Non Atomized Gel Coat Comparison for Conformance Manual

Produced for MVP Equipment ONLY.

Results on Competitive Equipment will Vary

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The purpose of this manual is to provide a guide to recognizing the subtle, yet significant, differences in non-atomized gelcoat vs. atomized gelcoat.

HISTORY

Emission reduction

In recent years, the awareness among government organizations of the problems caused by styrene emissions both inside and outside the workshop has increased. The industry struggles through research to develop equipment that meets current standards and anticipates future regulations. Recent studies by the Clean Manufacturing Technology and Safe Materials Institute (CMTI) at Purdue University and the U.S. based Composites Fabricators Association (CFA) prove that FIT® technology (consisting of a low pressure pumping system, modular gun, combined with a unique nozzle and mix chamber) can significantly reduce styrene emissions.

Research has shown that styrene emissions can be increased by atomization created by high pressures at the gun and spray techniques previously thought acceptable. The use of flowcoat technology was found to significantly reduce styrene emissions for wet-out. When correctly used, flow coat technology, which does not atomize the resin, reduces VOC's during wetout because of the simple geometry of the resin flow.

A flow coat style nozzle provides continuous streams of catalyzed resin continuously flowing onto the open mold. These resin streams reach the mold intact without atomizing. A spray fan, unlike flowcoat, breaks into droplets and atomizes before reaching the mold surface. Most of the research on VOC's for spray is based on droplet size, and as the diameters of the resin droplets decrease, the overall surface area of the resin increases, which increases emission. In fact, if the "spray" droplets get too small, they don't even reach their target; they drift off as fumes into the atmosphere.

The FRP industry embraced the new FloCoat technology as a viable and cost effective means for reducing styrene emissions, however the individual linear streams proved to be challenging for filled resin systems. The difficulty of chopping glass into the resin streams required the operator to increase pump pressures to such a high level that the streams broke into droplets, producing atomization and misting. This high velocity creates a spray fan similar to airless spray techniques, therefore reducing the benefits of flow coating.

While flow coating worked well with unfilled resin, it did not work with filled systems as the fillers in the resin would plug the holes associated with a FloCoat nozzle. At this time, governmental agencies were demanding a reduction in the emission levels of filled resins applications. To reduce emissions in these applications meant an entirely new and radical technology would have to be developed. That technology was Fluid Impingement Technology (FIT®).

The FIT® System uses low-pressure impinging streams to break gelcoat into large droplets after mixing.

The unique 2-hole FIT® tip design creates a sheet when the two streams intersect. The sheet carries forward and breaks up into ligaments which then break up into large droplets.

Atomized Systems

Standard nozzles require excessive pressures to develop patterns. True low pressure fluid impingement produces patterns that are 50% wider at a fraction of the pressure with less overspray.

Competitive nozzles use 3 streams instead of 2 resulting in a loss of impingement energy at impingement point.

Why FIT® Gel?

Tests conducted at the Clean Manufacturing Technology and Safe Materials Institute at Purdue University consistently showed that FIT® Gelcoat reduced emission levels by as much as 50% compared with conventional spray technology.

Both FIT® and a conventional spray system were used to apply gelcoat to a CFA designed mold surface in an approximate thickness of 18 to 23 mils.

The testing showed that the FIT® Gelcoat System "adequately covered the mold flange with little requirement of overspray beyond the flange lip; whereas the conventional spray system required a 2 to 4 inch overspray to provide adequate flange coverage."

When the testing was complete, the conventional spray system had an average styrene concentration of 49 ppm, and the FIT® Gelcoat System average was 22 ppm. That is a reduction of more than half.

The data shows the use of the low-pressure FIT® Gelcoat System will drastically lower styrene emissions, and save materials.

FLUID PRESSURES

Pressure plays a key role in obtaining a proper non-atomized pattern.

Typical pumps use compressed air to generate spray pressure.

Gelcoat pumps can be 11:1, 15:1 or 20:1 ratio pumps. This means for every 1 psi (pound per square inch) you would get 11, 15 or 20 psi of pump pressure.

The pump then forces the gelcoat through the hose to the spray gun. While traveling through the hose there is significant loss of pressure due to friction called Line Loss or Pressure Drop.

The average gelcoat spray system loses about 4 psi per foot. The average spray system has 25 feet of hose which results in a 100 psi pressure drop (4 psi x 25 ft.) **See Figure 1 for Non-Atomized pressure drops, and Figure 1a for Atomized results.**

Figure 1 -
Non-Atomized

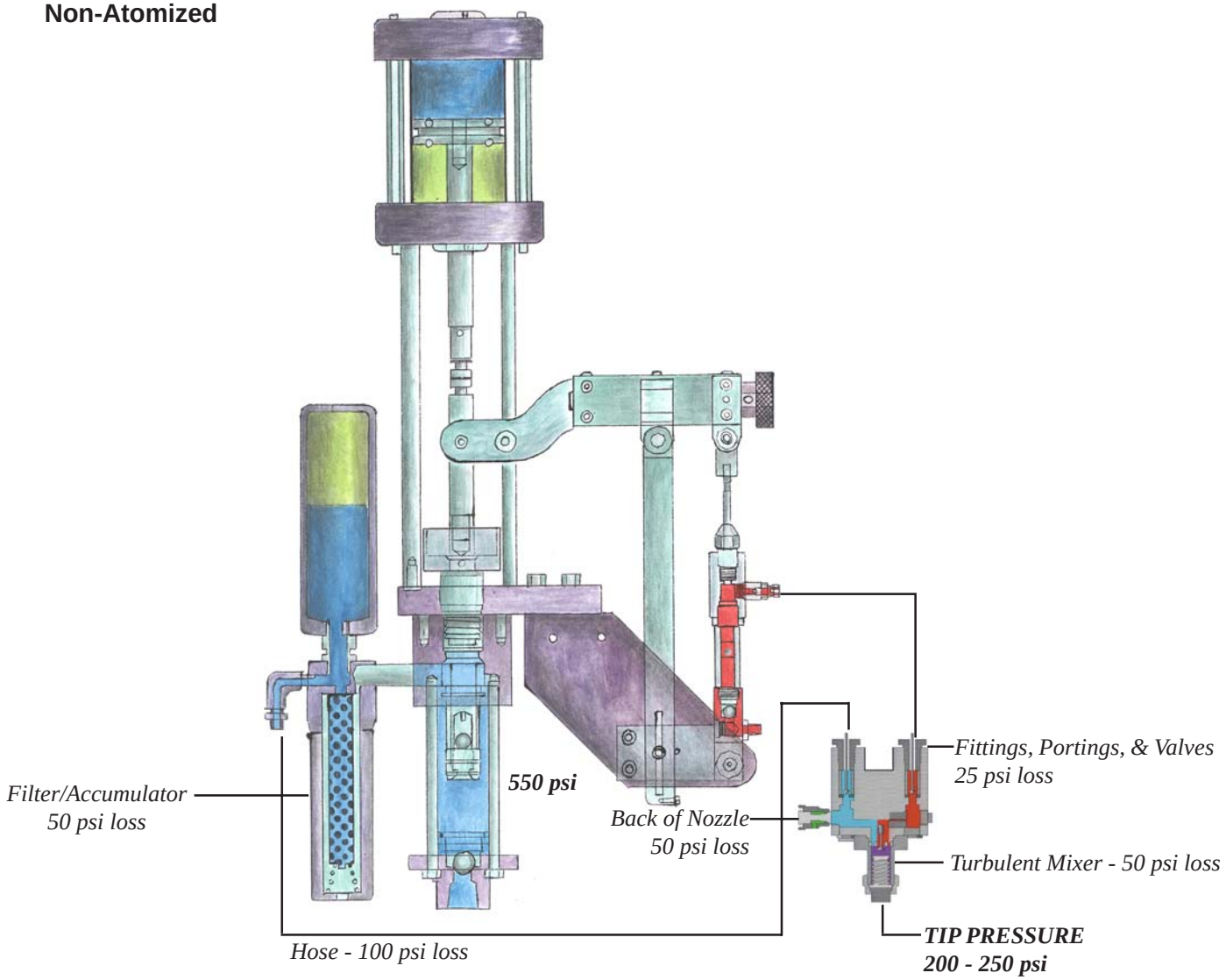
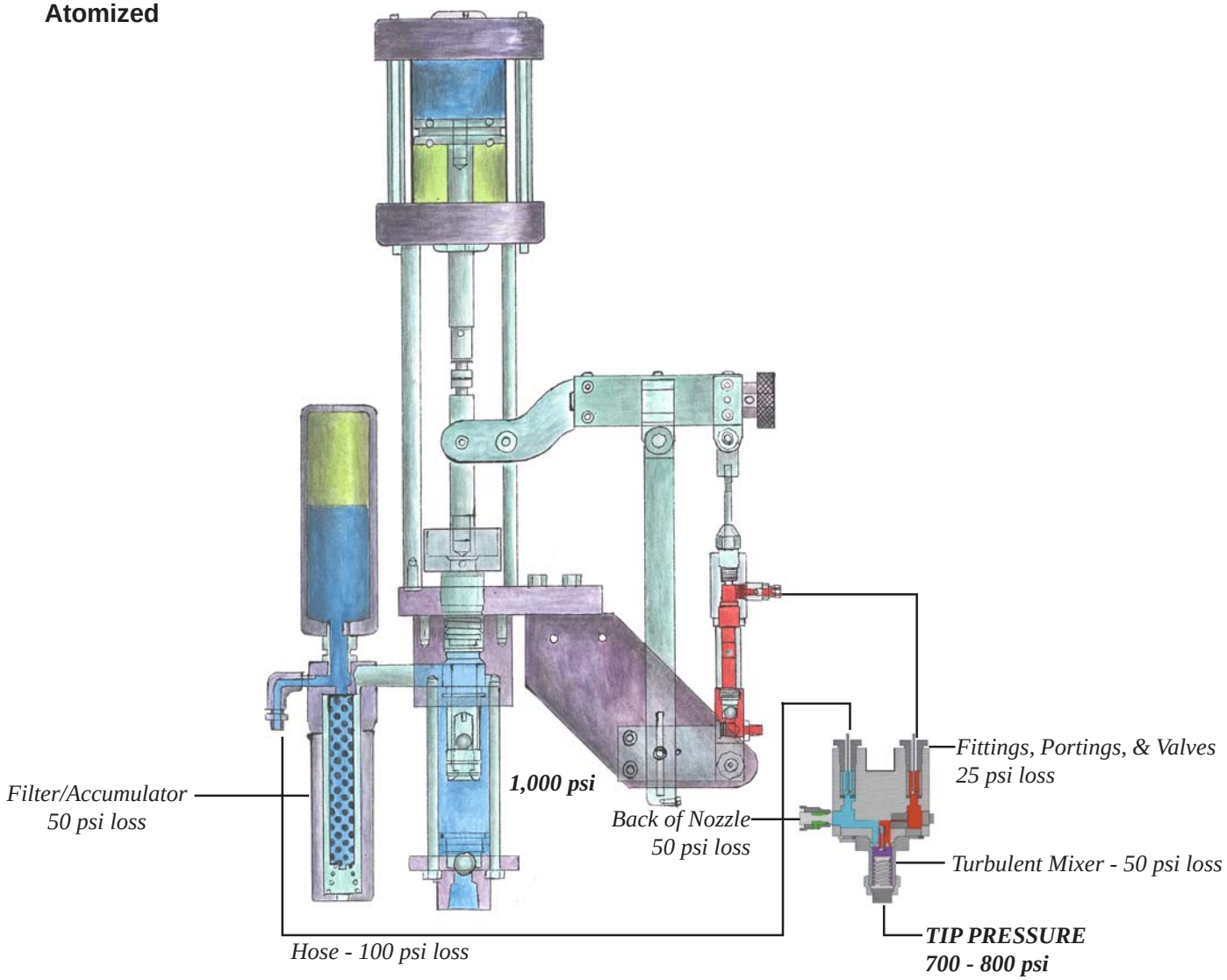


Figure 1a - Atomized



DROPLET SIZE COMPARISON

The atomized particles result in over 30 times the surface area causing increased styrene evaporation.

