), C_O is the corresponding chamber background VOC concentration (mg/m^3), and A_S is the tested specimen exposed area (m^2). A mass-specific emission factor (EF_M) is calculated in the same manner using the mass of the tested specimen in grams instead of the area of the tested specimen. In this case, the mass is the mass of the wet applied product (Tables 2 and 3).

The calculation of formaldehyde mass emissions over the 165-h interval in mg/g for the specimen of the Sample 1product is given in Equation 2 as an example of the integration procedure.

$$Area = \int_3^{168}\left(0.2257x^{-1.0636}\right)dx = 0.2257\times\left(\frac{x^{-1.0636+1}}{-1.0636+1}\right)\Bigg|_3^{168}$$

$$= 0.2257\left[\left(\frac{168^{-1.0636+1}}{-1.0636+1}\right)-\left(\frac{3^{-1.0636+1}}{-1.0636+1}\right)\right] = 0.7476 mg/g \qquad (2)$$

Results

Table 6. Formaldehyde concentrations and calculated emission factors (product mass-specific and applied area-specific)

Product	Sample Name	Volume (L)	Mass (ng)	Conc (mg/m^3)	Emission Factor (mg/g-h)	Emission Factor (mg/m^2-h)
Sample 1	3-Hour	2.0	10,507	5.254	0.0844	11.25
Sample 1	5-Hour	5.0	14,718	2.944	0.0473	6.301
Sample 1	8-Hour	5.0	7,826	1.565	0.0252	3.350
Sample 1	24-Hour	20.0	5,928	0.296	0.0048	0.634
Sample 1	48-Hour	54.0	9,310	0.172	0.0028	0.369
Sample 1	72-Hour	54.0	7,714	0.143	0.0023	0.306
Sample 1	168-Hour	54.0	5,115	0.095	0.0015	0.203
Sample 2	3-Hour	1.0	14,480	14.480	0.4164	31.00
Sample 2	5-Hour	1.0	10,202	10.202	0.2934	21.84
Sample 2	8-Hour	2.0	11,740	5.870	0.1688	12.56
Sample 2	24-Hour	5.0	10,178	2.036	0.0585	4.357
Sample 2	48-Hour	10.0	13,376	1.338	0.0385	2.863
Sample 2	72-Hour	10.0	9,728	0.973	0.0280	2.082
Sample 2	168-Hour	10.0	5,668	0.567	0.0163	1.213

Table 7. Power law curve fit equations and estimated mass emissions of formaldehyde over 3 hour to 168 hour exposure period calculated as mass of formaldehyde emitted per gram of product and per square meter of applied surface area

Product Name	Power Law Curve Fit 3 to 168 hours EF (mg/g-h vs. h)	Power Law Curve Fit 3 to 168 hours EF (mg/m^2-h vs. h)	Σ Mass Emissions (mg/g)	Σ Mass Emissions (mg/m^2)
Sample 1	$y = 0.2257x^{-1.064}$	$y = 30.07x^{-1.064}$	0.748	99.6
Sample 2	$y = 0.9914x^{-0.829}$	$y = 73.80x^{0.829}$	6.92	515

Results

Figure 1. Product mass-specific emissions of formaldehyde versus time (mg/g-h) for sample of Sample 1

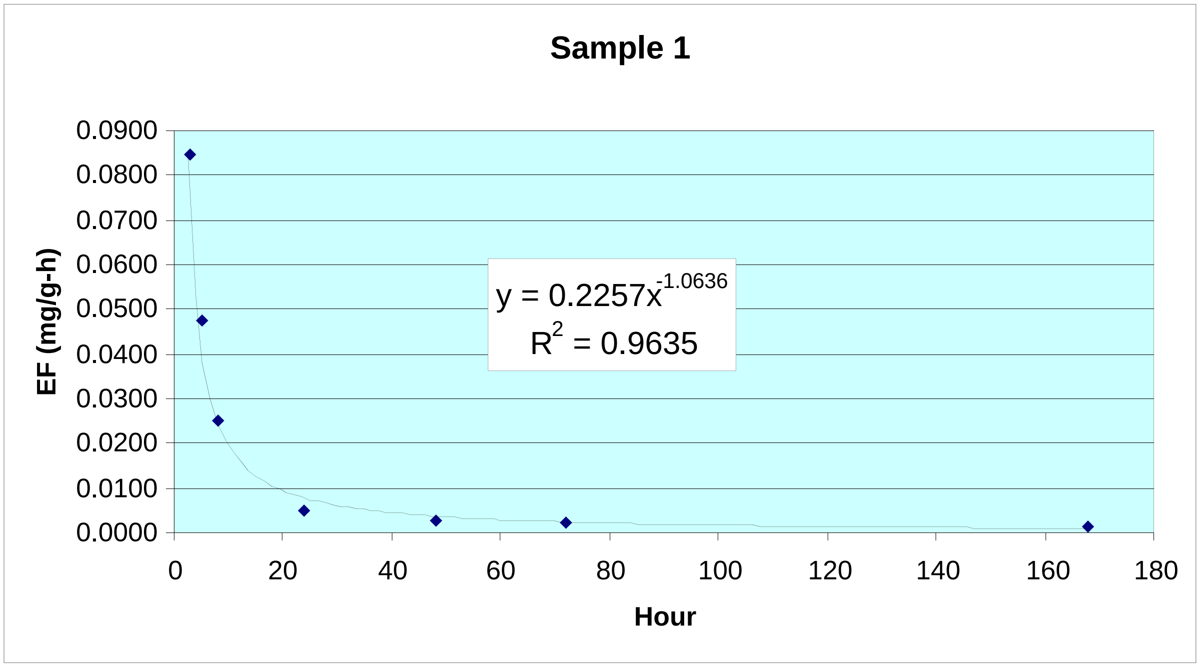
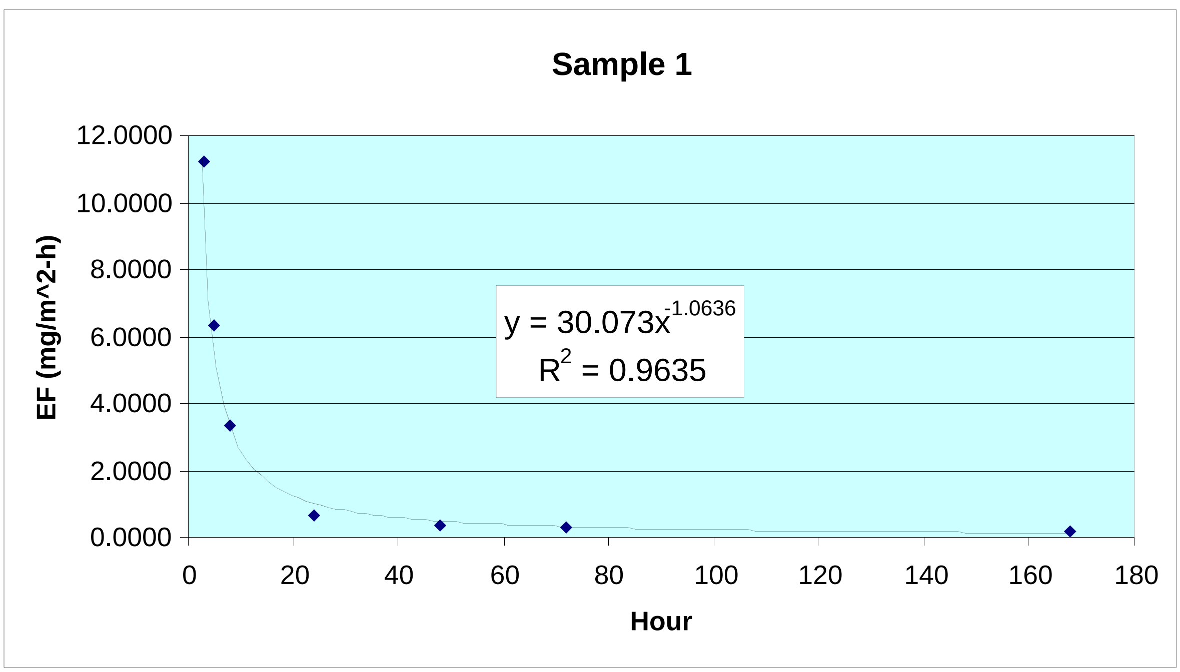


