

The file name refers to the file number, the AP42 chapter and then the section. The file name "rel01_c01s02.pdf" would mean the file relates to AP42 chapter 1 section 2. The document may be out of date and related to a previous version of the section. The document has been saved for archival and historical purposes. The primary source should always be checked. If current related information is available, it will be posted on the AP42 webpage with the current version of the section.

AP42 Section:	4.4
Related:	15
Title:	Open Molding Styrene Emissions Test Project, Phase I- Baseline Study Hand Lay-Up Gel Coating Spray Up Composite Fabricators Association September 1997

*Composites Fabricators Association
Open Molding Styrene
Emissions Test Project*

Phase I - Baseline Study
Hand Lay-Up
Gel Coating
Spray-Up
Final Report

Prepared by:
Robert Lacovara, CFA
Larry Craigie, Dow Chemical
Terry Cowley, Dow Chemical
Paul Wykowski, Dow Chemical
Gary Webster, Dow Chemical

*Composites Fabricators Association
McLean, VA
September 1996*

© CFA 1996

The information contained in this report is property of
the Composites Fabricators Association (CFA)
and is protected under copyright law.

© Composites Fabricators Association 1996

The Composites Fabricators Association has engaged in this styrene emissions test project to enhance the understanding of emissions, and emissions mechanisms, with regard to the open molding process. The CFA offers this information for use by its members, governmental agencies, industry associations and parties who may purchase copies of this report, with the following restrictions and understanding:

This report is to be considered a body of information. The information contained in the Phase I Baseline Test Report and the Optimization Study Report is intended to comprise this body of information. Except by express agreement, CFA does not permit, condone the use, citation or reproduction of unauthorized portions of the information or data contained in this report.

The intended purpose of the above limitations is to prevent potential context limited misunderstanding, misrepresentation of the scope of data, or inappropriate application of this information through the use of portions of this work which do not provide adequate context to properly frame the use of the data. The purpose of these limitations is to safeguard against misuse or misrepresentation of the data contained in this report.

The CFA is willing to provide access to, and accommodate the use of this information. Additionally, CFA is willing to assist individuals, organizations and regulatory agencies in understanding the scope, mechanisms, and implications of styrene emissions from the open molding process, provided the information herein is used in context and within the scope of the body of work.

Composites Fabricators Association
8201 Greensboro Drive, Suite 300
McLean, VA 22102
(703)-610-9025

The Phase I - Baseline Study has provided a mass of data on styrene emissions from the hand lay-up, gel coating and spray-up. These data have been analyzed for the purpose of this report. However, further analysis will be ongoing, as our understanding of styrene emissions increases. The related Optimization Study has shed light on the significant effects of overspray in the gel coat and spray-up process. The Phase II Study, scheduled for completion in late 1996, will provide data on source reduction methods, such as styrene suppressants, filled systems, alternative application equipment, and will explore effects of molding a large female part. The phase II Study is further interrelated to the Phase I study, and therefore the available data will increase greater than the sum of the individual studies.

The goal of this project has been to provide "good science" to the quantification of styrene emissions. To this end the project has been successful in that we have learned how to measure styrene emissions accurately and with good repeatability. The factors which contribute to emissions have been identified, and accurate emissions levels have been established for baseline operating scenarios.

The Project Team

Table of Contents

A. List of Tables & Figures	i
B. Acronyms	iii
Executive Summary	1
1.0 Introduction	6
1.1 Background	6
1.2 Purpose	7
1.3 Approach	7
2.0 Facility and Experimental Set-Up	8
2.1 Laboratory Facility	8
2.2 Temporary Total Enclosure	8
2.3 Exhaust System and Air Flow	8
2.4 Measurement Equipment	9
2.5 Emission Sampling Location	9
2.6 Data Acquisition System	10
2.7 Mold Configuration and Size	12
2.8 Air Flow Over Mold Surface	12
2.9 Application Equipment	13
2.10 Resin and Gel Coat Application	14
3.0 Materials	21
3.1 Resins	21
3.2 Gel Coats	22
3.3 Glass Fiber Reinforcement	22
3.4 Initiator	22
4.0 General Experimental Procedure	23
5.0 Resin Property Testing Laboratory	24
6.0 Critical and Non-Critical Measurements	25
6.1 Explanation of Measurements	25
6.2 Laminate/Gel Coat Thickness	25
6.3 Styrene Content	25
6.4 Gel Time	26
6.5 Resin Flow	26
6.6 Air Flow Over Mold	27
6.7 TTE Temperature	27
6.8 Listing of Critical & Non-Critical Measurements	27
7.0 Experimental Design	30
7.1 Experimental Design for Spray Applications	30
7.2 Experimental Design for Hand Lay-Up Application	30
8.0 Emissions Testing Results	34
8.1 Hand Lay-Up Summary	34
8.2 Gel Coat Summary	34
8.3 Spray-Up Summary	34