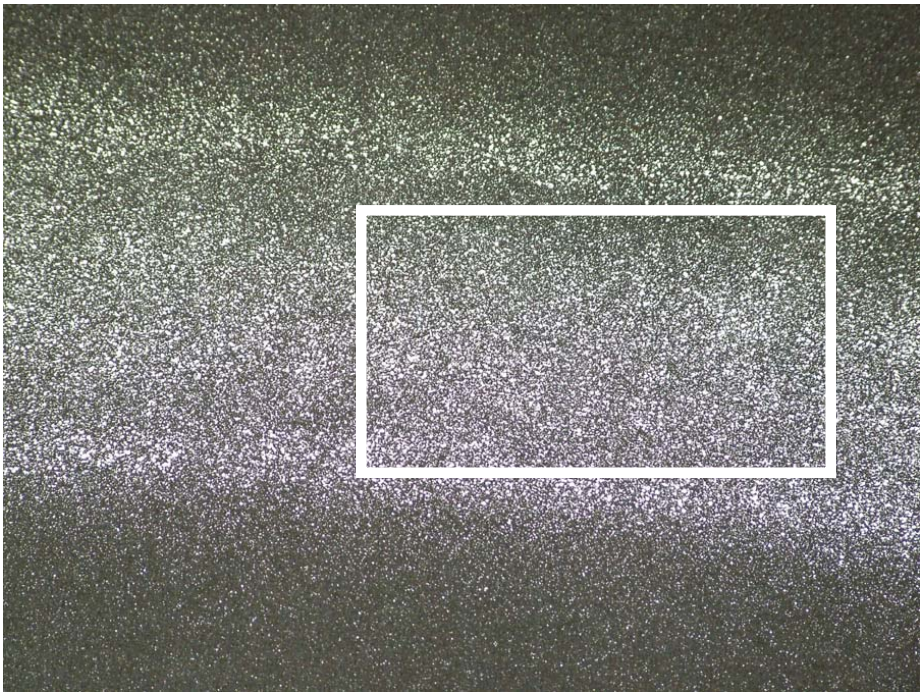


FIGURE 2

Non-atomized tip pressure (200 - 250 psi)
Average particle size is .030 or greater (about the diameter of a paperclip)

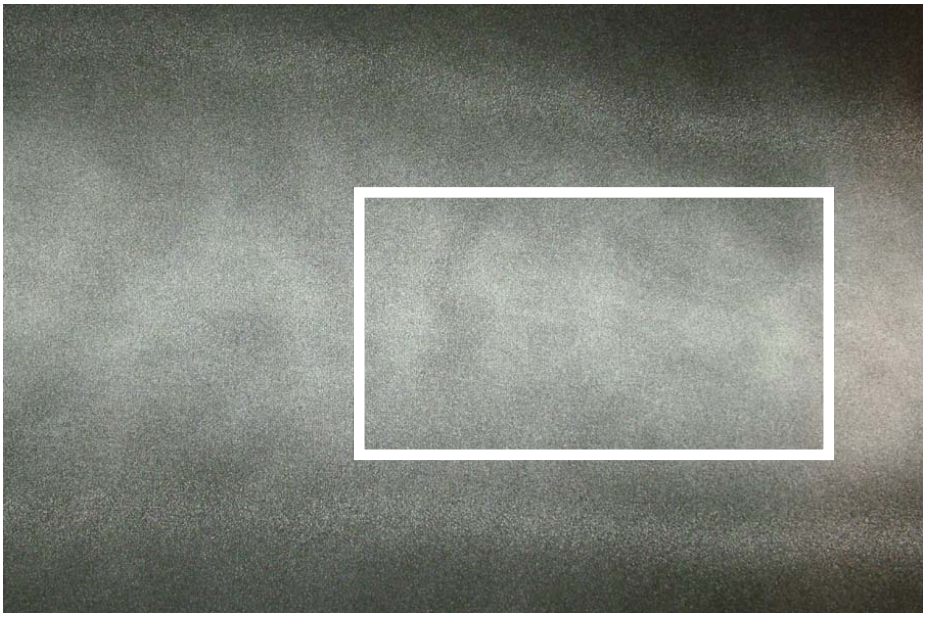


FIGURE 3

Atomized tip pressure (700 - 800 psi)
Average particle size is .001 or less (less than 1/3 the diameter of a human hair)

PATTERN DEVELOPMENT COMPARISON

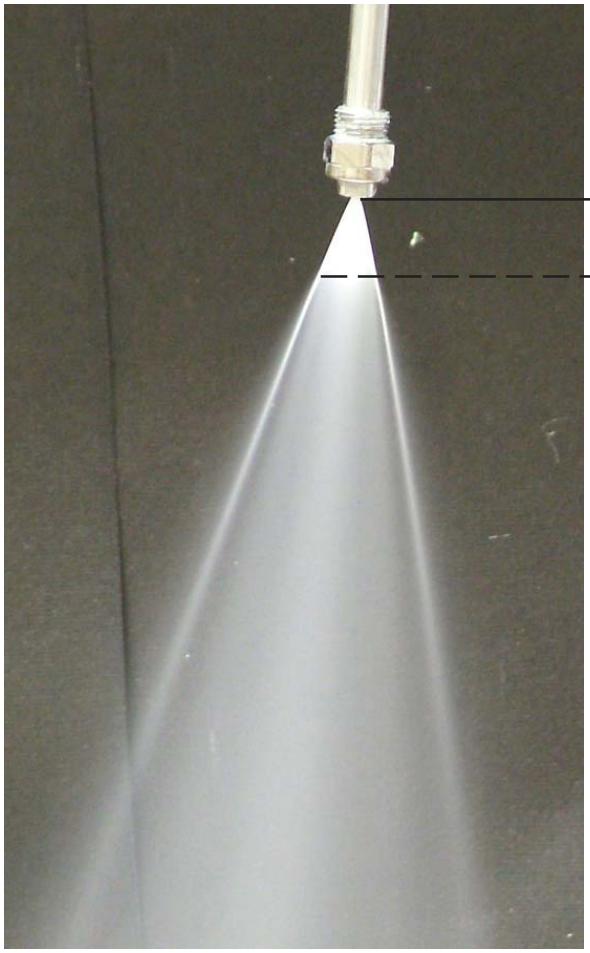


FIGURE 4

Atomized Spray Fan
Atomization occurs 1-1 1/4 inches from tip or less.

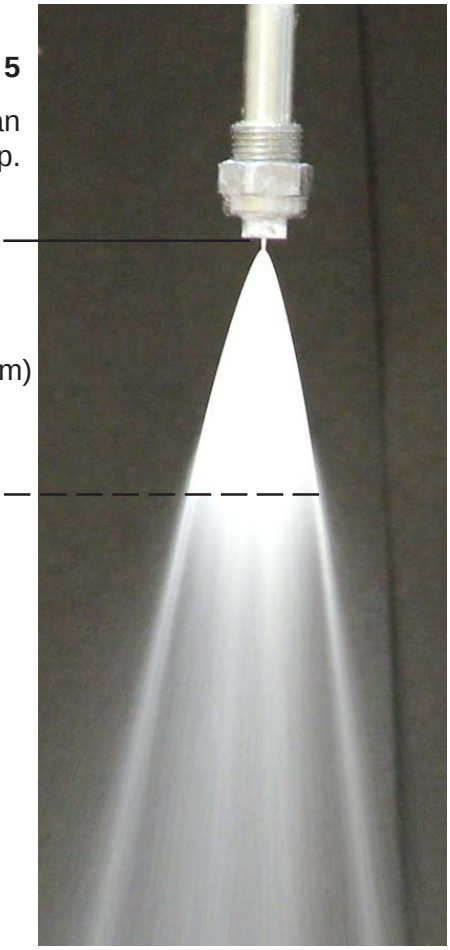


FIGURE 5

Non-atomized Spray Fan
Atomization occurs 2-2 1/2 inches from tip.

FIELD EXAMPLES

FIGURE 6

Atomized
Note first inch

FIGURE 7

Non-Atomized
Note first 2 - 3 inches (5.10-07.6 cm) from tip

PROPER ADJUSTMENTS FOR NON-ATOMIZED GELCOAT APPLICATION

Fluid Pumps

The most common type of resin pump is termed an “air over fluid pump”. An air driven piston drives a fluid piston, which forces the material out to the spray gun at high pressure. The difference between the diameter of the air piston and the fluid piston is termed the *pump ratio*. Pump ratios usually range from about 11:1 up to 33:1. By multiplying the air input pressure by the pump ratio the fluid pressure at the spray tip can be determined.

Example:

- Pump Ratio = 15:1
  (15 psi of fluid pressure for every 1 psi of air pressure)
- Pump air pressure set at 40 psi
- Multiply: Pump Ratio x Pump Pressure Setting to determine the tip pressure
- 15 psi x 40 psi = 600 psi fluid tip pressure

SPRAY GUN SET-UP & PRESSURE CALIBRATION

(courtesy of ACMA “Controlled Spray Training” Program)

1. Flow Rate

Flow rate is the amount of material sprayed in a given period. The flow rate is primarily controlled by the size of the spray tip, pump pressure, resin viscosity and resin temperature. Flow rate considerations include:

• Large parts, requiring large amounts of resin or gel coat, are usually sprayed with larger size tips. Smaller parts, or parts with more detailed shapes, may be easier to spray with lower flow rates using smaller orifice fluid tips.

• The viscosity (thickness) of gel coat or resin will affect both the flow rate and fan pattern.

• The formulated viscosity is normally adjusted by the material manufacturer, but is affected by temperature. Cooler material will be thicker and will reduce the flow rate; where warmer gel coat is lower in viscosity and flows at a higher rate.

2. Determining Proper Fluid Pressure

Determining the ideal pump pressure for a specific combination of material and equipment is an important element of controlled spraying. Because of the many variables in the materials delivery system there is not a specific set pressure for a spray gun, nor can a specific pressure limitation be set These variables require that each spray unit, with a specific material, operated under specific conditions be adjusted to produce an ideal spray pattern. There are a myriad of variables that affect the optimal pressure selling of any given application unit. These variables include:

Equipment design

- Fluid pump ratio (air input pressure to fluid pressure generated)
- Fluid tip design and configuration
- Design of filter and fluid lines
- Number of fittings or elbows in fluid lines
- Requirement for a surge chamber
- Internal or external initiator mixing

Material

- Inherent resin rheology
- Formulated viscosity
- Use of filled systems

Operating Conditions

- Material temperature
- Residual build-up in fluid lines
- Condition of pump packings
- State of filter particle accumulation
- Required spray distance from mold
- Geometry of mold (i.e., highly contoured or flat)
- Size of mold
- Accuracy and wear of pressure gauges and air pressure regulators

Equipment Set-up

- Fluid tip orifice size Length of fluid lines ID of fluid lines
- Size of filter screen mesh
- Height of fluid lines with overhead boom Adjustment of spray gun fluid needles Adjustment of spray gun trigger Required flow rate
- Required fan pattern width

2.1 The Objective of Spraying at Low Pressure

The objective of this spray gun pressure calibration method is to determine the lowest pressure at which any application unit will operate, while acknowledging that the pressure range may vary widely based on the combination of complex variables. It is always an advantage to spray at the lowest possible pressure. The lowest pressure will:

- Reduce Styrene Emissions
- Minimize overspray
- Create better working conditions
- Enhance catalyst mixing
- Reduce material usage / cost
- Reduce equipment wear
- Reduce high pressure hazards
- Reduce static charge build-up
- Increase product quality

In all cases, with resin and gel coat application equipment, *minimum pressure provides maximum performance* in terms of, transfer efficiency, emissions, and finished product quality.

3. Pressure Calibration Procedure

The spray gun pressure calibration procedure is a simple and straightforward approach to determining the proper fluid pressure for any combination of equipment, material, and conditions. This procedure is appropriate for all atomized and non-atomized application equipment, including both internal and external initiator delivery systems.

Step I - Verify that the resin or gel coat is the correct temperature, and has been properly mixed according to the manufacturer’s recommendations.

Step 2 - Verify that the fluid tip is in good condition (without excess wear and capable of producing an acceptable spray pattern); and the orifice size is within a suitable in flow rate range and fan pattern width for the given job.

Step 3 - Reduce the pump air input pressure down the level where the pump will no longer stroke.

Step 4 - If the unit uses external assist air, set the air assist pressure in the middle of the normal range and according to the manufacturers' recommendations.

Step 5 - Aim the spray gun at a disposable surface covering on the floor, maintaining a distance of 12" to 18" and perpendicular to the floor.

Step 6 - Increase the pump pressure to the point where the pump just begins to stroke. Quickly pull and release the trigger to provide a "snapshot" spray pattern.

Step 7 - Record the results on the Spray Gun Calibration Worksheet.

Step 8 - Repeat the procedure, increasing pump pressure in 5 psi increments until the spray pattern is fully developed.

Step 9 - If using air-assist equipment, once a fully-developed spray pattern is attained, fine-tune the assist pressure for final shaping of the fan pattern. Use the lowest air-assist pressure that produces a symmetrical spray pattern.

Step 10 - Do not increase the pressure past this point. Any increase in pump pressure past the point of creating a fully-developed spray pattern will result in an over-developed spray pattern.

Step 11 - Record this pressure the final pump pressure and air-assist pressure on the spray gun calibration worksheet.

4. Determining the Proper Spray Pattern

The size and shape of a fan pattern results from a unique combination of orifice size, fluid tip geometry, and resin flow characteristics. The required fan pattern width is specific to the size and configuration of the part being sprayed. The size of the spray pattern should match the spraying requirements. For example, spraying a large flat part benefits from producing a wide fan pattern. A small part or one with a complex shape may require a narrow fan pattern. There is, however, one trait all spray patterns have in common; a symmetrical shape where the material is distributed evenly across the length and width of the spray pattern.