Figure 2. Applied area-specific emissions of formaldehyde versus time (mg/m²-h) for sample of Sample 1



Results

Figure 3. Product mass-specific emissions of formaldehyde versus time (mg/g-h) for sample of Sample 2

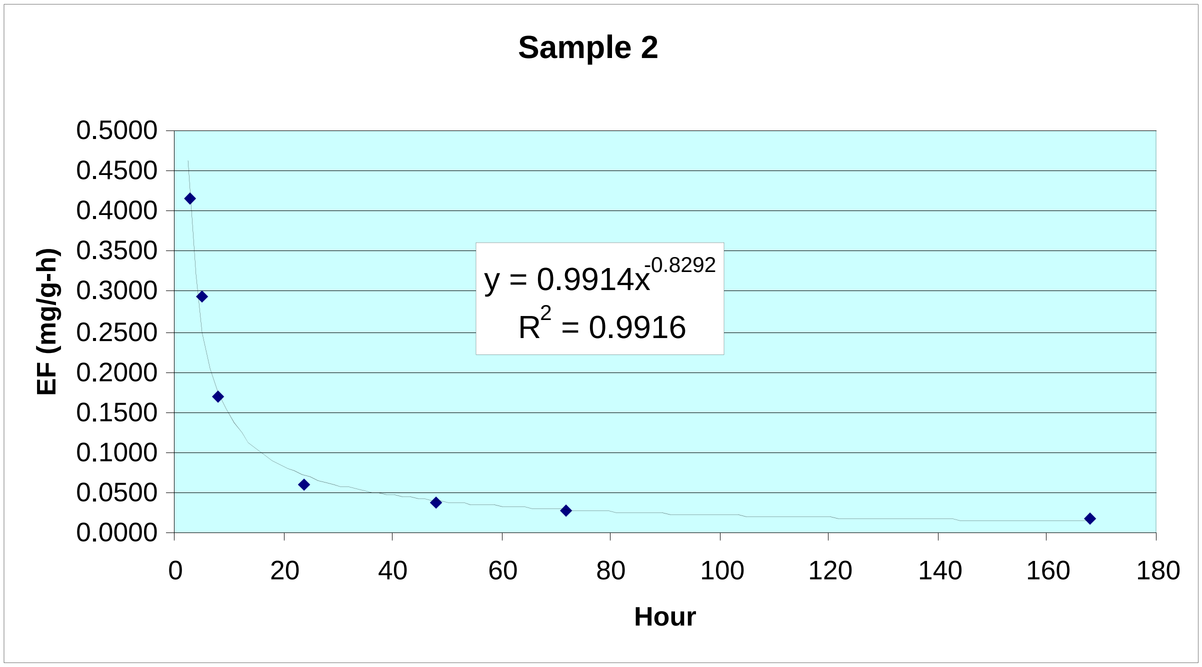
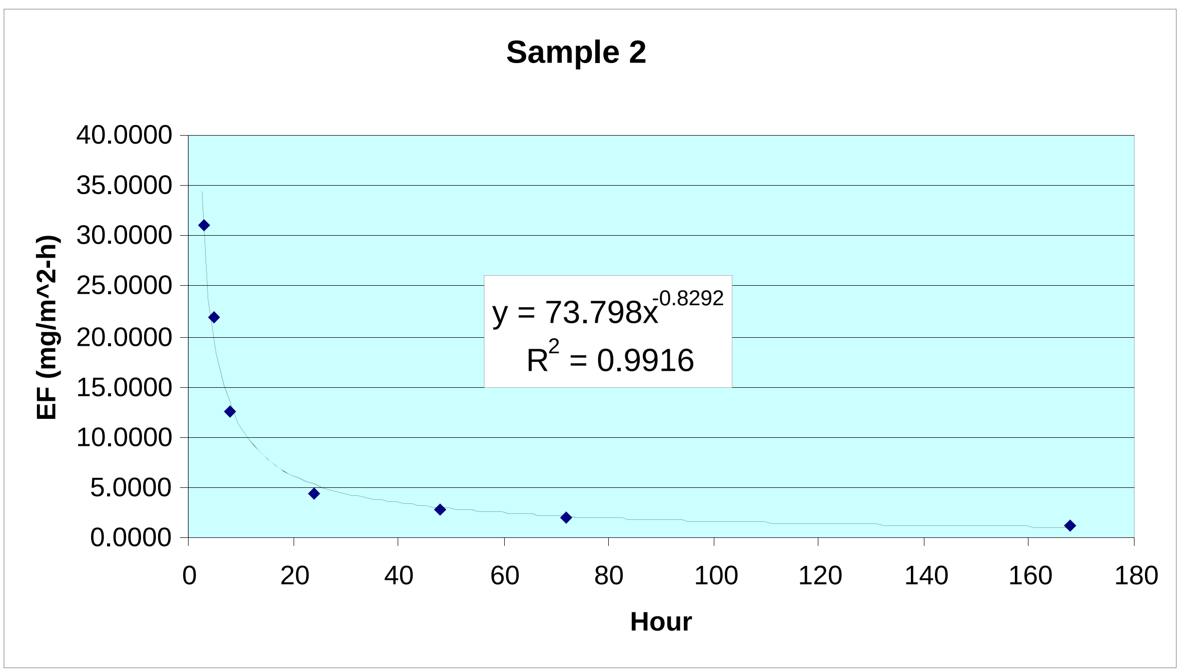


Figure 4. Applied area-specific emissions of formaldehyde versus time (mg/ m^2-h) for sample of Sample 2



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Formaldehyde Emissions from Wood Coatings

