

American Composites Manufacturers Association

Gel Coat Screening Emissions Test

Low Atomized Gel Coat Application (LAGA)

Test Method 25A

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1. Introduction

1.1. **Background** – The initial development of composites open molding emissions factors took place in the form of a series of test programs conducted by the Composites Fabricators Association (CFA) at the Dow Chemical facility in Freeport, Texas. These tests are documented in the *“Phase I – Baseline Study – Hand Lay-up, Gel Coating, Spray-up”* report issued in 1996. In conjunction with the CFA studies, the National Marine Manufacturers Association (NMMA) conducted testing described in *“Baseline Characterization of Emissions from Fiberglass Boat Manufacturing”* in 1997. The data from the two test programs was merged forming the basis for the Unified Emissions Factors (UEF) emissions model. The UEF model is widely used as the basis for emissions reporting and the emissions factors in both the Reinforced Plastic Composites and Boatbuilding NESHAP’s, also known as MACT Standards.

The 1996 *Phase I – Baseline Study* includes the use of air-assisted airless (AAA) spray gun technology for resin and gel coat application. These atomized spray guns were considered state-of-the-art technology at the time. Flow coaters were a developing technology for resin application, but not refined to the point of being adaptable for gel coat application.

By the year 2001 spray gun manufacturers began to offer the first-generation of equipment described as being suitable for “non-atomized” application of gel coat. Emissions from this equipment were quantified at Purdue University – Clean Manufacturing Technology Institute (CMTI) through an ACMA sponsored test project. These data were added to the Unified Emissions Factors as “Gel Coat Non-Atomized Application” based on the performance of the spray guns tested in 2001. This equipment featured internal-mix initiator delivery and a low-pressure spray pattern mechanically formed by the geometry of the fluid orifice.

The subsequent evolution of spray equipment design has been driven by production demands and increasing requirements for a uniform gel coat film on the mold surface. By the year 2007 spray gun manufacturers were offering the next generation of gel coat application equipment designed to meet production requirements. This equipment uses external-mix initiator delivery and the introduction of “shaping air” to form a more controllable spray pattern as compared to the first generation technology.

The advent of these new spray gun designs has created a new class of application equipment that is not accurately characterized by either the atomized or the non-atomized gel coat emissions factors. The term “Low Atomization Gelcoat Application” (LAGA) is the descriptor used to characterize the performance of this current generation of equipment.

1.2. **Stated Purpose** – The need has been identified to develop emissions data for Low Atomization Gelcoat Application (LAGA). This test program is designed to provide a performance assessment of current application equipment with a selection of available gel coat formulations. The factors or emissions guidance developed with this test data will allow open molders to derive more accurate and enforceable emission estimates for gel coat application using currently available equipment and gel coat formulations.

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This program is designed to provide emissions data to supplement the existing *UEF Non-Atomized and Atomized* emissions factors. It is hypothesized that current combinations of “non-atomized” spray equipment and gel coat formulations, when set-up to produce acceptable quality, are producing emissions that fall between the UEF non-atomized and atomized factors. The purpose of this test is to determine the emissions rates from four different spray guns and with gel coat having three styrene-monomer levels. The emissions measurements will be made using Method 25A and the full scale test mold application following the ACMA emissions test protocol at the Purdue CMTI/CARL laboratory facility. The results of this Screening Test will be used to provide guidance to molders on determining and reporting emissions from the use of low atomized application equipment.

The gel coat formulations used in this test program were selected by a group of gel coat suppliers and chosen to represent widely used and currently available products. The spray equipment set-ups (i.e. orifice sizes, delivery rates, pressures, etc.) reflect actual scenarios used in production facilities and known to produce acceptable production quality.