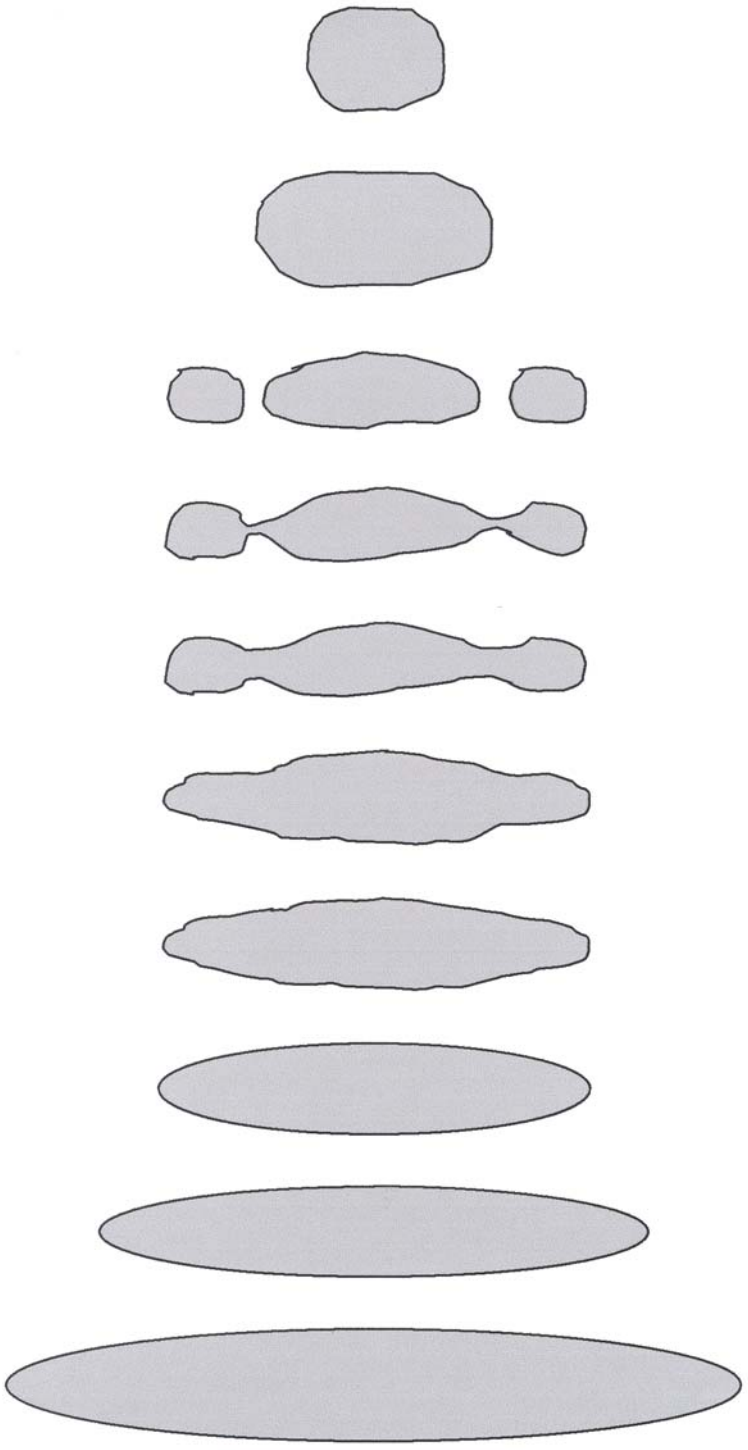
Fan patterns develop from a straight stream of resin, produced at very low fluid pressures, to an elongated oval pattern with increasing pressure. An *under-developed* spray pattern does not exhibit an oval configuration. A *partially-developed* spray pattern may have an irregular oval shape. A *fully-developed* spray pattern will be a uniform oval shape of the proper working width, An *over-developed* spray pattern presents a uniform oval shape that is wider than a fully-developed pattern, and produces increased atomization resulting from increased tip fluid pressure. This excess atomization is apparent by the increase in overspray surrounding the spray pattern.

As the fluid pressure reaches a specific optimum level for a specific combination of factors, a symmetrical elliptical shaped spray pattern develops. This pattern may need slight fine-tuning, with incremental pressure adjustments; or in the case of an air-assist spray gun, may be refined with additional air-assist pressure adjustments. The goal of air-assist/fluid pressure adjustments is to determine the combination that requires the lowest pressures, while producing a workable spray pattern.

Pump pressures and/or air-assist pressures set to greater than required levels to produce a fully-developed uniform spray pattern are considered excessive.

EXAMPLES OF SPRAY PATTERN DEVELOPMENT

Note: These pressures are for illustration purposes only. Actual pressures will vary with specific equipment, resin, spray tip size and angle, material temperature and other factors.



20 psi - Undeveloped

25 psi - Undeveloped

30 psi - Undeveloped

35 psi - Partially Developed

40 psi - Partially Developed

50 psi - Partially Developed

50 psi - Fully Developed
without Air Assist Fine Tuned

50 psi - Fully Developed
with Air Assist Fine Tuned

55 psi - Over Developed

60 psi - Over Developed

SPRAY GUN CALIBRATION WORKSHEET - EXAMPLE

Date:_____ Operator:_____

Spray Unit Designation:_____

Resin Designation:_____

Spray Tip Size & Angle:_____

Spray Tip Condition: New_____ Used_____

Spray Gun Pressure Calibration Record				
Pump Pressure Setting	**Air Assist Pressure Setting**	**Spray Pattern Development**		
		Under Developed	**Partially Developed**	**Fully Developed**
10 psi				
15 psi				
20 psi				
25 psi				
30 psi				
35 psi				
40 psi				
45 psi				
50 psi				
55 psi				
60 psi				
65 psi				
70 psi				
75 psi				
80 psi				
85 psi				
90 psi				
100 psi				

Final Pump Pressure Setting: _____ psi

Initial Air Assist Pressure Setting: _____ psi

Final Air Assist Pressure Setting: _____ psi

Signature:_____

New Gel-Coat Application Technology Emission Testing

May 30 – June 2, 2000

Emission Tests

Performed at Coating Applications Research Laboratory (CARL)

CARL Test Engineers
S. J. Hall
J. R. Noonan

Summary Report
(Technical Revision - - November 22, 2000)
Compiled and Written
By
S. J. Hall
J. R. Noonan
July 24, 2000

Clean Manufacturing Technology and Safe Materials Institute
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New Gel-coat Application Technology
Emission Testing
May 30 – June 2, 2000
Magnum Industries, Inc.

From May 30 through June 2 the Magnum Company was present at the Coating Applications research Laboratory (CARL), at Purdue University, to perform a series of emission tests on a new type of application technology designed to apply gel-coat material in non-atomized form.

Gel-coat Materials Used:
The emission tests were performed using a standard type of resin material manufactured by Lilly Industrial Coating Company, product number 5784E90016, batch # EL2000050137, 38% styrene (by wt.).

Application equipment operational settings (all application equipment supplied and operated by Magnum personnel):

Tests 1, 2, 3, 4, 5

Conventional, External Mix
518 tip size
11 to 1 pump, 70 psi
1.45% by weight (approx.) catalyst mix
20 psi catalyst atomizing air

Test 6, 7, 8, 9, 10

Fit Technology, External Mix
0.025 orifice size & 25 degree angle
11 to 1 pump, 28 - 30 psi
1.45% by weight (approx.) catalyst mix
18 - 20 psi (static) catalyst air pressure

All tests were performed in accordance with the following EPA methods:

- Method 204 - Temporary/permanent enclosure — Collection of 100 % Emissions
- Method 1 - Sample and Velocity Traverse for Stationary Sources
- Method 2A - Standard Pitot Tube
- Method 25A - Determination of Total Gaseous, Organic Concentration, Using Flame Ionization Analyzer

The emissions data in this report are given as percent styrene emission as compared to the pounds of styrene applied.

Equipment Used During Test

Magnum application equipment (as noted above)
J.U.M. Engineering, Inc. flame ionization detector (FID), model 3-100
Dwyer Instrument, Inc.-2 standard-design pitot tubes, mold 160 series
Dwyer Instrument, Inc. primary standard manometer, model #424
NEC data-logging Pentium portable computer
National Instruments: LabVIEW, version 5.1 Graphical Programming Software, data acquisition software
National Instruments: LabVIEW DAQCARD AI-16XE-50 voltage to digital converter
National Instruments: SCB-68 voltage to digital interface
Dwyer Instrument, Inc. pressure transducer, model 607-4—convert inches of water pressure to linear voltage readout
Alnor Velometer series 6000—air velocity measurement instrument
Barnant temperature & relative humidity logger, model 6919000
Dwyer Instrument, Inc. temperature transducer (linear voltage readout), model 4151D
Binks standard paint booth modified for 100% emission capture

EPA method 204 temporary/permanent enclosure—collection of 100% of emissions
Sartorious scale—360 pounds maximum, 2 gram sensitivity (computer readout)
Sartorious scale—150 pounds maximum, 1 gram sensitivity
CFA certified male mold with overspray capture flange

Emission Test Procedure:

TCA-FID was calibrated via EPA certified propane gas standards prior to the beginning of each test.

Application began only after the lab had reached a VOC PPM baseline level of approximately 1-PPM (as indicated on the TCA-FID).

Gel-coat material was applied to a CFA designed, male mold surface (35.66 sq. ft. including flange but not including overspray of approximately 2 inches).

The gel-coat was applied to an approximate wet-mil thickness of 18 to 23 mils.

Typical spray time was approximately 130 to 170 seconds allowing a targeted resin deposition onto the mold surface of approximately 2.27 Kg. (5.00 lbs.). The actual spray time varied depending on the gel-coat resin flow rate from the subject application equipment.

The TCA-FID was verified and re-calibrated (if required) via EPA certified propane gas standards at the end of each test. The calibration drift of the TCA-FID was less than 5% for each of the tests. Calibration drift of less than 5% is deemed acceptable by the EPA for Method 25A emission tests.

Catalyst (initiator) ratio to resin (determined by actual weight of catalyst used) equaled 1.4% (catalyst wt./resin wt.) for all tested samples.

The gel-coat material, applied to the CFA male mold, was monitored for emissions (and data was logged every two seconds) during the entire time, from the start of the resin application process, through cure of the material. The emission test was deemed complete only when the gel-coat had cured and the emissions had returned to original baseline levels. The entire emission test process, for each of the test run, spanned approximately 45 to 70 minutes.

Test acceptance or rejection from the emission factor calculation:

Tests 1 and 2 were performed as practice trials designed for the spray operator and test participants to practice the test protocol requirements. Tests 1 and 2 were not meant to be emission factor tests and therefore, were not included in the emission factor calculation.

Test 6 was also a practice trial for the operator to acquaint himself with the new FIT technology applicator since its operation and application characteristics differed from the conventional application used in the prior set of tests. The test was not meant to be an emission factor test and therefore, it was not included in the emission factor calculation.

Test 9 was rejected from inclusion in the emission factor calculations because the gel-coat application operator inadvertently strayed from the test protocol application technique. The mold flanges received only 60% coverage with the remaining 40% receiving a “dust coat” of 4 to 6 mils of gel-coat. All other acceptable tests 3, 4, 5, 7, 8, and 10 received proper full coverage over the entire mold including the flange area as the test protocol dictated.

Please see following tables:

Table 1 – application specifications for each individual test

Table 2 – pounds resin (gel-coat) applied, pounds styrene applied, pounds and percent emitted for each test

Table 3 – emissions comparison of Conventional verses FIT technology, statistical ANOVA tests and commentary

Table 4 – application portion emissions as percent of total emissions (attached to chart 3)

Table 5 – comparison of average PPM and peak PPM of Conventional verses FIT technology (attached to chart 8, 9, 10)

Table 6 – t-test statistics analyzing the emissions test data for statistical significance

Please see following charts:

Chart 1 – Normal-Distribution graph comparing Conventional and FIT emissions for full test

Chart 2 – Normal-Distribution graph comparing Conventional and FIT emissions for only the application portions of the tests

Chart 3 – graph of application emissions portions of the tests as compared to percent of total emissions

Chart 4 – graph of PPM styrene emission traces verses time, comparing all accepted tests (tests 3, 4, 5, 7, 8, 10) for the full duration of the tests

Chart 5 – graph of PPM styrene emission traces verses time, comparing each accepted Conventional applicator test (tests 3, 4, 5)

Chart 6 – graph of PPM styrene emission traces verses time, comparing each accepted FIT applicator test (tests 7, 8, 10)

Chart 7 – graph of PPM styrene emission traces verses time, comparing all accepted tests (tests 3, 4, 5, 7, 8, 10) for the application period of the tests plus time for booth to complete 5 complete air changes after end of each application

Chart 8 – graph of PPM styrene average emission traces verses time, comparing Conventional and FIT applicators for application periods only (pauses between surface application of mold top, side, and front are cropped-out)

Chart 9 – bar chart comparing cropped, average PPM styrene emissions during application periods of Conventional verses FIT

Chart 10 - bar chart comparing cropped, approximate peak styrene emissions during application periods of Conventional verses FIT

TABLE 1

Test #	Catalyst % wt. Ratio	Lbs. Gel-coat Applied	Kg. Gel-coat Applied	Ave. wet-mil Thickness Applied			Est. Percent Overspray	Kg. Flow per Min.	Comments
				Top	Front	Side			
1	1.27	3.236	1.468	--	--	--	--	0.786	Initial Checkout of Conventional. Gun
2	1.20	4.852	2.201	18.00	16.67	18.50	--	0.776	Low Catalyst ratio detected
3	**1.43**	**4.888**	**2.217**	**18.67**	**16.75**	**18.75**	**13.78**	**0.786**	**1st Repl. -- Conv. Gun - Typ. O'spray**
4	**1.46**	**4.967**	**2.253**	**20.00**	**17.50**	**20.50**	**9.15**	**0.800**	**2nd Repl. -- Conv. Gun - Typ. O'spray**
5	**1.49**	**4.996**	**2.266**	**20.50**	**16.25**	**21.50**	**9.28**	**0.810**	**3rd Repl. -- Conv. Gun - Typ. O'spray**
6	1.47	4.932	2.237	19.50	18.00	19.00	--	0.951	Initial Checkout of FIT gun technology
7	**1.41**	**5.516**	**2.502**	**23.50**	**18.00**	**21.50**	**11.13**	**1.009**	**1st Repl. -- FIT. Gun**
8	**1.42**	**4.912**	**2.228**	**24.50**	**16.38**	**23.00**	**0.00**	**1.027**	**2nd Repl. --FIT Gun**
9	1.39	4.996	2.266	23.86	16.75	22.50	--	1.030	Altered Application technique
10	**1.41**	**5.101**	**2.314**	**23.75**	**18.00**	**24.25**	**0.00**	**1.049**	**3rd Repl. -- FIT. Gun**

The above table contains data pertinent to all the tests performed over the three-day testing period. The comments column contains key information relative to each test run. Tests included in the performance evaluation are highlighted in bold print and the comments column identifies the "Replication" identity of each. The estimated percent overspray column is included in the table to indicate or suggest consistency of overspray beyond the mold's flange surface. The overspray calculation is based on the surface area of the mold (35.66 sq. ft.) and the wet-mil thickness readings taken across the mold's three surfaces. The Conventional and FIT apllicators were used in a manner that applied an even coat to the entire mold, including the flange surfaces. The test experience demonstrated that the FIT applicator adequately covered the mold flange with little requirement of overspray beyond the flange lip; whereas, the Conventional system required a 2 to 4 inch overspray to provide adequate flange coverage. Wet-mil thickness readings were taken for each of the Conventional and FIT application tests. The Conventional applicator provided a smooth, even gel-coat surface on which to measure coating thickness. However, the FIT application produced a more mottled, pebbled type of gel-coat surface, with numerous bumps and depressions. The thickness measurements on such an undulated surface were difficult and probably are overstated (the high spots would be detected without compensation for the low spots. It is believed that this "overestimate" for the FIT applicator is responsible for th "0%" entries for overspray for tests 8 and 10. Test personnel observed that the FIT technology required less overspray in covering the flange than did the Conventional applicator technology.