Customer and Project Information

Report Certification	
Report number	509-002-IH-Aug3011
Report date	September 2, 2011
Certified by (Name/Title)	Alfred T. Hodgson, Research Director
Signature	
Date	*January 31, 2012*

Methods	
ASTM D 5116-10	Standard Guide for Small-Scale Environmental Chamber…
ASTM D 5197-09	Determination of Formaldehyde and Other Carbonyl Compounds in Air…

Customer Information	
Customer:	Bay Area Air Quality Management District
City/State/Country	San Francisco, CA, USA
Contact name/Title	Guy A. Gimlen, Senior Air Quality Engineer
Phone number	415-749-4734

Project Information	
Project number	None given
Project description	Small-scale, testing of catalyzed wood coatings for emissions of formaldehyde
Project location	Not given
Project date	Not given

Laboratory Receiving Information	
Date samples received by lab	August 17, 2011
Condition of samples	No observed problems
Lab tracking numbers	509-002-01A through 509-002-04A

Product Information and Chamber Test Parameters

Table 1. Coating Product Descriptions

Product Name	System Type	Manufacturer	Distributor/ Location
Sample 3	2-component	Manufacturer 3	Location 3
Sample 4	Pre-catalyzed	Manufacturer 4	Location 4
Sample 5	2-component	Manufacturer 5	Location 5
Sample 6	2-component	Manufacturer 6	Location 6

Table 2. Test parameters for Sample 3

Parameter	Symbol	Units	Value
Mass of applied product	M	g	2.61
Area of applied product	A	m^2	0.0313
Product coverage		g/m^2	83.4
Chamber volume	V_C	m^3	0.067
Inlet gas flow rate	Q_C	m^3/h	0.067
Ventilation rate	a_C	h^{-1}	1 ± 0.03
Avg Temperature & Range		^oC	23.3 (22-24)
Avg Relative humidity & Range		%	49.1 (45-55)
Start date			Aug 22, 2011
Duration		h	168

Table 3. Test parameters for Sample 4

Parameter	Symbol	Units	Value
Mass of applied product	M	g	4.25
Area of applied product	A	m^2	0.0313
Product coverage		g/m^2	136
Chamber volume	V_C	m^3	0.067
Inlet gas flow rate	Q_C	m^3/h	0.067
Ventilation rate	a_C	h^{-1}	1 ± 0.03
Avg Temperature & Range		^oC	23.1 (22-24)
Avg Relative humidity & Range		%	51.9 (45-55)
Start date			Aug 22, 2011
Duration		h	168

Chamber Air Sample Information

Table 4. Test parameters for Sample 5

Parameter	Symbol	Units	Value
Mass of applied product	M	g	3.20
Area of applied product	A	m^2	0.0313
Product coverage		g/m^2	102
Chamber volume	V_C	m^3	0.067
Inlet gas flow rate	Q_C	m^3/h	0.067
Ventilation rate	a_C	h^{-1}	1 ± 0.03
Avg Temperature & Range		^oC	22.9 (22-24)
Avg Relative humidity & Range		%	49.2 (45-55)
Start date			Aug 22, 2011
Duration		h	168

Table 5. Test parameters for Sample 6

Parameter	Symbol	Units	Value
Mass of applied product	M	g	2.90
Area of applied product	A	m^2	0.0313
Product coverage		g/m^2	92.7
Chamber volume	V_C	m^3	0.067
Inlet gas flow rate	Q_C	m^3/h	0.067
Ventilation rate	a_C	h^{-1}	1 ± 0.03
Avg Temperature & Range		^oC	23.0 (22-24)
Avg Relative humidity & Range		%	49.8 (45-55)
Start date			Aug 22, 2011
Duration		h	168

Chamber Air Sample Information

Table 6. Chamber air sample data

Product	Sample Name	Sample No.	Date Collected	Description	Vol. (L)	Analysis Type	Specified Method
Sample 3	3-Hour	SA025328	Aug 22, 2011	3-h Chamber	1.0	Formaldehyde	ASTM D 5197
Sample 3	5-Hour	SA025333	Aug 22, 2011	5-h Chamber	1.0	Formaldehyde	ASTM D 5197
Sample 3	8-Hour	SA025338	Aug 22, 2011	8-h Chamber	2.0	Formaldehyde	ASTM D 5197
Sample 3	24-Hour	SA025361	Aug 23, 2011	24-h Chamber	5.0	Formaldehyde	ASTM D 5197
Sample 3	48-Hour	SA025377	Aug 24, 2011	48-h Chamber	10.0	Formaldehyde	ASTM D 5197
Sample 3	72-Hour	SA025396	Aug 25, 2011	72-h Chamber	10.0	Formaldehyde	ASTM D 5197
Sample 3	168-Hour	SA025432	Aug 29, 2011	168-h Chamber	10.0	Formaldehyde	ASTM D 5197
Sample 4	3-Hour	SA025329	Aug 22, 2011	3-h Chamber	1.0	Formaldehyde	ASTM D 5197
Sample 4	5-Hour	SA025334	Aug 22, 2011	5-h Chamber	1.0	Formaldehyde	ASTM D 5197
Sample 4	8-Hour	SA025339	Aug 22, 2011	8-h Chamber	2.0	Formaldehyde	ASTM D 5197
Sample 4	24-Hour	SA025362	Aug 23, 2011	24-h Chamber	5.0	Formaldehyde	ASTM D 5197
Sample 4	48-Hour	SA025378	Aug 24, 2011	48-h Chamber	10.0	Formaldehyde	ASTM D 5197
Sample 4	72-Hour	SA025397	Aug 25, 2011	72-h Chamber	10.0	Formaldehyde	ASTM D 5197
Sample 4	168-Hour	SA025433	Aug 29, 2011	168-h Chamber	10.0	Formaldehyde	ASTM D 5197
Sample 5	3-Hour	SA025330	Aug 22, 2011	3-h Chamber	2.0	Formaldehyde	ASTM D 5197
Sample 5	5-Hour	SA025335	Aug 22, 2011	5-h Chamber	5.0	Formaldehyde	ASTM D 5197
Sample 5	8-Hour	SA025340	Aug 22, 2011	8-h Chamber	5.0	Formaldehyde	ASTM D 5197
Sample 5	24-Hour	SA025363	Aug 23, 2011	24-h Chamber	20.0	Formaldehyde	ASTM D 5197
Sample 5	48-Hour	SA025379	Aug 24, 2011	48-h Chamber	54.0	Formaldehyde	ASTM D 5197
Sample 5	72-Hour	SA025398	Aug 25, 2011	72-h Chamber	54.0	Formaldehyde	ASTM D 5197
Sample 5	168-Hour	SA025434	Aug 29, 2011	168-h Chamber	54.0	Formaldehyde	ASTM D 5197