The tested gel coat formulations contain only styrene monomer. Time and resource limits prevent testing of methyl methacrylate (MMA) containing gel coat as a part of this project. However, the resulting emissions factors and guidance should improve the accuracy of emissions estimates including estimates for MMA-containing gel coats. Currently the UEF accounts for a presumed 75% emissions loss of MMA. This may be an over-estimate, but protects molders from under-reporting emissions. At this time the need to develop specific MMA co-monomer emissions factors is not a regulatory priority.

The requirements in the MACT standard make it imperative that spray gun manufacturers provide emissions data and operating instructions for their equipment. In previous ACMA testing, specific equipment and/or material combinations were not identified by brand or manufacturer. In this case, the emissions data for each tested spray gun will be provided to the participating spray equipment manufacturer for release to their users. In the test report the individual spray gun data will be identified by an assigned designator or aggregated into emissions factors.

- 1.3. **Participating Spray Gun Equipment Suppliers** – The test program includes four currently available spray guns supplied by the following equipment manufacturers, listed in alphabetical order:

Manufacturer	Spray Gun Model
GlasCraft, Inc.	Formula – External Mix
GS Manufacturing, Inc.	X-Gun
ITW Binks Div.	Century LEL
Magnum Venus Plastech, Inc.	ATG 3500

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The individual test results from a specific spray gun model are available directly from the supplier of the spray equipment. For the purposes of this report, and to avoid potential commercial implications, the data for the individual spray guns will be designated as alpha, beta, gamma, and delta or aggregated into emissions data points.

- 1.4. **Test Method** - Method 25A uses a Total Hydrocarbon Analyzer/Flame Ionizing Detector (FID) to measure non-specified VOC emissions. Used in conjunction with the *ACMA Emissions Test Protocol – Revision 2.2b¹*, this quantification method has been very successful in measuring single monomer (styrene-only) emissions. The Total Hydrocarbon Analyzer is calibrated using a propane standard and applying a conversion ratio for styrene.
- 1.5. **Gel Coat Selection** – A committee of gel coat manufacturers met to determine the range and type of unsaturated polyester gel coats to be included in the tests. The consensus of the Committee was to include the following formulations in the test design. These gel coats represent widely used formulations processed by the composites open molding industry and deemed to be representative of a broad spectrum of products used in production plants. It was determined that the white low styrene formulation was typically heated to 90-100⁰F in production, whereas the black and clear formulations are most commonly used at room temperature.

- White – 30.49% Styrene
- Black – 36.32% Styrene
- Clear – 44.00% Styrene

Table 1

Gel Coat Specifications - Batch Certificate of Analysis			
Gel Coat Type	White	Black	Clear
Styrene %	30.49%	36.32%	44.00%
Weight per Gallon	11.10	10.05	9.00
Viscosity	RV#4@2 – 23,800 cps RV#4@20 – 4,200 cps	LV#4@6 – 16,500 cps	#3@6 – 11,000 cps #3@60 – 1,900 cps
Thix Index	5.60	5.61	5.80
Gel Time	1.50% HP-90 12.0 min	1.80% HP-90 11.3 min	2.00% HP 90 10.0 min
Gel to Peak	10.0 min	-	12.0 min
Peak Exotherm	336 ⁰ F	-	406 ⁰ F

- 1.6. **Processing Method** – Spray delivery was used to apply the selected gel coats to the standard ACMA test mold. The application method consisted of applying a specific weight of gel coat to the mold surface, with a target application weight of 2250 grams (4.96 lbs). The application consisted of three passes (wet-on-wet) across the mold surface. Gel coat film thickness was variable based on the gel coat system density.

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1.6.1. Spray Gun Set-Up – Prior to the commencement of the project at the CMTI/CARL lab each participating equipment supplier received batches of the gel coats to be tested. It was requested that they poll their customers using similar materials to determine the range of spray gun set-ups used in the field. Based on this feedback, the suppliers “pre-tested” their equipment using the representative field configurations as reported by industry users. These spray gun configurations consisted of fluid tip orifice size, spray tip angle, fluid pressure, shaping air pressure, flow rate, and material temperature. The white gel coat was heated to 90-100°F using a in-line heater located at the gel coat pump. The black and clear were applied at ~70°F specified as ambient temperature.