TABLE 2

CONVENTIONAL

Test #	Applied		Emissions		
	# Resin	# Styrene	# Styrene	% Emiss.	
3	4.8875982	1.857287	0.90194	48.56%	Full Test
			0.492129	26.50%	Appl. + 48s.(Abbreviated Data)
4	4.9669638	1.887446	0.880067	46.63%	Full Test
			0.539378	28.58%	Appl. + 48s.(Abbreviated Data)
5	4.9956236	1.898337	0.901887	47.51%	Full Test
			0.53443	28.15%	Appl. + 48s.(Abbreviated Data)
			Full test Conv. Ave.	47.57%	
			Applicaton + 48 seconds Ave.	27.74%	

F I T

	Applied		Emissions				
7	5.5159092	2.096045	0.675399	33.03%	Full Test		
			0.310462	15.18%	Appl. + 48s.(Abbreviated Data)		
8	4.911849	1.866503	0.586589	31.43%	Full Test		
			0.280122	15.01%	Appl. + 48s.(Abbreviated Data)		
10	5.101444	1.938549	0.613427	31.64%	Full Test		
			0.265387	13.69%	Appl. + 48s.(Abbreviated Data)		
			Full test FIT Ave.	32.03%	32.65%	FIT % Reduction	
			Applicaton + 48 seconds Ave.	14.63%	47.28%	FIT % Reduction	

The table above provides details of the gel-coat resin applied, its styrene content, the monitored styrene emitted and the styrene emitted as a percent of styrene applied. Full-Test values are presented as well as the values that had been attained at 48 seconds (approximately 5 booth air changes) after spray application had stopped. The FIT % Reduction values are the reduction from Conventional as a percent of Conventional, e.g. (47.57 - 32.03)/47.57

Table 3

Styrene Emissions / Styrene Applied

Expressed as a Percentage

Full Emissions Comparison

Replication	Conventional	FIT	FIT vs Conv. Reduction
1	48.56%	32.22%	33.65%
2	46.63%	31.43%	32.60%
3	47.51%	31.64%	33.39%
Ave.:	47.57%	31.76%	33.22%

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Conventional	3	1.426989289	0.4756631	9.383E-05
FIT	3	0.952933486	0.3176445	1.691E-05

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.037454817	1	0.0374548	676.43292	1.298E-05	7.708649719
Within Groups	0.000221484	4	5.537E-05			
Total	0.037676302	5				

Application + 48 Seconds Comparison

Replication	Conventional	FIT	FIT vs Conv. Reduction
1	26.50%	14.81%	44.10%
2	28.58%	15.01%	47.48%
3	28.15%	13.69%	51.37%
Ave.:	27.74%	14.50%	47.72%

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Conventional	3	0.832268318	0.2774228	0.0001208
FIT	3	0.435096223	0.1450321	5.056E-05

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.026290945	1	0.0262909	306.89636	6.234E-05	7.708649719
Within Groups	0.000342669	4	8.567E-05			
Total	0.026633614	5				

The information above lists the percent emissions observed from three test replications for conventional gun application and three for the FIT gun. Below are ANOVA tabulations for Full-test data and "Abbreviated" data. For each, an *"F" value* is determined which is greater than the corresponding *"F-Critical" value*, from which we can infer that the different gun technologies do perform differently. The *"P-value"* s indicate that we can be more than 99.99% sure of this. Sample Estimated Normal Distribution Curves (Charts 1&2) are provided for visual reference. Note: This does not mean that we are that sure how different the population means are from each other, only that they are different. See additional data analyses in Table 6 for "difference" statistics comparisons.

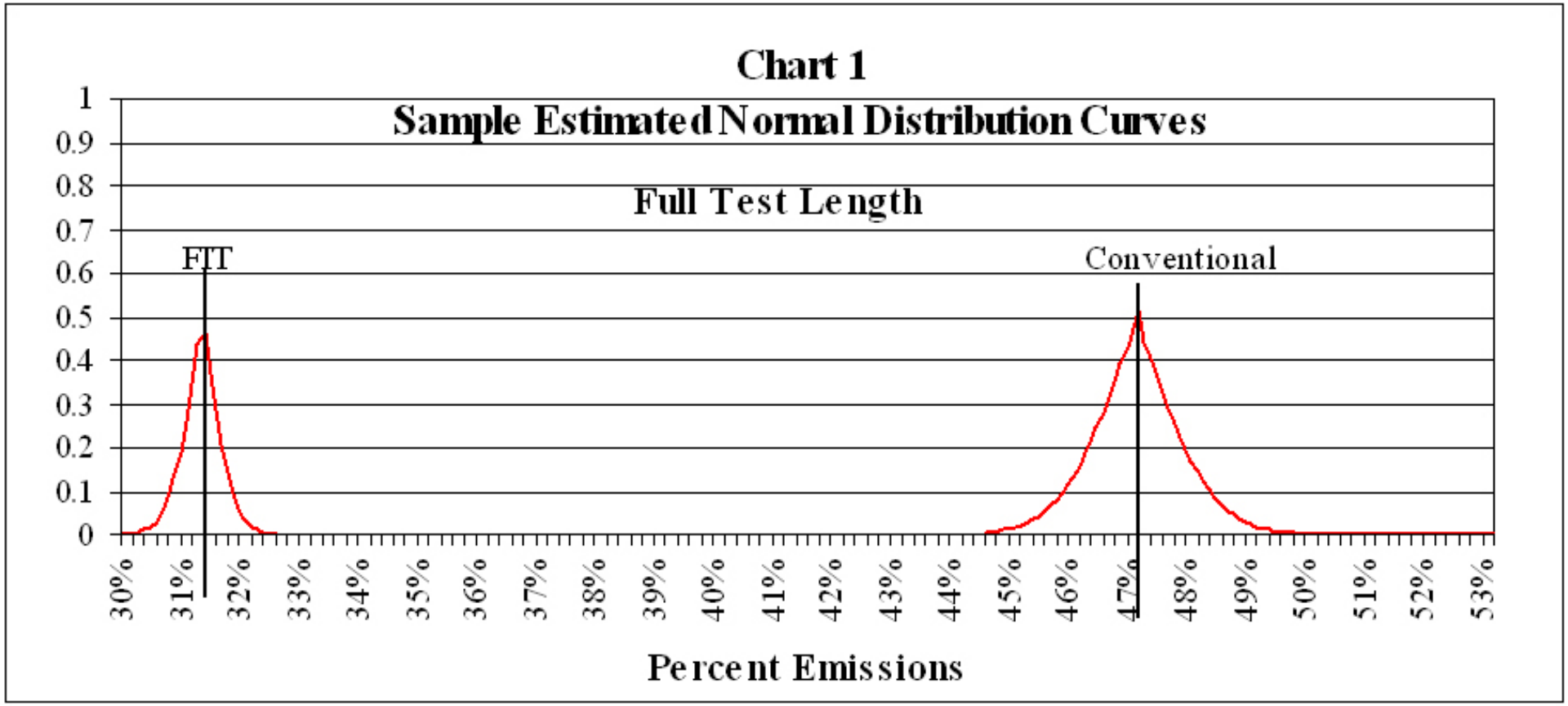


Chart 1
Sample Estimated Normal Distribution Curves
Full Test Length
FIT
Conventional
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
30%
31%
32%
33%
34%
35%
36%
37%
38%
39%
40%
41%
42%
43%
44%
45%
46%
47%
48%
49%
50%
51%
52%
53%
Percent Emissions

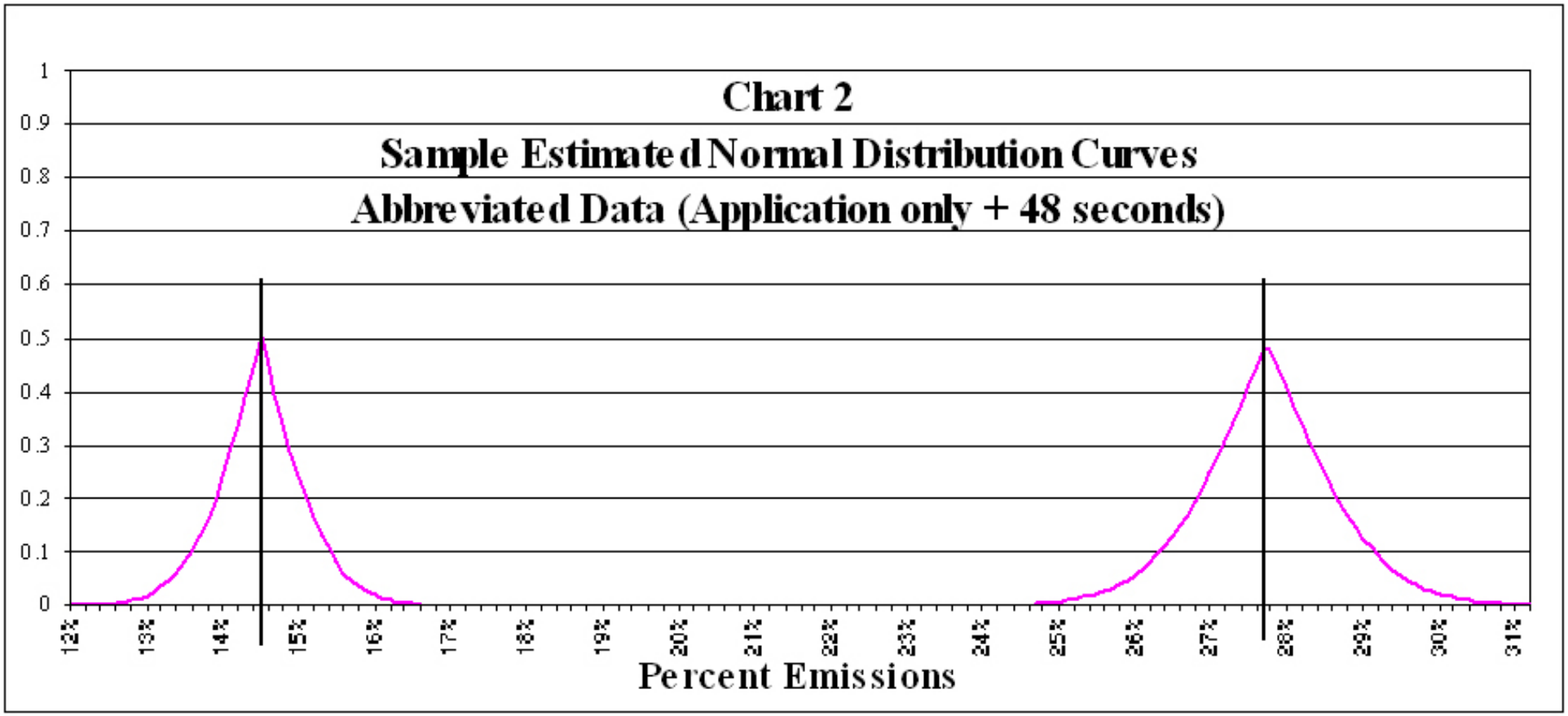
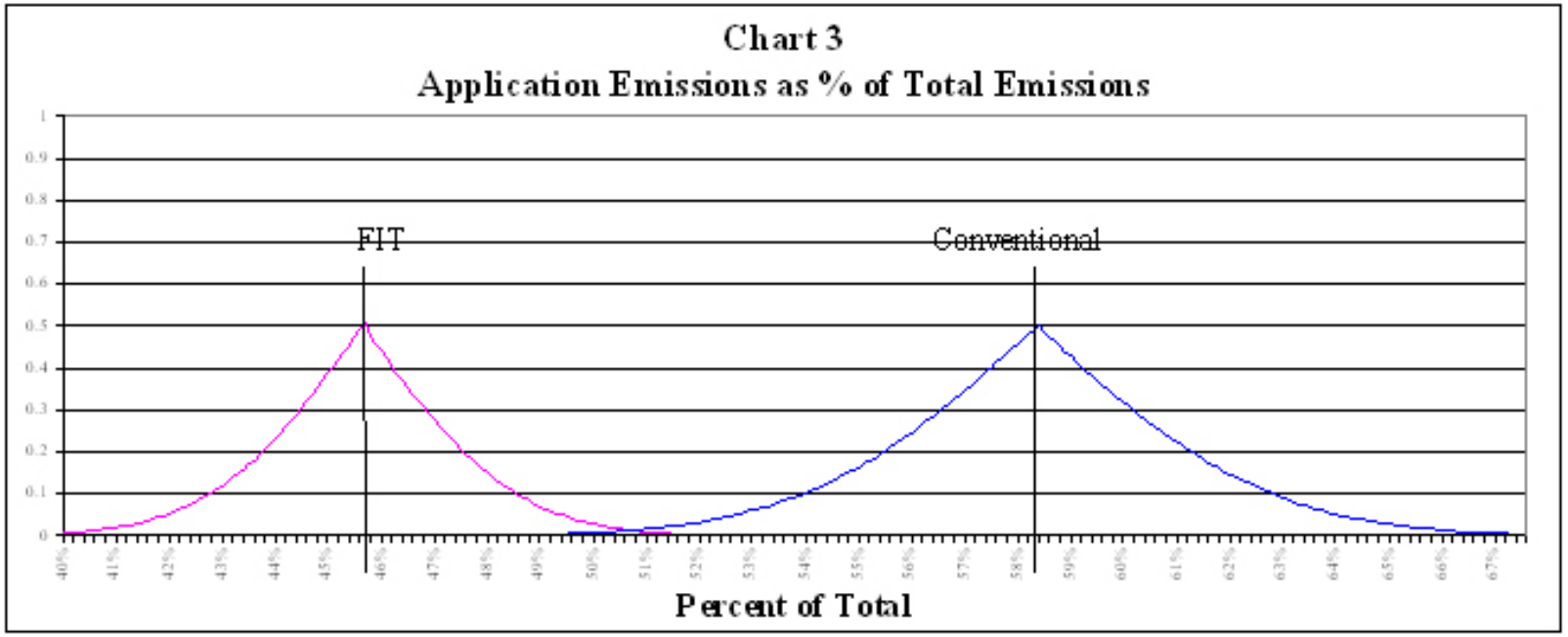


Chart 2
Sample Estimated Normal Distribution Curves
Abbreviated Data (Application only + 48 seconds)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
12%
13%
14%
15%
16%
17%
18%
19%
20%
21%
22%
23%
24%
25%
26%
27%
28%
29%
30%
31%
Percent Emissions

Table 4

	Emissions		
	Appl.+48s % of Total	Appl.+48s % of Total	
T#	**Convent'l**	**FIT**	T#
3	54.56%	45.97%	7
4	61.29%	47.75%	8
5	59.26%	43.26%	10
Ave.	***58.37%***	***45.66%***	Ave.