Table 6. Chamber air sample data; continued

Product	Sample Name	Sample No.	Date Collected	Description	Vol. (L)	Analysis Type	Specified Method
Sample 6	3-Hour	SA025331	Aug 22, 2011	3-h Chamber	1.0	Formaldehyde	ASTM D 5197
Sample 6	5-Hour	SA025336	Aug 22, 2011	5-h Chamber	1.0	Formaldehyde	ASTM D 5197
Sample 6	8-Hour	SA025341	Aug 22, 2011	8-h Chamber	1.0	Formaldehyde	ASTM D 5197
Sample 6	24-Hour	SA025364	Aug 23, 2011	24-h Chamber	5.0	Formaldehyde	ASTM D 5197
Sample 6	48-Hour	SA025380	Aug 24, 2011	48-h Chamber	10.0	Formaldehyde	ASTM D 5197
Sample 6	72-Hour	SA025399	Aug 25, 2011	72-h Chamber	10.0	Formaldehyde	ASTM D 5197
Sample 6	168-Hour	SA025435	Aug 29, 2011	168-h Chamber	10.0	Formaldehyde	ASTM D 5197

Table 7. Air sample analysis data

Product	Sample Name	Sample No.	Method	Date Analyzed	Analyst	Data File
Sample 3	3-Hour	SA025328	ASTM D 5197	Aug 22, 2011	R. Gill	110823_A\006-0601.D
Sample 3	5-Hour	SA025333	ASTM D 5197	Aug 22, 2011	R. Gill	110823_A\014-1401.D
Sample 3	8-Hour	SA025338	ASTM D 5197	Aug 22, 2011	R. Gill	110823_A\011-1101.D
Sample 3	24-Hour	SA025361	ASTM D 5197	Aug 23, 2011	R. Gill	110823_A\017-1701.D
Sample 3	48-Hour	SA025377	ASTM D 5197	Aug 24, 2011	R. Gill	110824_A\010-1001.D
Sample 3	72-Hour	SA025396	ASTM D 5197	Aug 25, 2011	R. Gill	110825_A\004-0401.D
Sample 3	168-Hour	SA025432	ASTM D 5197	Aug 29, 2011	R. Gill	110830_A\002-0201.D
Sample 4	3-Hour	SA025329	ASTM D 5197	Aug 22, 2011	R. Gill	110823_A\005-0501.D
Sample 4	5-Hour	SA025334	ASTM D 5197	Aug 22, 2011	R. Gill	110823_A\010-1001.D
Sample 4	8-Hour	SA025339	ASTM D 5197	Aug 22, 2011	R. Gill	110823_A\012-1201.D
Sample 4	24-Hour	SA025362	ASTM D 5197	Aug 23, 2011	R. Gill	110823_A\018-1801.D
Sample 4	48-Hour	SA025378	ASTM D 5197	Aug 24, 2011	R. Gill	110824_A\011-1101.D
Sample 4	72-Hour	SA025397	ASTM D 5197	Aug 25, 2011	R. Gill	110825_A\005-0501.D
Sample 4	168-Hour	SA025433	ASTM D 5197	Aug 29, 2011	R. Gill	110830_A\003-0301.D

Table 7. Air sample analysis data; continued

Product	Sample Name	Sample No.	Method	Date Analyzed	Analyst	Data File
Sample 5	3-Hour	SA025330	ASTM D 5197	Aug 22, 2011	R. Gill	110823_A\013-1301.D
Sample 5	5-Hour	SA025335	ASTM D 5197	Aug 22, 2011	R. Gill	110823_A\015-1501.D
Sample 5	8-Hour	SA025340	ASTM D 5197	Aug 22, 2011	R. Gill	110823_A\016-1601.D
Sample 5	24-Hour	SA025363	ASTM D 5197	Aug 23, 2011	R. Gill	110823_A\019-1901.D
Sample 5	48-Hour	SA025379	ASTM D 5197	Aug 24, 2011	R. Gill	110824_A\012-1201.D
Sample 5	72-Hour	SA025398	ASTM D 5197	Aug 25, 2011	R. Gill	110825_A\006-0601.D
Sample 5	168-Hour	SA025434	ASTM D 5197	Aug 29, 2011	R. Gill	110830_A\004-0401.D
Sample 6	3-Hour	SA025331	ASTM D 5197	Aug 22, 2011	R. Gill	110823_A\007-0701.D
Sample 6	5-Hour	SA025336	ASTM D 5197	Aug 22, 2011	R. Gill	110823_A\009-0901.D
Sample 6	8-Hour	SA025341	ASTM D 5197	Aug 22, 2011	R. Gill	110823_A\008-0801.D
Sample 6	24-Hour	SA025364	ASTM D 5197	Aug 23, 2011	R. Gill	110823_A\020-2001.D
Sample 6	48-Hour	SA025380	ASTM D 5197	Aug 24, 2011	R. Gill	110824_A\013-1301.D
Sample 6	72-Hour	SA025399	ASTM D 5197	Aug 25, 2011	R. Gill	110825_A\007-0701.D
Sample 6	168-Hour	SA025435	ASTM D 5197	Aug 29, 2011	R. Gill	110830_A\005-0501.D

Project Specific Information

The customer delivered four wood coating product samples to the laboratory. The four products are identified in Table 1. The Sample 3, Sample 5 and Sample 6 conversion varnish are two-component products and were mixed according to manufacturer's specified ratio immediately prior to the test. The Sample 4 product was pre-catalyzed. The products were applied by brush to a stainless steel plates. The coated area for each product was 17.5 cm x 17.5 cm (0.313 m^2). The target product loadings were determined based on the manufacturers' specifications. For Sample 3, the manufacturer specified a coverage of 580 ± 10 square feet per gallon and a product density of 10.04 ± .02 pounds per gallon. This produced a target mass of 2.65 g and a target coverage of 84.7 g/m2. For Sample 4, the manufacturer specified a coverage of 290 square feet per gallon and a product density of 7.6 pounds per gallon. This produced a target mass of 4.01 g and a target coverage of 128 g/m^2. For Sample 5, the manufacturer specified a coverage of 497 square feet per gallon and a product density of 10.61 pounds per gallon. This produced a target mass of 3.26 g and a target coverage of 104 g/m^2. For the Sample 6 product, the manufacturer specified a coverage of 503 square feet per gallon and a product density of 8.55 pounds per gallon. This produced a target mass of 2.60 g and a target coverage of 83.1 g/m^2. The actual values achieved in the tests are shown in Tables 2 – 5.

The chamber tests were conducted in small-scale chambers (0.067 m^3) following ASTM standard D 5116-10 at conditions of 1 air change rate per hour, 23^o C average temperature, and 50% relative humidity (Tables 2 – 5). Air samples for the analysis of formaldehyde were periodically collected from the chamber exhausts over an interval of 3-h (three full chamber air changes) to 168-h elapsed time. Sampling flow rates were regulated by electronic mass-flow controllers. Sampling volumes were adjusted to match anticipated chamber concentrations. The sampling information is given in Table 6. The samples were collected on XpoSure Aldehyde Samplers (Waters Corp.). The samples were analyzed for formaldehyde by high-performance liquid chromatography (HPLC) following ASTM standard D 5197-09. The sample analysis information is given in Table 7.