1.6.2. Spray Equipment Calibration

The spraying system was calibrated according to the ACMA Spray Gun Pressure Calibration method. This consists of selecting a fluid tip of the appropriate orifice size and pattern width, and then progressively increasing the fluid pressure until the optimal spray pattern is established. As the fluid pressure is incrementally increased from an initial columnar stream the state of the spray pattern is recorded as; under-developed, partially-developed, fully-developed, or over-developed. Once the fluid pressure range is established the gel coat and initiator flow rates and percentages are determined.

For this test project configuring the equipment for optimized laboratory conditions was avoided. Rather than setting fluid pressures to the low-end of the optimized range they were set toward the higher end of the range to while producing an acceptable spray pattern. The set-up of the spray equipment duplicated equipment configurations reported in actual production plants.

1.6.3. Spray Application Technique

The spray gun handling technique used for gel coat application during this test was semi-controlled spraying. In terms of application techniques there are two methods found in the field: 1) *Uncontrolled Spraying* is a method where the molds do not have extended flanges and the operator sprays off the edges of the mold on a routine basis. The operator also holds the spray gun at various angles to the mold surface according to the geometry of the application surface. 2) *Controlled Spraying* entails the use of extended flanges around the mold perimeter and the operator maintains the gel coat “wet-line” within the flanges. The operator also maintains the spray pattern angle as closely to 90° to the surface as possible.

The semi-controlled spraying technique employed for these test runs used a mold with extended flanges. However, the operator produced a visually observable quantity of over-spray off the flanges without extending the full pattern width of the spray stroke off the mold edge. The operator also sprayed at angles varying from 30° to 90° to the mold surface as the geometry of the mold dictated, and at a distance from the mold as might commonly be found in a production operation.

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The gel coat was applied in three sequential wet-on-wet passes on each panel of the mold surface. The spray operator was fitted with a communications earpiece with a laboratory technician directing a uniform weight distribution of the gel coat across the mold surface. Following the application of gel coat a wet film gauge was used to record the applied gel coat thickness.

- 1.7. **Test Facility** – Testing was conducted at Purdue University, Clean Manufacturing Technology Institute (CMTI) in the Coatings Application Research Laboratory (CARL Lab). The CARL Lab uses Method 25A with the ACMA Styrene Emissions Test Protocol in a calibrated test enclosure and has a considerable history in successfully quantifying styrene emissions. The lab typically uses Method 25A, employing a THA/FID to measure stack concentrations of emissions. Styrene recovery rates for Method 25A were measured in the 98 -101% range providing a high confidence level in recovery capability.
- 1.8. **Experimental Design** – Constant factors included weight of material applied, adjusted gel coat gel times, mold surface area, and ambient temperature. Experimental variables include; spray gun model, gel coat type, and gel coat temperature. [Note: Gel coat temperatures are based on the black and clear formulations reported as used in the field at ambient temperature and the white low-styrene formulation being used at elevated temperature.]

Table 2

Experimental Design		
Spray Gun	Gel Coat Formulation / HAP Content	Gel Coat Temperature
Alpha	White - Low	100 ⁰ F
Alpha	White - Low	100 ⁰ F
Alpha	White - Low	100 ⁰ F
Alpha	Black - Mid	70 ⁰ F
Alpha	Black - Mid	70 ⁰ F
Alpha	Black - Mid	70 ⁰ F
Alpha	Clear - High	70 ⁰ F
Alpha	Clear - High	70 ⁰ F
Alpha	Clear - High	70 ⁰ F
Beta	White - Low	100 ⁰ F
Beta	White - Low	100 ⁰ F
Beta	White - Low	100 ⁰ F
Beta	Black - Mid	70 ⁰ F
Beta	Black - Mid	70 ⁰ F
Beta	Black - Mid	70 ⁰ F
Beta	Clear - High	70 ⁰ F
Beta	Clear - High	70 ⁰ F
Beta	Clear - High	70 ⁰ F