The data above represent a comparison of the "Abbreviated" emissions (Application Only plus 48 seconds) that occurred for each test compared to its related "Full Test" emissions, expressed as a percent. On the average 58.37% of the emissions occurred from Application with the Conventional gun; whereas, 45.66% of the total emissions occurred during Application with the FIT gun. Sample Estimated distributions are provide on Chart 3 and suggest that there can be a lot of variation. However, the two distributions are clearly separated. It should be noted that this abbreviated test still contains non-spray time that varies substantially, one test to another. This time is the time between applications to the different surfaces of the mold when wet-mil thickness was being checked. Additional information is provided in this report (Table 5, Chart 8) to depict "Cropped" data - (i.e. the abbreviated test with the non-spray periods cropped out as an approximation to what a continuous, uninterrupted spray to the complete mold surface would have been like.

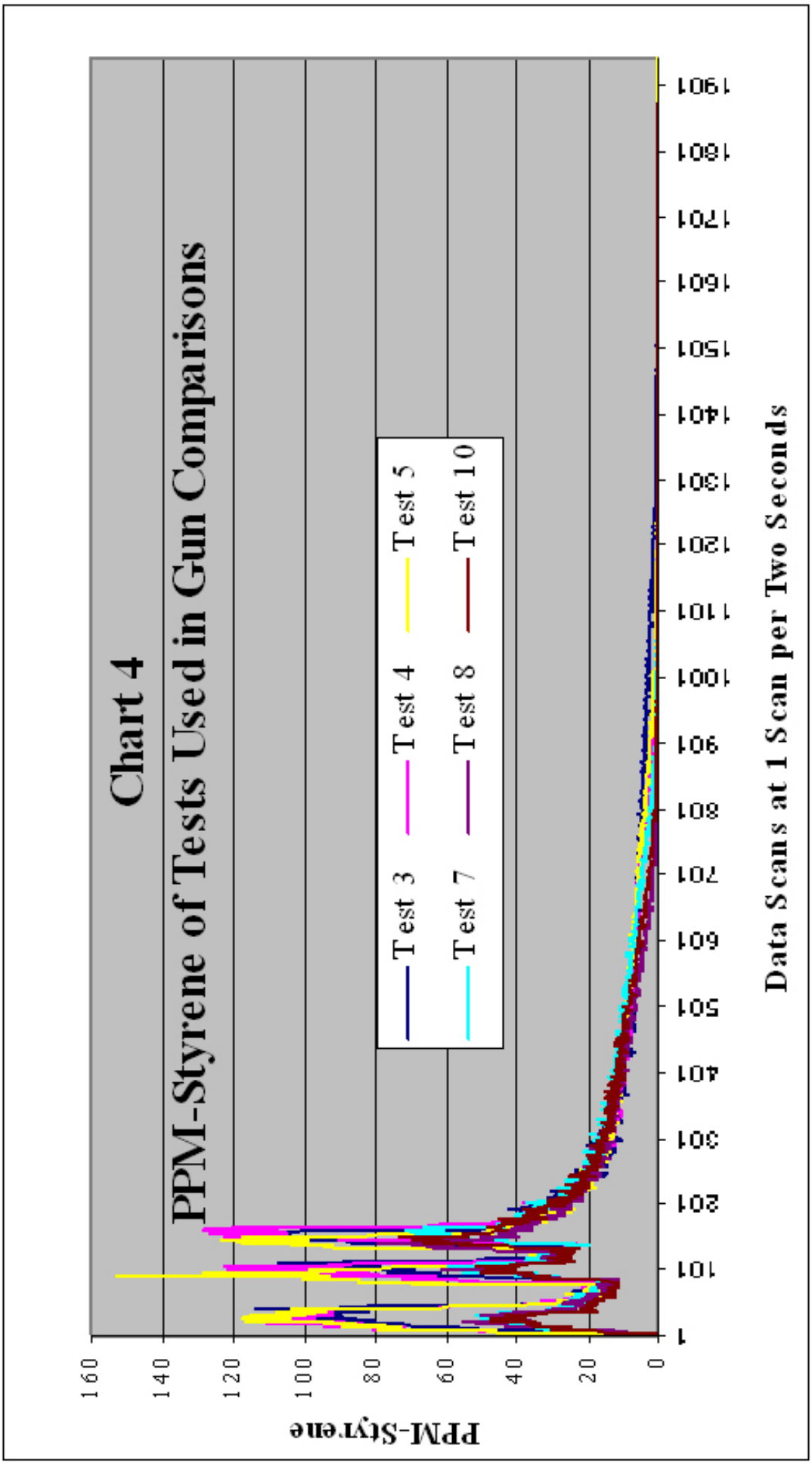
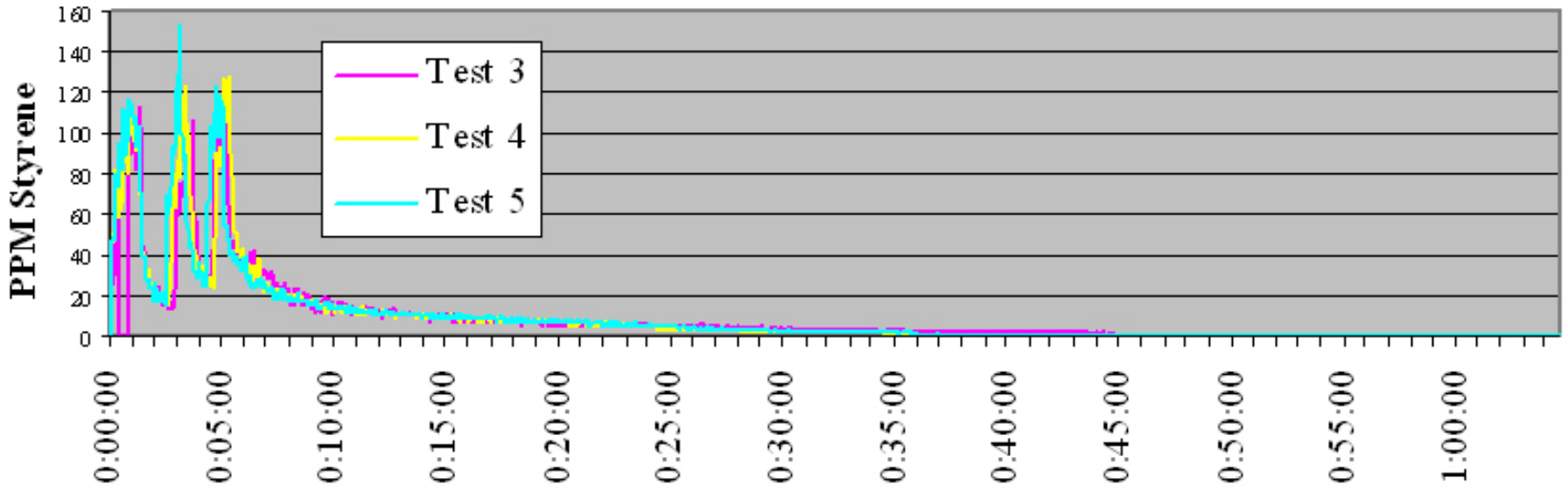


Chart 4
PPM-Styrene of Tests Used in Gun Comparisons
Test 3
Test 4
Test 5
Test 7
Test 8
Test 10
PPM-Styrene
0
20
40
60
80
100
120
140
160
1
101
201
301
401
501
601
701
801
901
1001
1101
1201
1301
1401
1501
1601
1701
1801
1901
Data Scans at 1 Scan per Two Seconds

Chart 5
Conventional Test Emissions



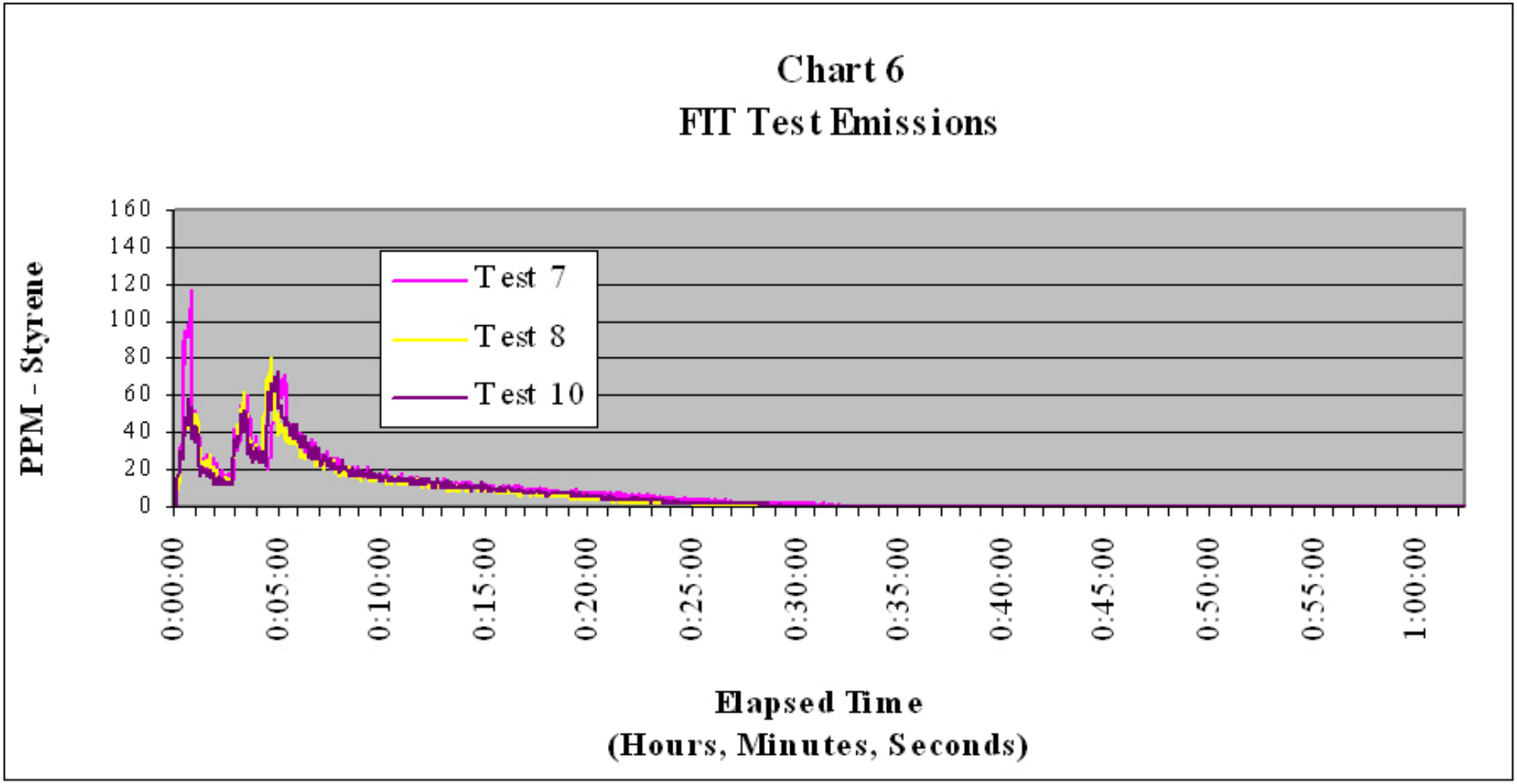
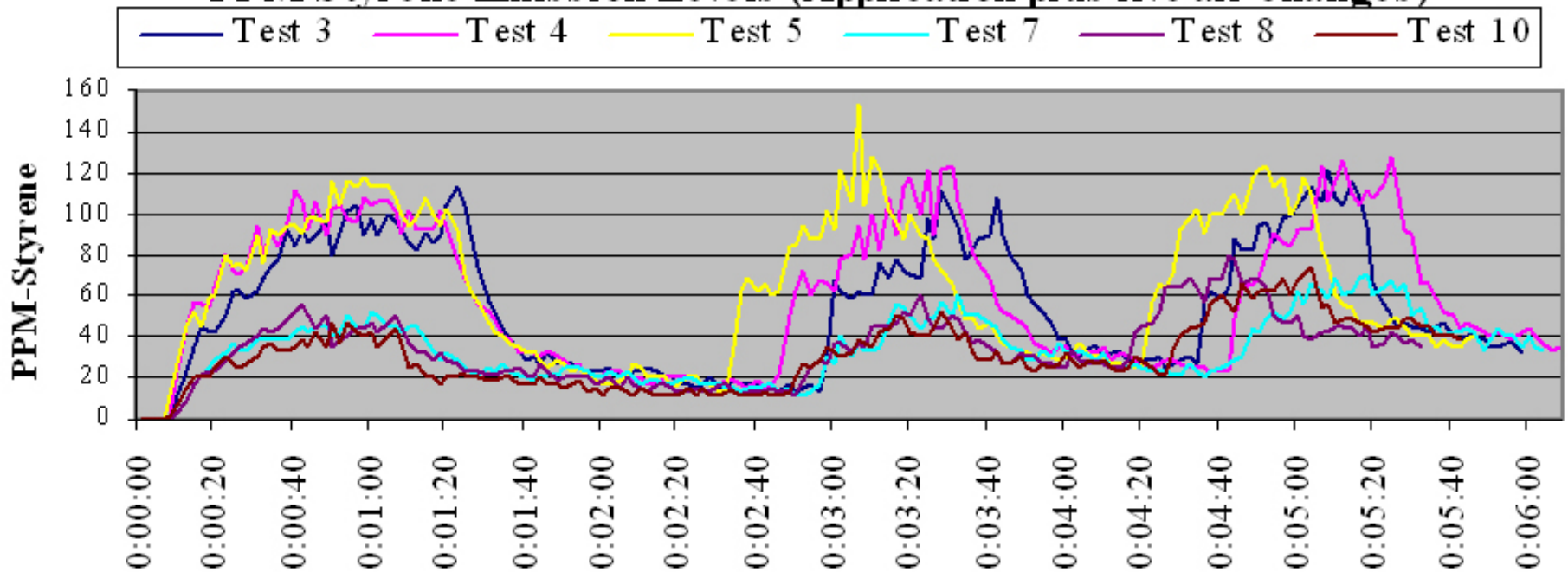