The chamber formaldehyde concentrations and calculated instantaneous emission factors (Equation 1) are presented in Results, Table 8. The emission factor data are plotted versus elapsed time in hours in Figures 1 – 8. A power-law curve function was fit to the emission factor data using the MS Excel 2003 power-law function. The coefficient of determination (r^2) for the curve fitting routine was 0.93 or better, demonstrating good fit to the data. The definite integral (Equation 2) was used to find the area under the curve bounded by the two given 'x' values, 3 h and 168 h. This area is called the 'area under the curve', which is the formaldehyde mass emission per gram of product (mg/g) or per square meter of applied surface area (mg/m^2). The results are presented in Results, Table 9.

Equations

Equations Used in Calculations – An area-specific emission factor (EF_A) in mg/m^2-h at steady-state conditions for a chemical emitted by a building product in a chamber test is calculated using Equation 1:

$$EF_A = (Q_c\,(C - C_o)) / A_S \qquad (1)$$

where Q_c is the chamber inlet air flow rate (m^3/h), C is the VOC chamber concentration (mg/m^3), C_O is the corresponding chamber background VOC concentration (mg/m^3), and A_S is the tested specimen exposed area (m^2). A mass-specific emission factor (EF_M) is calculated in the same manner using the mass of the tested specimen in grams instead of the area of the tested specimen. In this case, the mass is the mass of the wet applied product (Tables 2 – 5).

The calculation of formaldehyde mass emissions over the 165-h interval in mg/g for the specimen of the Sample 3 product is given in Equation 2 as an example of the integration procedure.

$$Area = \int_3^{168}\left(0.8357x^{-0.9587}\right)dx = 0.8357\times\left(\frac{x^{-0.9587+1}}{-0.9587+1}\right)\Bigg|_3^{168}$$

$$= 0.8357\left[\left(\frac{168^{-0.9587+1}}{-0.9587+1}\right)-\left(\frac{3^{-0.9587+1}}{-0.9587+1}\right)\right] = 3.8297 mg/g \qquad (2)$$

Results

Table 8. Formaldehyde concentrations and calculated emission factors - product mass-specific and applied area-specific

Product	Sample Name	Volume (L)	Mass (ng)	Conc (mg/m^3)	Emission Factor (mg/g-h)	Emission Factor (mg/m^2-h)
Sample 3	3-Hour	1.0	11,137	11.137	0.2859	23.8396
Sample 3	5-Hour	1.0	8,482	8.482	0.2177	18.1564
Sample 3	8-Hour	2.0	8,219	4.110	0.1055	8.7967
Sample 3	24-Hour	5.0	6,662	1.332	0.0342	2.8521
Sample 3	48-Hour	10.0	7,208	0.721	0.0185	1.5429
Sample 3	72-Hour	10.0	5,585	0.559	0.0143	1.1955
Sample 3	168-Hour	10.0	2,678	0.268	0.0069	0.5732
Sample 4	3-Hour	1.0	18,752	18.752	0.2956	40.1401
Sample 4	5-Hour	1.0	7,765	7.765	0.1224	16.6216
Sample 4	8-Hour	2.0	7,301	3.650	0.0575	7.8142
Sample 4	24-Hour	5.0	8,310	1.662	0.0262	3.5576
Sample 4	48-Hour	10.0	11,221	1.122	0.0177	2.4019
Sample 4	72-Hour	10.0	8,676	0.868	0.0137	1.8572
Sample 4	168-Hour	10.0	4,482	0.448	0.0071	0.9594
Sample 5	3-Hour	2.0	905	0.453	0.0116	0.9686
Sample 5	5-Hour	5.0	1,108	0.222	0.0057	0.4744
Sample 5	8-Hour	5.0	892	0.178	0.0046	0.3819
Sample 5	24-Hour	20.0	2,415	0.121	0.0031	0.2585
Sample 5	48-Hour	54.0	5,369	0.099	0.0026	0.2128
Sample 5	72-Hour	54.0	4,539	0.084	0.0022	0.1799
Sample 5	168-Hour	54.0	3,261	0.060	0.0016	0.1293

Table 8. Formaldehyde concentrations and calculated emission factors – product mass-specific and applied area-specific; continued

Product	Sample Name	Volume (L)	Mass (ng)	Conc (mg/m^3)	Emission Factor (mg/g-h)	Emission Factor (mg/m^2-h)
Sample 6	3-Hour	1.0	44,593	44.593	1.1447	95.4547
Sample 6	5-Hour	1.0	27,138	27.138	0.6966	58.0909
Sample 6	8-Hour	1.0	14,448	14.448	0.3709	30.9270
Sample 6	24-Hour	5.0	20,267	4.053	0.1041	8.6766
Sample 6	48-Hour	10.0	20,198	2.020	0.0518	4.3235
Sample 6	72-Hour	10.0	13,557	1.356	0.0348	2.9020
Sample 6	168-Hour	10.0	6,909	0.691	0.0177	1.4789

Table 9. Power law curve fit equations and estimated mass emissions of formaldehyde over 3 hour to 168 hour exposure period calculated as mass of formaldehyde emitted per gram of product and per square meter of applied surface area

Product Name	Power Law Curve Fit 3 to 168 hours EF (mg/g-h vs. h)	Power Law Curve Fit 3 to 168 hours EF (mg/m^2-h vs. h)	Σ Mass Emissions (mg/g)	Σ Mass Emissions (mg/m^2)
Sample 3	$y = 0.8357x^{-0.9587}$	$y = 69.685x^{-0.9587}$	3.83	319
Sample 4	$y = 0.5081x^{-0.8643}$	$y = 68.988x^{-0.8643}$	3.16	429
Sample 5	$y = 0.0137x^{-0.4396}$	$y = 1.1427x^{-0.4396}$	0.387	32.2
Sample 6	$y = 3.524x^{-1.0664}$	$y = 293.85x^{-1.0664}$	11.6	965

Results

Figure 1. Product mass-specific emissions of formaldehyde versus time (mg/g-h) for Sample 3