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Gamma	White - Low	100 ⁰ F
Gamma	White - Low	100 ⁰ F
Gamma	White - Low	100 ⁰ F
Gamma	Black - Mid	70 ⁰ F
Gamma	Black - Mid	70 ⁰ F
Gamma	Black - Mid	70 ⁰ F
Gamma	Clear - High	70 ⁰ F
Gamma	Clear - High	70 ⁰ F
Gamma	Clear - High	70 ⁰ F
Delta	White - Low	100 ⁰ F
Delta	White - Low	100 ⁰ F
Delta	White - Low	100 ⁰ F
Delta	Black - Mid	70 ⁰ F
Delta	Black - Mid	70 ⁰ F
Delta	Black - Mid	70 ⁰ F
Delta	Clear - High	70 ⁰ F
Delta	Clear - High	70 ⁰ F
Delta	Clear - High	70 ⁰ F

2. Validation of Test Lab Set-up and Analytical Equipment

2.1. **Styrene Capture Efficiency** – A known quantity of styrene was evaporated in the Method 204 temporary total enclosure. The recovery indicates the air capture efficiency of the test chamber/stack, air flow measurements in the stack, and the accuracy of the total hydrocarbon analyzer propane/styrene conversion ratio. The styrene recovery range of 98.0% to 101.0% demonstrates very high capture efficiency and validates the function of the laboratory analytical system.

Table 3 – Styrene Recovery Check

Test	Purpose	Result
Pre-Test 1	Styrene Recovery	98.0%
Pre-Test 2	Styrene Recovery	101.0%
	Average Recovery	99.5%

3. Spray Gun Configurations

3.1. The variables that comprise a spray gun configuration for the application of a specific material include:

- Orifice size
- Spray pattern angle (width)
- Pump ratio (Air to fluid pressure ratio)

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- Shaping air pressure
- Tip to target distance
- Required flow rate
- Gel coat rheological properties
- Gel coat temperature.

3.2. Spray gun set-ups were rigorously evaluated to determine configurations that: 1) Could be identified as set-ups used in actual production operations. 2) Produced delivery rates considered appropriate for the gel coat formulation. 3) Produced gel coat surface quality considered acceptable by production standards. Spray gun configurations as tested are detailed in Table 4.

Table 4
Spray Gun Configurations

White Gel Coat - 30.49% Styrene – 100 F				
Spray Gun Set-Up	Spray Gun Alpha	Spray Gun Beta	Spray Gun Gamma	Spray Gun Delta
Orifice Size (0.001")	0.021	0.021	0.021	0.022
Designated Tip Angle (degrees)	40	40	40	17
Pump Ratio	12:1	20:1	15:1	15:1
Pump Pressure (psi)	85	52	72	60
Tip Pressure (calc)	1020	1040	1080	900
Shaping Air Pressure (psi)	35	40	20	23
Tip to Target Distance (in)	18-24"	18-24"	18-24"	18-24"
Target Gel Coat Weight (g)	2250	2250	2250	2250

Black Gel Coat - 36.32% Styrene – 70 F				
Spray Gun Set-Up	Spray Gun Alpha	Spray Gun Beta	Spray Gun Gamma	Spray Gun Delta
Orifice Size (0.001")	0.021	0.018	0.019	0.022
Designated Tip Angle (degrees)	24	45	40	27
Pump Ratio	12:1	20:1	15:1	15:1
Pump Pressure (psi)	70	60	55	70
Tip Pressure (calc)	840	1200	825	1050
Shaping Air Pressure (psi)	30	30	20	24
Tip to Target Distance (in)	18-24"	18-24"	18-24"	18-24"
Target Gel Coat Weight (g)	2250	2250	2250	2250