Chart 6
FIT Test Emissions
PPM - Styrene
160
140
120
100
80
60
40
20
0
Test 7
Test 8
Test 10
0:00:00
0:05:00
0:10:00
0:15:00
0:20:00
0:25:00
0:30:00
0:35:00
0:40:00
0:45:00
0:50:00
0:55:00
1:00:00
Elapsed Time
(Hours, Minutes, Seconds)

Chart 7

PPM-Styrene Emission Levels (Application plus five air changes)



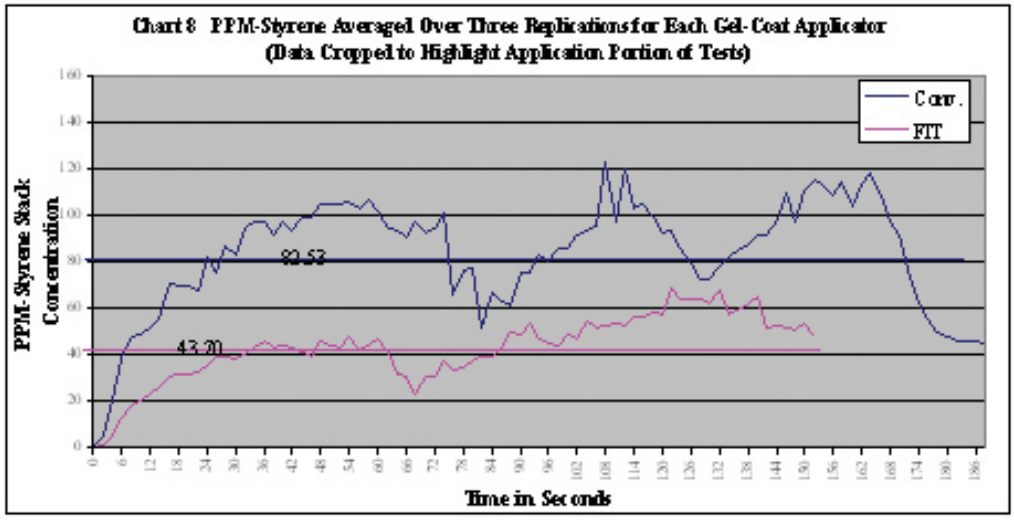
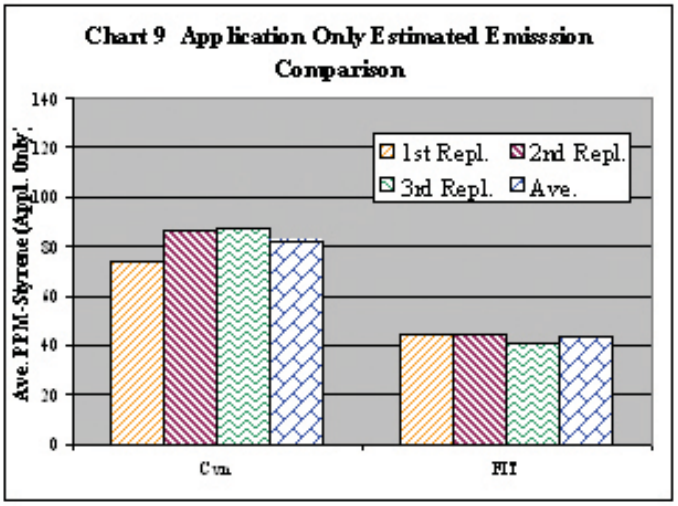
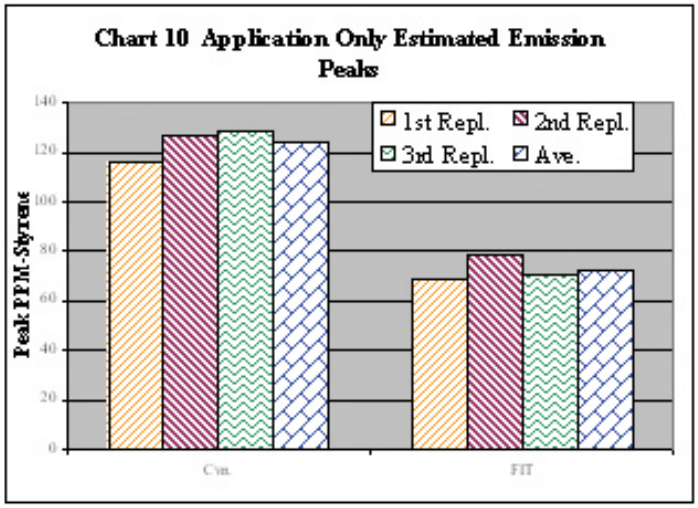


Table 5
Abbreviated, Cropped Test Data

	Averages			Peaks	
	Cvn.	FIT		Cvn.	FIT
1st Repl.	73.97497	44.9631	1st Repl	115.91	68.97
2nd Repl.	86.09201	45.00259	2nd Repl	126.98	78.22
3rd Repl.	87.53274	41.11959	3rd Repl	128.81	70.17
Ave.	82.53324	43.6951	Ave.	123.9	72.45333





The above table and charts display information relative to the application period of the tests, only. The data has been abbreviated to drop all data following the basic application of gel-coat, and further, has had the emission data from the non-application delays between mold surfaces (for wet-mil thickness checks) removed. This gives an approximation of what a continuous application to all surfaces, without interruption, would be like. The average emission level for this period was 82.5 ppm styrene for Conventional and 43.7 ppm styrene for FIT application. Similarly, the approximate sustained peak for the Conventional gun was 123.9 ppm and 72.5 ppm for the FIT application. Stack airflow was approximately 5900 acfm.

Table 6

t-Test: Two-Sample Assuming Equal Variances

Alpha = .00002 — 99.998% conf.

	Conventional	*FIT*
Mean	0.475663	0.317644
Variance	9.38E-05	1.69E-05
Observations	3	3
Pooled Variance	5.54E-05	
Hypothesized Mean Difference	0	
df	4	
t Stat	26.00832	
P(T<=t) one-tail	6.49E-06	
t Critical one-tail	10.9151	
P(T<=t) two-tail	1.3E-05	
t Critical two-tail	13.03852	

t-Test: Two-Sample Assuming Equal Variances

Alpha = .5

	Conventional	*FIT*
Mean	0.475663	0.317644
Variance	9.38E-05	1.69E-05
Observations	3	3
Pooled Variance	5.54E-05	
Hypothesized Mean Difference	0.158	
df	4	
t Stat	0.003062	
P(T<=t) one-tail	0.498852	
t Critical one-tail	2.84E-07	
P(T<=t) two-tail	0.997704	
t Critical two-tail	0.740697	

t-Test: Two-Sample Assuming Equal Variances

Alpha = .02

	Conventiona	*FIT*
Mean	0.475663	0.317644
Variance	9.38E-05	1.69E-05
Observations	3	3
Pooled Variance	5.54E-05	
Hypothesized Mean Difference	0.15	
df	4	
t Stat	1.319784	
P(T<=t) one-tail	0.128686	
t Critical one-tail	0.740697	
P(T<=t) two-tail	0.257373	
t Critical two-tail	1.344397	

t-Test: Two-Sample Assuming Equal Variances

	Conventiona	*FIT*
Mean	0.475663	0.317644
Variance	9.38E-05	1.69E-05
Observations	3	3
Pooled Variance	5.54E-05	
Hypothesized Mean Difference	0.135	
df	4	
t Stat	3.788638	
P(T<=t) one-tail	0.009646	
t Critical one-tail	2.776451	
P(T<=t) two-tail	0.019292	
t Critical two-tail	3.495406	

In testing differences we use "t-Test" statistics. The upper test statistics are for a comparison of the Conventional verses FIT applications, using the basic premise that they have the same mean value (I.e. the Hypothesized Mean Difference = 0). The t-Test indicates, as did the ANOVA test, that they are not the same. The "*t Stat* istic" of 26.008 exceeds the "*t Critical two-tail* "value with 99.998 % confidence (1 minus an alpha of .00002). The difference in average sample means was 15.8% (.158). If we plug this number into the *Hypothesized Mean Difference* in the lower left-hand t-Test set, we find that the *t Stat* is extremely smaller than the *t Critical two-tail* value, even at the 50 % confidence level (1 minus an alpha of .5). Proceeding to the central t-Test set and lowering our *Hypothesized Mean Difference to 15%* we find that we are nearly 80% confident of a difference that great, and in the rightmost t-Test set we see that we are over 97.5% confident that there is a difference of at least 13.5%.

Emission Factors for Non-Atomized Application of Gel Coats used in the Open Molding of Composites

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July 17, 2001

Introduction

A new process for applying gel coat has been developed by the equipment manufacturers since the UEF factors were released in April 1999. Traditional gel coat spray application uses a high-pressure mechanical fluid delivery system to apply gel coat to the open mold surface. This traditional process employs a pressurized spray gun to coat the mold with a fine mist of catalyzed gel coat aerosol droplets. The new gel coat process uses specialized equipment that can apply gel coat to the open mold surface with little or no atomization of the gel coat material. For this reason, the new process is called “non-atomized gel coat application.”

Non-atomized gel coat application is fundamentally different than traditional atomized gel coat spray application. In order to determine the proper emission factors for this new gel coating process, the CFA engaged the Clean Manufacturing Technology Institute (CMTI) located in West Lafayette, Indiana to determine the styrene emission rates for non-atomized gel coat application. The same test procedures and methodologies employed by the CFA in the earlier emission test programs were used by CMTI. The goal of the testing by CMTI is the development of a non-atomized gel coat factor equation for inclusion as an update to the CFA UEF equations. These new factors are described in this report.

The new emission factors are shown in **Table 3** on page 13. Non-atomized gel coat application shows an average 43% emission reduction compared to atomized application, although the exact reduction depends on the monomer content of the gel coat.

Background

From 1996 through 1998, the Composites Fabricators Association (CFA) conducted extensive styrene emissions testing at the Dow Chemical facility at Freeport, Texas. The CFA testing program consisted of three test phases, which investigated the effects of various process parameters on the styrene emissions from the open molding of composite parts. The emission test protocol used in the CFA testing was described in the November 1998 CFA report entitled “*Styrene Emissions Test Protocol & Facility Certification Procedures, Revision 2.1*.” The results of the CFA Phase I testing were detailed in the September 1996 CFA report entitled:

“*Phase I - Baseline Study; Hand Lay-up, Gel Coating, Spray Lay-up including Optimization Study*.”

On February 28, 1998, Engineering Environmental Consulting Services (EECS), on behalf of the CFA, released a report entitled “*CFA Emission Models for the Reinforced Plastics Industries*.”

This report detailed a set of equations and factors developed from the CFA emission test data.

These equations and factors predicted the styrene emission rates from typical open-molding lamination processes employed by the reinforced plastics industry. The report was subsequently posted on the EPA CHIEF web site as an acceptable replacement for the obsolete AP-42 factors that had been developed by the EPA for reinforced plastics.

In 1997, the National Marine Manufacturers Association (NMMA) also conducted emission testing using the CFA emission test protocol. The NMMA testing focused on the emissions from the open molding of large

composite boat parts. The results of this testing are described in the August 1997 NMMA report entitled "*Baseline Characterization of Emissions from Fiberglass Boat Manufacturing*." The NMMA report was also posted on the EPA CHIEF web site.

In November 1998, the CFA and NMMA tentatively agreed to merge the emissions data from their respective test programs. The merged data set was then used to develop a new set of equations and factors that "unified" the methodology employed by boat builders and non-boat builders for estimating the emissions from the open molding of composite parts. For this reason, the new emission factors were named the Unified Emission Factors (UEF). The UEF factors were described in an April 7, 1999 EECS report entitled *Technical Discussion of the Unified Emission Factors for Open Molding of Composites*, which was published by the CFA and posted on the CFA website.

Styrene Emissions Testing at the CARL Facility

CMTI operates a comprehensive research and development facility named the Coatings Application Research Laboratory (CARL), which is located in West Lafayette, Indiana next to the local airport and near Purdue University. The purpose of the CARL facility is to investigate new and existing coating technologies. The CARL facility site has a small research building, which houses a small spray booth enclosure that is ventilated through a small exhaust stack. The spray booth enclosure meets the EPA Method 204 criteria for a permanent total enclosure, so 100% capture of the emissions released inside the enclosure can be assumed. A detailed discussion of the equipment and procedures at the CARL facility is provided in the next section.