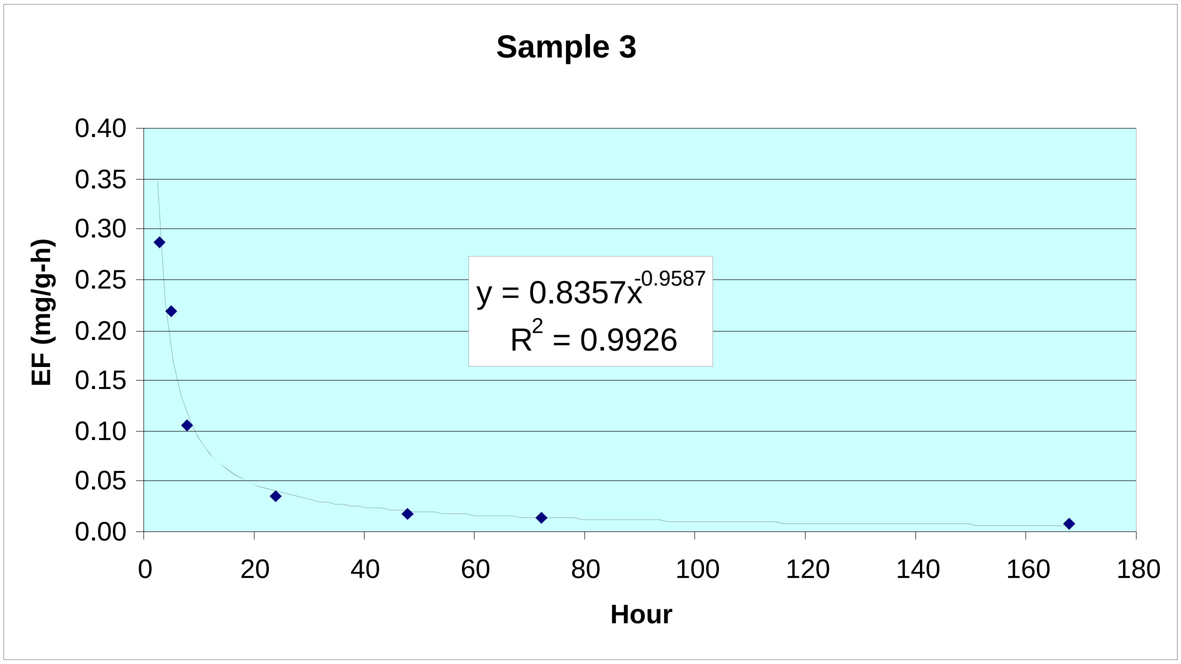
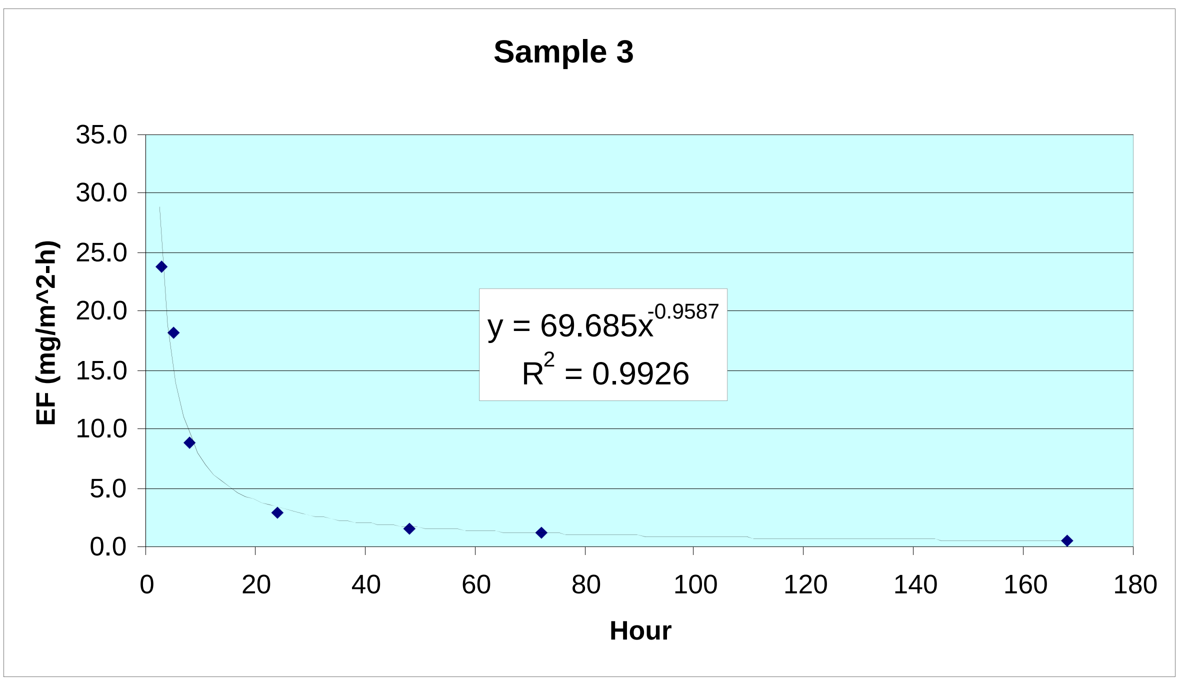


Figure 2. Product mass-specific emissions of formaldehyde versus time (mg/m^2-h) for Sample 3



Results

Figure 3. Product mass-specific emissions of formaldehyde versus time (mg/g-h) for Sample 4