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Clear Gel Coat - 44.00% Styrene – 70 F				
Spray Gun Set-Up	Spray Gun Alpha	Spray Gun Beta	Spray Gun Gamma	Spray Gun Delta
Orifice Size (0.001")	0.017	0.018	0.019	0.017
Designated Tip Angle (degrees)	24	25	40	22
Pump Ratio	12:1	20:1	15:1	15:1
Pump Pressure (psi)	45	32	50	50
Tip Pressure (calc)	540	640	750	750
Shaping Air Pressure (psi)	25	40	20	25
Tip to Target Distance (in)	18-24"	18-24"	18-24"	18-24"
Target Gel Coat Weight (g)	2250	2250	2250	2250

4. Effects of Gel Coat Formulation / Styrene Level on Emissions

4.1. Table 5 lists measured emissions from all spray guns within the three gel coat formulations tested.

Table 5

Emissions Measurements				
Data Point	Gel Coat Formulation	Styrene Content (% wt)	Gel Coat Application Temperature (°F)	Emissions (% Gel Coat Weight)
1	Clear	44.00	70	18.56%
2	Clear	44.00	70	17.56%
3	Clear	44.00	70	18.58%
4	Clear	44.00	70	19.52%
5	Clear	44.00	70	17.22%
6	Clear	44.00	70	16.01%
7	Clear	44.00	70	21.51%
8	Clear	44.00	70	20.15%
9	Clear	44.00	70	18.65%
10	Clear	44.00	70	16.34%
11	Clear	44.00	70	16.03%
12	Clear	44.00	70	16.64%
Clear 44.00% - Average Emissions				18.06%

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13	Black	36.32	70	12.80%
14	Black	36.32	70	12.19%
15	Black	36.32	70	12.26%
16	Black	36.32	70	14.26%
17	Black	36.32	70	12.76%
18	Black	36.32	70	12.94%
19	Black	36.32	70	14.32%
20	Black	36.32	70	13.34%
21	Black	36.32	70	13.36%
22	Black	36.32	70	12.78%
23	Black	36.32	70	12.12%
24	Black	36.32	70	12.11%
Black 36.32% - Average Emissions				12.94%
25	White	30.49	100	9.62%
26	White	30.49	100	9.79%
27	White	30.49	100	10.83%
28	White	30.49	100	10.29%
29	White	30.49	100	10.61%
30	White	30.49	100	10.50%
31	White	30.49	100	10.86%
32	White	30.49	100	10.57%
33	White	30.49	100	11.35%
34	White	30.49	100	9.41%
35	White	30.49	100	9.58%
36	White	30.49	100	9.38%
White 30.49% - Average Emissions				10.23%

5. Gel Coat Screening Test Results in Comparison to Unified Emissions Factors (UEF)

5.1. Table 6 compares average measured emissions with both the UEF non-atomized and atomized equation predictions. The difference between the measured emissions and UEF predictions is expressed as a percentage of the UEF.

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Table 6
Average Emissions Results

	White Gel Coat 30.49 % Styrene 100 F	Black Gel Coat 36.49% Styrene 70 F	Clear Gel Coat 44.00% Styrene 70 F
Percent Emissions (Gel Coat Weight)	10.23%	12.94%	18.06%
Non-Atomized UEF Prediction	8.70%	11.30%	14.80%
Measured % of Non-Atomized UEF	117.01%	114.49%	122.82%
Atomized UEF Prediction	13.60%	18.10%	26.10%
Measured % of Atomized UEF	74.85%	71.48%	69.65%

5.2. Table 7 plot depicts the UEF emissions curve for non-atomized, atomized, and LAGA application data range. The upper and lower bounds represent the 95% confidence interval of the mean curve. The vertical axis emissions are plotted as emissions as a percent of resin weight. The horizontal axis is resin percent of available styrene (resin styrene content).

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Table 7

Gel Coat Screening Test Results LAGA Emissions Range