A CFA technical representative visited the CARL facility in May 2000. During this visit, the emissions test equipment setup and testing procedures in place at the CARL facility were thoroughly inspected. A series of calibration runs to verify the capture efficiency of the test enclosure and the quantitative accuracy of the sampling equipment for measuring styrene vapor were also performed during the visit. Based upon the field observations and results of the calibration runs, the CARL facility was recommended as a certified emissions test facility for measuring styrene emissions from open-molding processes.

A series of non-atomized gel coat application emissions test runs were performed at the CARL facility from March 16 through April 6, 2001. Jim Noonan, assistant director at CMTI, and Jean Hall, process engineer at CMTI, conducted this testing. Larry Craigie, the CFA Technical Services Manager, observed the testing. Experienced gun operators on loan from the equipment suppliers applied the gel coat test materials. Two different operators were employed during the testing.

Test Procedures and Methods at the CARL Facility

The CMTI personnel adhered to the formal styrene emission test protocol developed by CFA in November 1998 in nearly all aspects, with two minor exceptions:

Exhaust flow measurement - CMTI conducted Method 1 and Method 2 flow traverses before and after each test run, and also continuously measured and recorded the velocity pressure at a fixed point in the exhaust stack using a permanently mounted pitot tube during each of the test runs.

Variable FID response at low styrene concentrations - CMTI confirmed that the FID instruments had a variable response to styrene vapor at low styrene concentrations.

CMTI verified this characteristic by repeatedly challenging the FID instrument with bag samples of known volume and styrene mass contents. CMTI used the collected data to derive a response factor equation that was applied to the FID output to correct for the variable FID response to styrene. After applying the correction factor equation, CMTI was able to show near perfect sample recovery during the styrene mass balance calibration runs.

CMTI personnel used the following test methods during the testing periods at the CARL facility:

Method 1 and Method 2 were used to measure the exhaust flow rate through the test enclosure at the CARL facility. These methods utilize a standard pitot tube and precision micromanometer to measure the average airflow velocity inside the test enclosure exhaust duct.

EPA Method 3 is often used to determine the CO2 and O2 concentrations and dry molecular weight of the exhaust streams from large industrial combustion processes, such as steam boilers and process ovens. However, the exhaust flow stream at the CARL facility was not the byproduct of a combustion process, and was essentially ambient moist air with a trace of styrene vapor. Therefore, CMTI did not use Method 3, but instead computed the air density correction factor from the moist air properties published by the American Society of Heating, Refrigeration & Air Conditioning (ASHRAE). The

ASHRAE correction factor was based upon the barometric pressure, elevation, temperature, and relative humidity of the exhaust airflow. These parameters were measured by CMTI during each test run and were used to correct the measured exhaust flow rate to the corresponding exhaust flow rate at standard conditions.

EPA Method 4 is frequently used to measure the moisture content in the exhaust streams from large industrial combustion processes. This method passes a known volume of gas through a pre-weighed amount of silica gel sorbent, and measures the increase in sorbent weight caused by to the moisture contained in the gas. As mentioned above, the exhaust stream at the facility is not the byproduct of a combustion process and was essentially nominal ambient moist air. Hence, Method 4 was not used by CMTI.

EPA Method 25A was used to measure the total hydrocarbon concentration (THC) in the exhaust stream. Only styrene was assumed to be present in the gel coat materials applied to the “standard CFA mold” during the test runs, so styrene was assumed to be the only hydrocarbon species contained in the exhaust air. Hence, the Method 25A results were converted to styrene emission rates for each test run.

The capture efficiency of the test enclosure at the CARL facility was compared to the Method 204 criteria for a permanent total enclosure to determine its capture efficiency.

The test enclosure met all of the Method 204 criteria, so the perfect (100%) capture of all test run emissions was assumed in the enclosure exhaust stream.

A portable personal computer (PC) was stationed next to the test enclosure. This PC recorded and processed the experimental data for each test run. Various sensors, which are discussed below, were connected to an analog-to-digital signal converter card that was installed in this PC.

This data converter changed the voltage and current signals from the sensors into digital data.

Data collection software produced by Labview was used to collect and store this data. A specialized MS Excel spreadsheet program developed by CMTI was used to process the data and report the experimental results in real-time.

The dry standard exhaust airflow rate through the exhaust stack was calculated by measuring the following test enclosure parameters:

Dry bulb air temperature - by means of an air temperature sensor in the stack.

Relative humidity - using a solid-state humidity sensor in the ambient air.

Static pressure - by use of a micromanometer pressure sensor in the stack.

Velocity pressure at fixed point in the exhaust stack - was monitored by a differential micromanometer pressure sensor connected to a “L-type” pitot tube. CMTI assumed a 1.00 factor but changed the factor to the more commonly accepted value of 0.99 during the May visit. A full Method 1/Method 2 velocity pressure traverse

is conducted inside the stack both before and after each test run to verify the correspondence of the fixed pitot velocity pressure reading to the exhaust flow rate. After repeated measurements,

CMTI discovered that the fixed-point measurement seemed to be an extremely reliable measure of the exhaust flow rate. CMTI developed a special laser-collimated pitot tube to ensure a consistent traverse path for each traverse. A small laser was attached to the pitot tube, and the laser beam was pointed at pre-positioned target plates attached to the roof trusses. The pitot tube followed the same path so long as the laser beam remained inside the target “bulls-eye.”

Flow rate conversion algorithm - CMTI developed an algorithm based upon the ASHRAE equations of state for moist air and the ASHRAE correction equation for local barometric pressure at the local elevation to calculate the equivalent standard flow rate in the exhaust stack in units of dry standard cubic feet per minute (dscfm). This algorithm used the dry bulb temperature, relative humidity, static pressure in the stack, fixed-point velocity pressure, and local barometric pressure values at each sample interval.

Flow stream conditioning to eliminate airflow vorticity - CMTI placed a bundle of flow straightening tubes inside the exhaust stack immediately down stream from the tube-axial exhaust fan outlet and just upstream from the pitot traverse path and fixed-pitot location. The tubes in this bundle were 24 inch long sections of aluminum gutter down spout that were tightly packed together to form a series of longitudinal flow channels. The flow channels dampened the turbulence caused by the axial fan motion and forced the swirling air flow motion caused by the rotating fan blades to straighten out and form a smooth parabolic velocity pressure profile at the outlet of the tube bundle. Flow vorticity at the flow measurement location inside the exhaust stack was practically eliminated, which allowed Method 1 and Method 2 flow measurement techniques to be used to measure the exhaust flow rate through the test enclosure.

Styrene Concentration

CMTI used two flame ionization detector (FID) instruments to measure the background styrene concentrations inside the CARL facility building and inside the test enclosure exhaust stack duct.

The stack concentration was measured downstream from the axial fan, so well mixed conditions existed inside the stack at the sample point.

The response signals from the FID instruments were sent to the analog-to-digital converter and the data was recorded in the PC. The FID response to styrene was determined prior to the testing by challenging the instrument with known styrene-in-air concentration samples that were prepared at the facility. The samples were made by injecting a small, known quantity of pure styrene liquid into a Tedlar bag that contained a known volume of pure air. The styrene was allowed to evaporate and mix with the air, and then the bag contents were passed through the FID instrument while the corresponding signal level was noted.

CMTI passed twenty-six (26) styrene samples through the FID instrument to calibrate the styrene response. These samples had styrene concentrations that ranged from 5 to 200 ppmv. Based upon the data from these samples, CMTI developed the following styrene response factor equations:

linear	Y = 0.4265 X - 1.1627	R^2 = 0.9979
polynomial	Y = 4E-05 X2 + 0.4101X - 0.1992	R^2 = 0.9981
power	Y = 0.3603 X1.028	R^2 = 0.9986

Where X is the FID instrument signal level in centivolts and Y is the volumetric styrene concentration in parts per million (ppmv).

CMTI selected the power equation as the best fit for the FID response to styrene. Note that most researchers assume a constant FID response factor for styrene, which proved to be an incorrect assumption for the FID equipment at the CARL facility.

Capture Efficiency Tests (Styrene)

The capture efficiency of the enclosure was further measured by evaporating an open pan of laboratory-grade styrene monomer placed on a small table inside the test enclosure. Initially these styrene capture efficiency test runs resulted in higher-then-possible sample recovery results that could not be explained by simple experimental error. These early tests consistently returned an average of about 108% capture of the styrene mass released in the test enclosure (the average of several runs should have been no more than 100%).

CMTI devoted several months of investigation to solve this mystery prior to the test period. CMTI finally discovered that the variable response of the FID instrument at lower styrene concentrations was the major cause of the higher-than-possible recovery results. When the response factor equation discussed previously was applied to the test data to correct for the variable FID response, the collection efficiency values were nearly perfect (very close to 100%).

Capture Efficiency Tests (Propane)

CMTI obtained several small cylinders of pure propane calibration gas that were carefully weighed by the gas supplier. These cylinder samples were then used to verify the capture efficiency of the test enclosure and setup. Since propane was used instead of styrene, the variable response of the FID instruments to styrene was not a factor. The propane tests resulted in near perfect capture efficiencies, ranging from 98% to 104% of the propane mass that was released inside the enclosure. These near-perfect results for propane strongly supported CMTI's belief that the earlier capture efficiency test results using styrene had been skewed due to the variable response of the FID instrument to different styrene concentration levels. This was especially noticeable at relative low styrene concentrations.

Test Run Results

CMTI conducted sixty-six (66) test runs at the CARL facility during the test period from March 16 through April 6, 2001. Thirty-seven (37) of the test runs involved non-atomized gel coat application. Two different non-atomizing applicators, produced by different equipment manufacturers, were used to apply gel coat to the mold during the non-atomized gel coat test runs. One test runs was aborted due to mechanical difficulties. The other twenty-eight (28) test runs involved an air-assisted airless spray gun, which atomized the gel coat during spray application. Fourteen (14) of these runs incorporated the controlled spray technique developed by CFA to reduce the emission rate from an atomizing gel coat spray gun. The remaining fourteen (14) test runs were uncontrolled, which meant that the controlled spray technique was not employed.

Eight different types of gel coat material were applied to the standard CFA test mold during the test program. These gel coat materials had the following styrene contents:

Description	% Styrene by wt. as Analyzed by Gas Chromatography
Gel coat #1	40.8%
Gel coat #2	19.2%
Gel coat #3	52.0%
Gel coat #4	40.9%
Gel coat #5	29.7%

Gel coat #6	27.7%
Gel coat #7	24.5%
Gel coat #8	30.0%

Two different types of non-atomized gel coat applicators were used during the testing. Two different operators applied gel coat during the testing.

The test data values for all sixty-six experimental test runs are listed in **Table 1**. The thirty-seven non-atomized gel coat test runs, which were used to develop the non-atomized gel coat emission factor equation, are listed in **Table 2**, which follows **Table 1**.

Table 1 - Raw Experimental Data

Test Type	Test Run (#)	Test Code	Styrene Content (% wt)	Styrene Emission Rate (% available styrene)	Styrene Emission Rate (% gel wt)
Uncontrolled	1	Unc	52	54.45%	28.31%
Uncontrolled	2	Unc	52	52.19%	27.14%
Uncontrolled	3	Unc	52 56.	32%	29.29%
Uncontrolled	4	Unc	24.5	42.60%	10.44%
Uncontrolled	5	Unc	24.5	41.28%	10.11%
Controlled AAA	6	Con	24.5	38.35%	9.40%
Controlled AAA	7	Con	24.5	38.78%	9.50%
Controlled AAA	8	Con	24.5	33.18%	8.13%
Controlled AAA	9	Con	*30*	32.04%	9.61%
Uncontrolled	10	Unc	*30*	35.21%	10.56%
Controlled AAA	11	Con	40.9	42.06%	17.20%
Uncontrolled	12	Unc	40.9	47.28%	19.34%
Uncontrolled	13	Unc	29.7	36.35%	10.79%
Controlled AAA	14	Con	29.7	27.83%	8.27%
Controlled AAA	15	Con	27.7	27.00%	7.48%
Controlled AAA	16	Con	27.7	29.61%	8.20%
Uncontrolled	17	Unc	27.7	43.67%	12.10%
Controlled AAA	18	Con	40.8	36.29%	14.81%
Uncontrolled	19	Unc	40.8	46.19%	18.85%
Controlled AAA	20	Con	40.9	35.66%	14.59%
Non-atomized	21	Non-A	40.8	29.72%	12.12%
ABORTED	22		NA	NA	NA
Non-atomized	23	Non-A	40.8	30.62%	12.49%
Non-atomized	24	Non-A	29.7	24.83%	7.37%
Non-atomized	25	Non-A	29.7	24.31%	7.22%
Non-atomized	26	Non-A	52.0	37.25%	19.37%
Non-atomized	27	Non-A	52.0	33.26%	17.30%
Non-atomized	28	Non-A	52.0	35.45%	18.44%