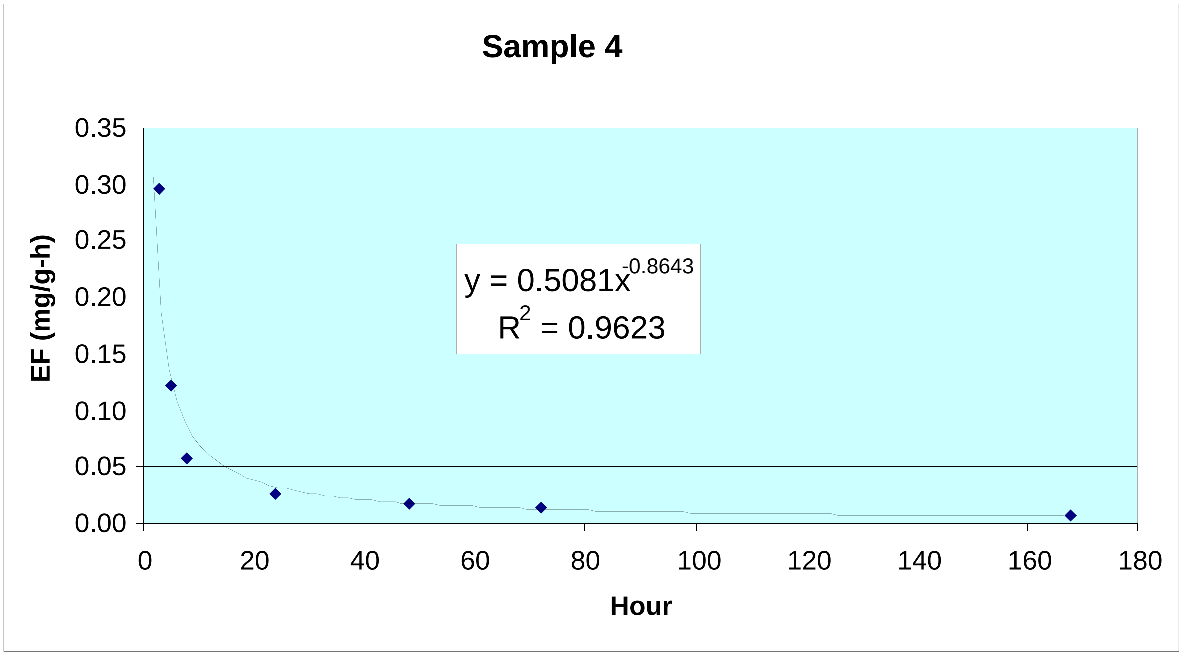
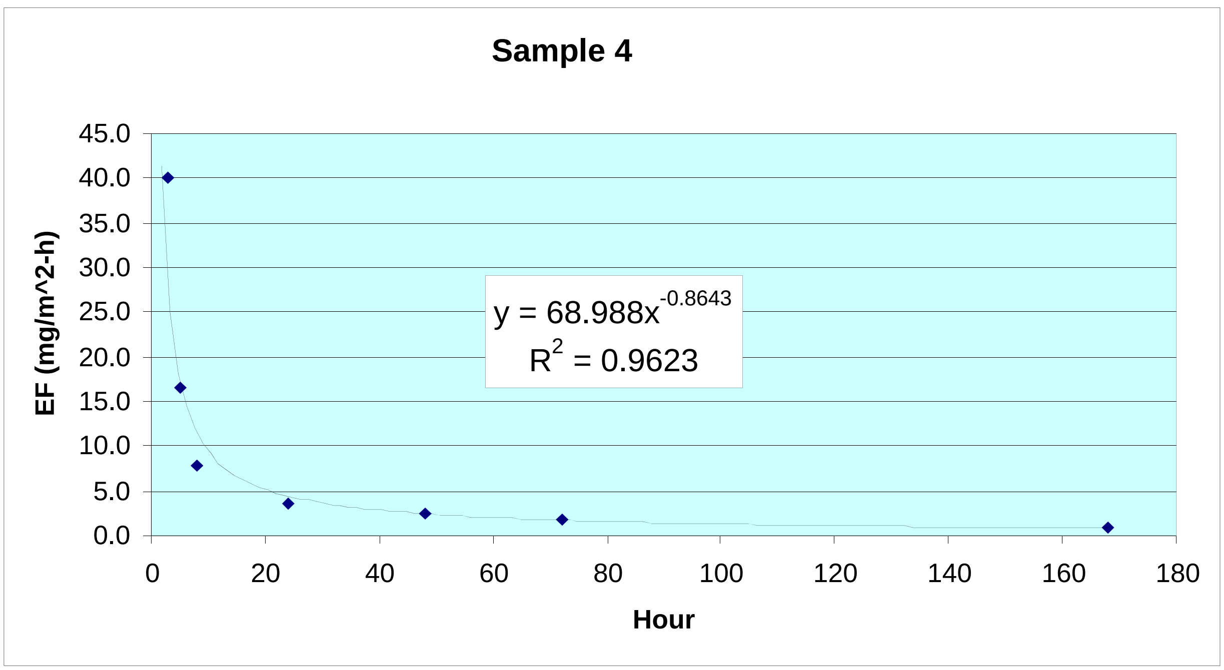


Figure 4. Applied area-specific emissions of formaldehyde versus time (mg/ m^2-h) for Sample 4



Results

Figure 5. Product mass-specific emissions of formaldehyde versus time (mg/g-h) for Sample 5

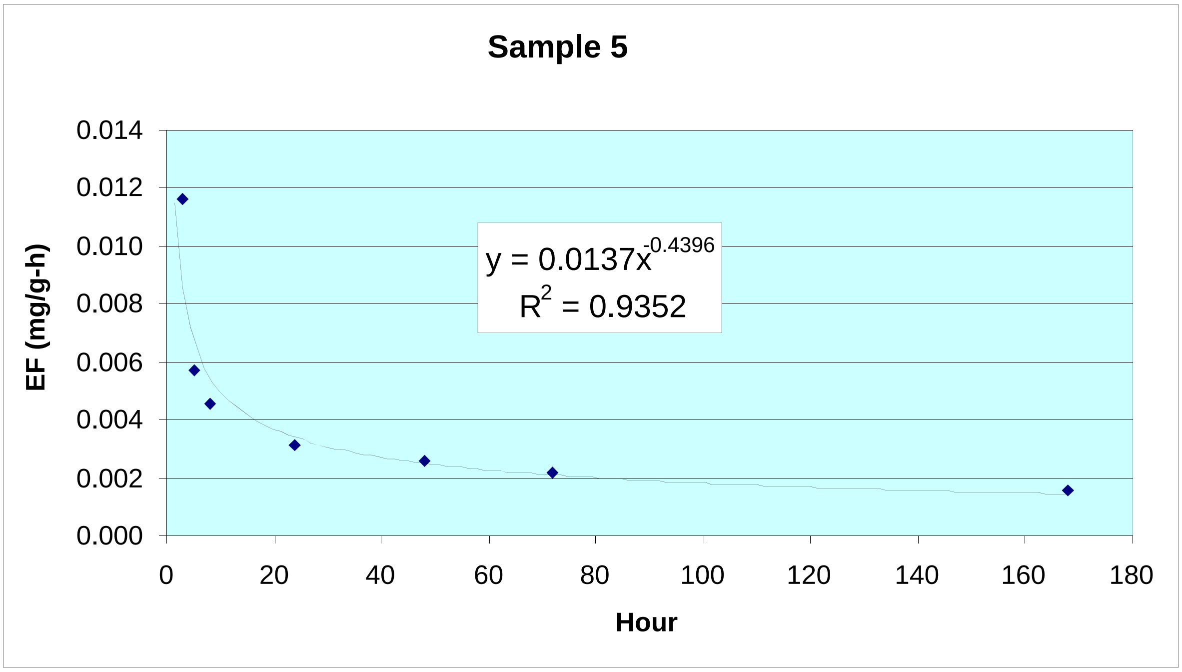
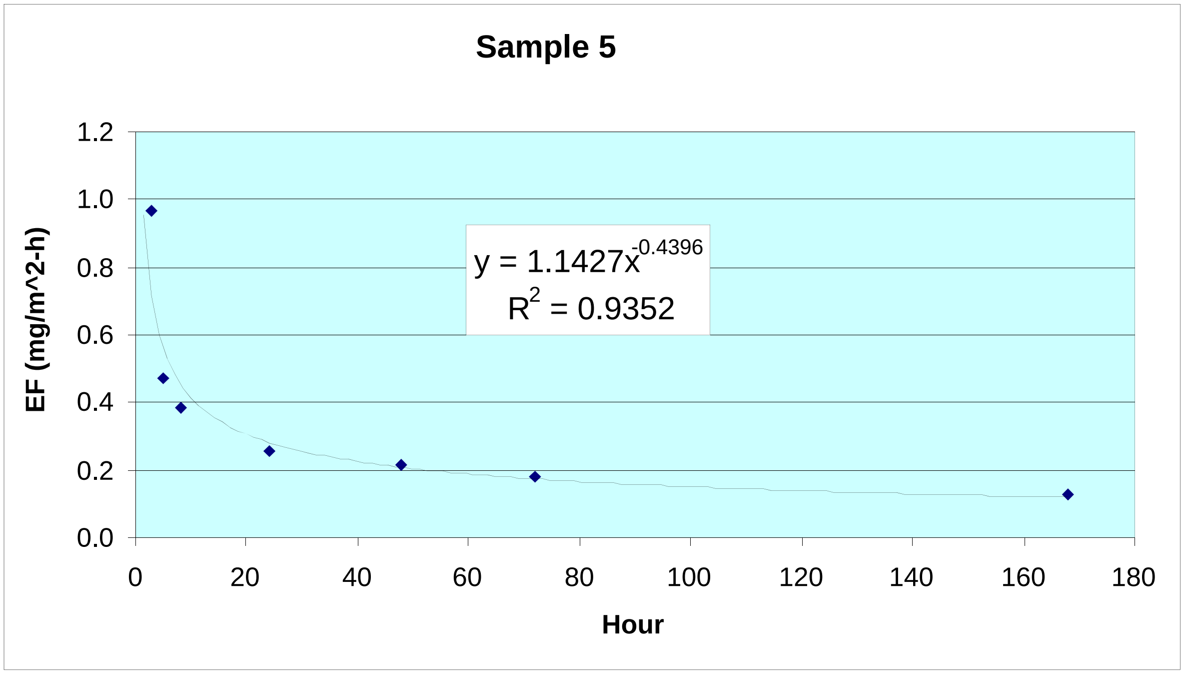