Table 1 - Raw Experimental Data, continued

Test Type	Test Run (#)	Test Code	Styrene Content (% wt)	Styrene Emission Rate (% available styrene)	Styrene Emission Rate (% gel wt)
Non-atomized	29	Non-A	24.5	32.14%	7.87%
Non-atomized	30	Non-A	24.5	30.35%	7.44%
Non-atomized	31	Non-A	40.9	29.56%	12.09%
Non-atomized	32	Non-A	40.9	32.83%	13.43%
Non-atomized	33	Non-A	*30*	26.76%	8.03%
Non-atomized	34	Non-A	*30*	26.17%	7.85%
Non-atomized	35	Non-A	19.2	15.29%	2.94%
Non-atomized	36	Non-A	19.2	17.46%	3.35%
Non-atomized	37	Non-A	19.2	18.38%	3.53%
Non-atomized	38	Non-A	27.7	23.55%	6.52%
Non-atomized	39	Non-A	27.7	24.63%	6.82%
Controlled AAA	40	Con	52.0	45.18%	23.49%
Non-atomized	41	Non-A	52.0	39.98%	20.79%
Non-atomized	42	Non-A	52.0	37.87%	19.69%
Non-atomized	43	Non-A	19.2	19.21%	3.69%
Non-atomized	44	Non-A	19.2	19.90%	3.82%
Controlled AAA	45	Con	19.2	24.03%	4.61%
Controlled AAA	46	Con	19.2	23.75%	4.56%
Uncontrolled	47	Unc	19.2	32.47%	6.23%
Uncontrolled	48	Unc	19.2	30.77%	5.91%
Uncontrolled	49	Unc	*30*	38.02%	11.41%
Non-atomized	50	Non-A	*30*	31.18%	9.35%
Non-atomized	51	Non-A	*30*	31.92%	9.58%
Non-atomized	52	Non-A	*30*	32.88%	9.87%
Controlled AAA	53	Con	24.5	34.57%	8.47%
Uncontrolled	54	Unc	24.5	41.42%	10.15%
Non-atomized	55	Non-A	24.5	29.67%	7.27%
Non-atomized	56	Non-A	24.5	30.96%	7.58%
Non-atomized	57	Non-A	27.7	26.09%	7.23%
Non-atomized	58	Non-A	27.7	25.22%	6.99%
Non-atomized	59	Non-A	40.9	33.43%	13.67%
Non-atomized	60	Non-A	40.9	32.49%	13.29%
Non-atomized	61	Non-A	40.9	33.02%	13.51%
Non-atomized	62	Non-A	40.8	28.60%	11.67%
Non-atomized	63	Non-A	40.8	30.41%	12.41%
Non-atomized	64	Non-A	29.7	27.84%	8.27%
Non-atomized	65	Non-A	29.7	26.32%	7.82%
Non-atomized	66	Non-A	29.7	24.46%	7.26%
	66a		29.7	14.73%	4.38%

Table 2 - Non-Atomized Gel coat Test Data

Test Run (#)	Test Code	Styrene Content (% wt)	Styrene Emission Rate (% gel wt)
21	Non-A	40.8	12.12
23	Non-A	40.8	12.49
24	Non-A	29.7	7.37
25	Non-A	29.7	7.22
26	Non-A	52	19.37
27	Non-A	52	17.30
28	Non-A	52	18.44
29	Non-A	24.5	7.87
30	Non-A	24.5	7.44
31	Non-A	40.9	12.09
32	Non-A	40.9	13.43
33	Non-A	30	8.03
34	Non-A	30	7.85
35	Non-A	19.2	2.94
36	Non-A	19.2	3.35
37	Non-A	19.2	3.53
38	Non-A	27.7	6.52
39	Non-A	27.7	6.82
41	Non-A	52	20.79
42	Non-A	52	19.69
43	Non-A	19.2	3.69
44	Non-A	19.2	3.82
50	Non-A	30	9.35
51	Non-A	30	9.58
52	Non-A	30	9.87
55	Non-A	24.5	7.27
56	Non-A	24.5	7.58
57	Non-A	27.7	7.23
58	Non-A	27.7	6.99
59	Non-A	40.9	13.67
60	Non-A	40.9	13.29
61	Non-A	40.9	13.51
62	Non-A	40.8	11.67
63	Non-A	40.8	12.41
64	Non-A	29.7	8.27
65	Non-A	29.7	7.82
66	Non-A	29.7	7.26

Non-Atomized Gel Coat Emission Factors

Both a linear equation and a power equation were derived for the experimental non-atomized gel coat test data using a standard least-squares approximation curve-fitting routine. The resulting emission factor equations have the following forms:

Linear Equation

Styrene emission rate (% gel coat wt.) = 0.4506 ´ [% styrene] - 0.0505

Power Equation

Styrene emission rate (% gel coat wt.) = 0.5442 ´ [% styrene] 1.5838

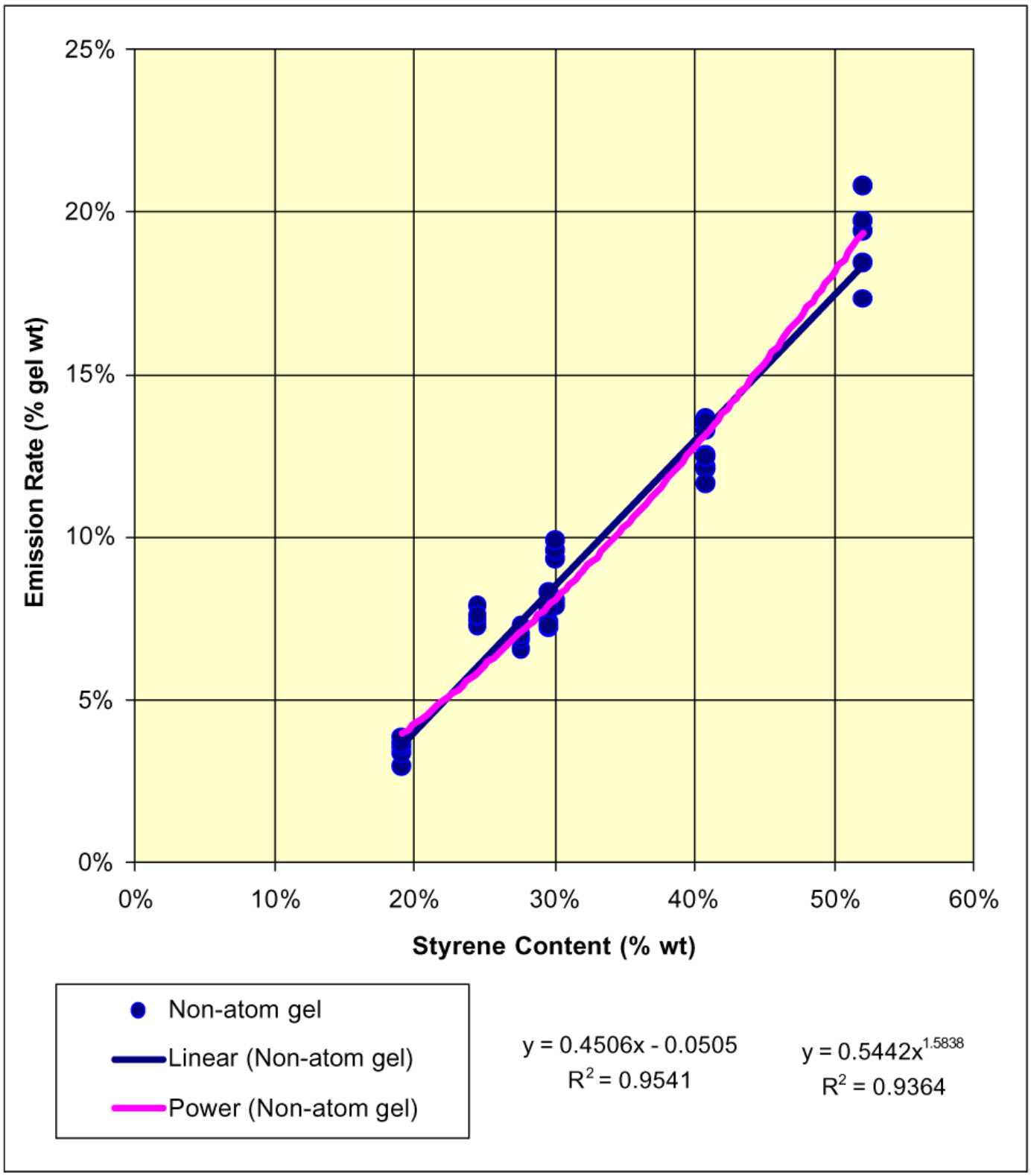
These equations compare the styrene content of a particular gel coat to the corresponding styrene emission rate expressed as a percentage of the gel coat weight. Both the styrene content and the emission rates are input as fractional numerical values (i.e., a 44% styrene content is input as the value 0.44, not as 44). These parameters and units were selected to remain consistent with numerical approach used in the derivation of the current UEF factor equation for gel coat spray application.

The linear equation has a slightly better fit to the experimental data (R2 = 0.9541) than the power equation (R2 = 0.9364). Therefore, the linear equation is selected as the UEF factor equation for estimating styrene emissions from the non-atomized gel coat application process.

The lowest styrene content for the experimental data was 19.2% styrene by weight of gel coat. Hence, a value of 19% was set as the lowest bound of the available experimental data. Based upon the linear equation, the emission rate for non-atomized application of a 19% styrene content gel coat is 3.5% (or 0.035) of the gel coat weight. The equivalent emission rate expressed as a percentage of the available styrene content in the gel coat is 18.5% (or 0.185) of the styrene monomer. In order to remain consistent with the approach used in the current UEF factor equations, a fixed emission rate of 18.5% of the available styrene monomer is assumed for any gel coat with a styrene monomer content less than 19%. This provides a conservative estimator for the lower styrene content gel coats and also causes the resulting emission factor equation to pass through zero emissions at zero styrene content (an important requirement for EPA acceptance).

A plot of the non-atomized gel coat emission factor equation is shown in **Figure 1** on the following page. This plot shows the individual experimental data values, and both the linear and the power equation curve-fits.

Figure 1 - Non-Atomized Gel coat Emission Factor Equations



A comparison of the non-atomized gel coat factor equation to the UEF gel coat spray factor equation is detailed in **Table 3**. A comparison plot of the two equations is shown in **Figure 2** on the following page.

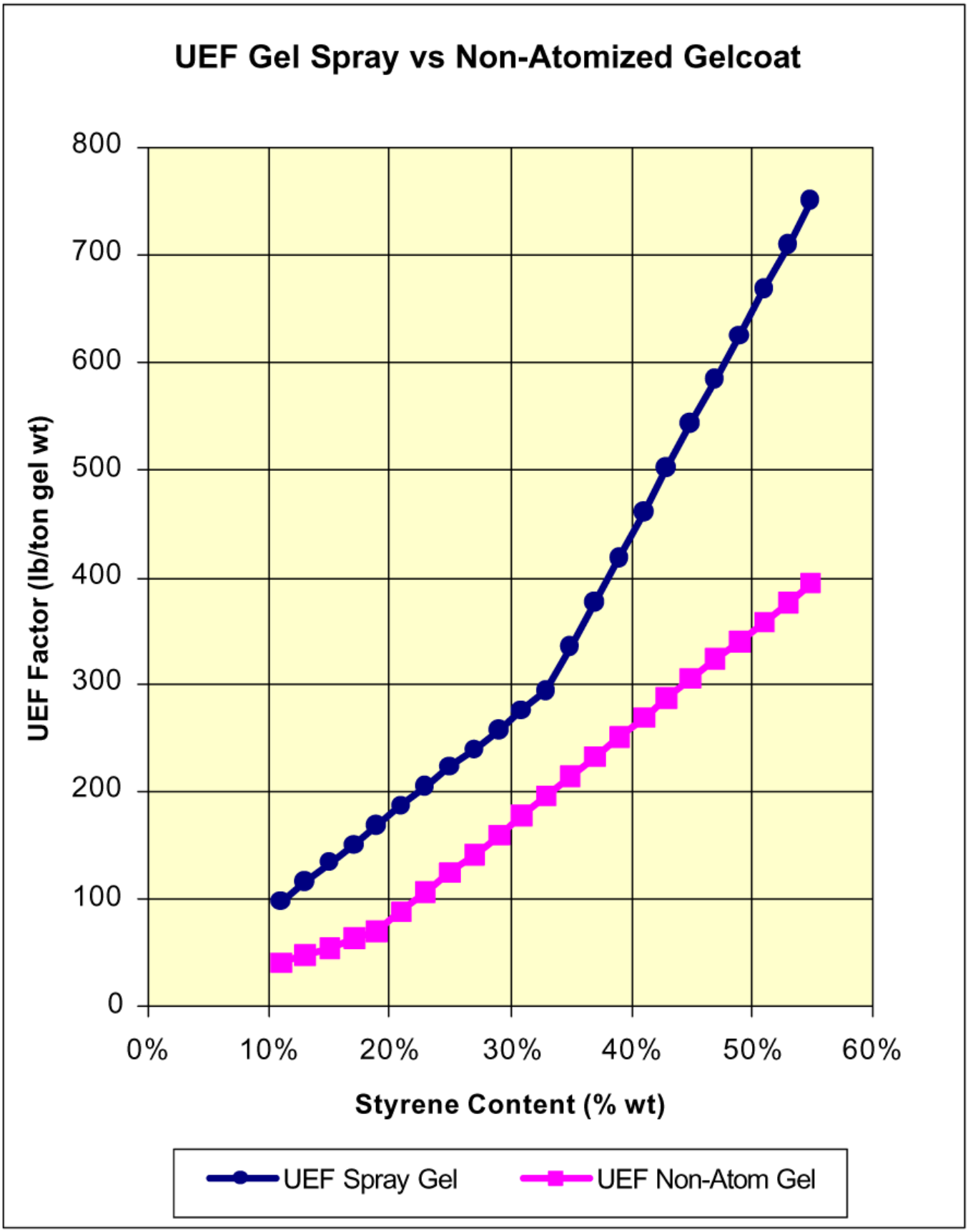
Table 3 - Comparison of Non-Atomized and Atomized (Spray) Gel Coat Factors

UEF Emissions Factors

Styrene Content in Gel Coat	Pounds of Styrene Emitted Per Ton of Gel Coat Applied	
	Atomized	Non-Atomized
19%	169	70
21%	187	88
23%	205	106
25%	223	124
27%	240	142
29%	258	160
31%	276	178
33%	294	196
35%	336	214
37%	377	232
39%	418	250
41%	460	268
43%	501	286
45%	543	304
47%	584	322
49%	626	340
51%	667	359

This data indicates a 43% average reduction in emissions by using the non-atomizing application equipment, although the exact reduction depends on the monomer content of the gel coat.

Figure 2 - Comparison of Non-Atomized and Atomized Gelcoat Emission Factors



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