Figure 6. Applied area-specific emissions of formaldehyde versus time (mg/ m^2-h) for Sample 5



Results

Figure 7. Product mass-specific emissions of formaldehyde versus time (mg/g-h) for Sample 6

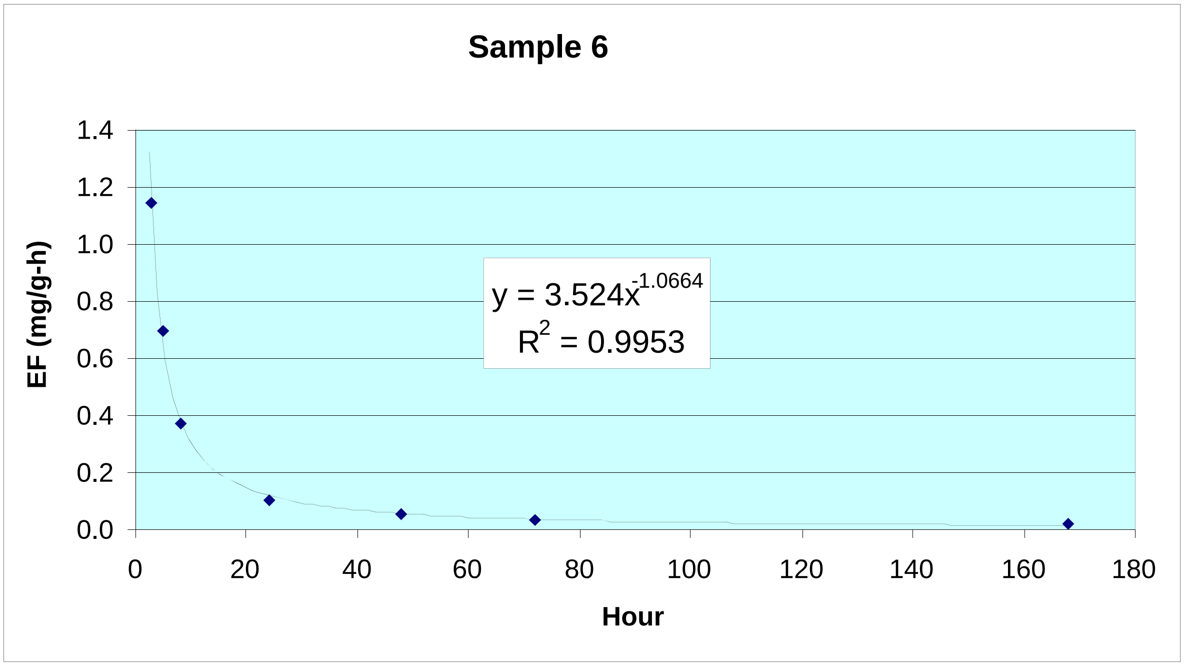
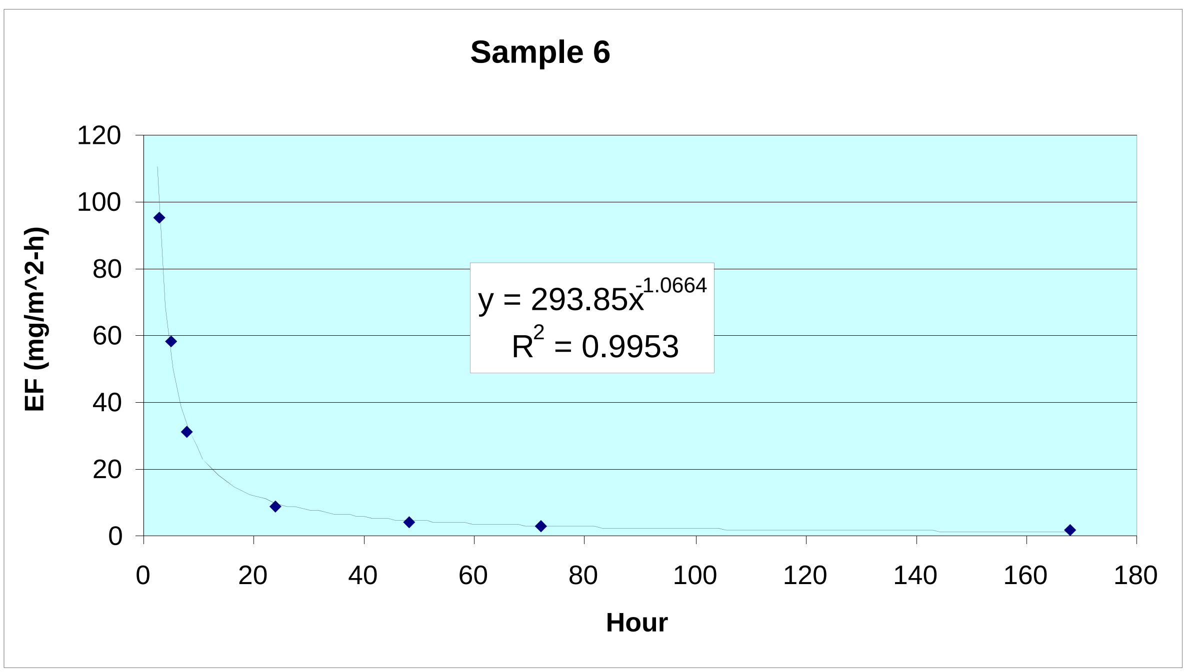


Figure 8. Applied area-specific emissions of formaldehyde versus time (mg/ m^2-h) for Sample 6



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