8.4 Conclusion of Baseline Studies	34
8.5 Expression of Emissions Data	35
8.6 Data Tables	36
9.0 Data Analysis	97
9.1 Data Reduction	
9.2 Evaluation of Results - Hand Lay-Up Study	97
9.3 Evaluation of Results - Gel Coat Study	107
9.4 Evaluation of Results - Spray-Up Study	115
9.5 Data Analysis Conclusions	123
10.0 Determination of Styrene Emissions	125
10.1 Emission Measurement Methods	125
10.2 Mass Balance Recovery Check	127
10.3 Leak Checks for Sample Limes	127
10.4 Air Flow Through TTE Calibration	127
11.0 Determination of Emission Quantities	129
11.1 Styrene Emissions Calculation	129
11.2 Emissions AS Calculation	129
11.3 Resin/Gel Coat Weight	129
12.0 Equipment Calibration	130
12.1 THA and GC Calibration	130
12.2 Spray Equipment Calibration	130
12.3 Balances Calibration	131
12.4 Gel Timer Calibration	132
12.4 Constant Temperature Water Bath Calibration	132
13.0 Quality Assurance	133
13.1 QA Project Activities	133
13.2 Internal Audit	134
14.0 Data Quality	136
14.1 Precision	136
14.2 Completeness	137
14.3 Accuracy	137
15.0 Laboratory Procedures	139
15.1 Percent Solids Determination	139
15.2 Gel Time Procedure	139
Acknowledgments	141
References	142
Optimization Study	Appendix A
Project Audits	Appendix B
Quality Assurance Project Plan (QAPp)	Appendix C

List of Figures and Tables

Figures:

2.2.1	Temporary Total Enclosure	8
2.7.1	Test Mold	12
2.8.1	Laminar Air Flow Over Mold	13
2.10.1.1	Spray Area Coverage	15
2.10.1.2	Fan Pattern Intercept Angles	16
2.10.1.3	Fan Pattern Intercept Angles	17
2.10.1.4	Hand Lay-Up Coverage Area	18
	Emissions Data Graphs - HLU	46
	Emissions Data Graphs - GC	66
	Emissions Graphs - SU	86
9.2	Main Effects Plot - HLU	104
9.3	Interaction Plots - HLU	104
9.4	Cube Plot of Predicted Response - HLU	106
9.5	Main Effects Plot - GC	112
9.6	Interaction Plots - GC	112
9.7	Cube Plot of Predicted Emissions - GC	114
9.8	Main Effects Plot - SU	120
9.9	Interaction Plot - SU	120
9.10	Cube Plot of Predicted Emissions - SU	122

Tables:

2.6.1	Sample of Camile Data Stream	11
3.1.1	Resin Designation	21
3.2.1	Gel Coat Designation	22
6.5.1	Flow Rate Targets	27
6.8.1	QA Objectives - Critical & Non Crit.	28
6.8.2	Summary of Measurements	29
7.1.1	Code Values	30
7.2.1	Resin Spray Study	31
7.2.3	Gel Coat Study	32
7.3.4	Resin Batch Study	33
8.5.1a	Data Expressions	35
8.1 - 8.10	Hand Lay-Up Data Tables	36
8.11 - 8.21	Gel Coat Data Tables	56
8.12 - 8.32	Spray-Up Data Tables	77
9.1	Effect Test of HLU Study	101
9.2	Effect Test of HLU Study	101
9.3	Evaluation of Blocking Effects	102
9.4	Effects Test - Stepwise Analysis	102
9.5	Effects Table	103
9.6	Effects Table	103
9.7a	Summary of Fit	105
9.7b	One-Way Analysis	105
9.7c	Lack-of-fit Table	105
9.8	Effect Test of GC Study	109
9.9	Evaluation of Blocking Effects	109
9.10	Effect Test of GC Study	110
9.11	Effects Test - Stepwise Analysis	110
9.12	Effects Table	111

9.13	Effects Table	111
9.14	Summary of Fit	111
9.15a	Summary of Fit	113
9.15b	One-Way Analysis	113
9.15c	Lack-of-fit Table	113
9.16	Effects Test SU Study	117
9.18	Evaluation of Blocking Effects	117
9.18	Effect Test of SU Study	118
9.19	Effects Test - Stepwise Analysis	118
9.20	Effects Table	119
9.21	Effects Table	119
9.22a	Summary of Fit	121
9.22b	One-Way Analysis	121
9.22c	Lack-of-fit Table	121
14.1.1	% Emissions & Relative % Diff.	136
14.3.1	% Styrene Recovery % Relative Error	138

ACRONYMS

AAA	Air-assisted airless
AF	Air Flow
AP-42	EPA's <i>Compilation of Air Pollutant Emissions Factors</i>
AS	Available styrene
CAAA	Clean Air Act Amendment
CAMP	Clean Air Management Partnership - (CFA, SPI/CI, NMMA, ICPA)
CFA	Composites Fabricators Association
EPA	U.S. Environmental Protection Agency
FID	Flame ionization detector
FRP	Fiberglass reinforced plastics
FRP/C	Fiberglass reinforced plastics/composites
GC	Gas Chromatograph
GC	Gel Coat
GT	Gel Time
HLU	Hand Lay-UP
ISO	International Standards Organization
MACT	Maximum Available Control Technology
MEKP	Methyl Ethyl Ketone Peroxide
MMA	Methyl methacrylate
NDO	Natural draft opening
QAP	Quality Assurance Plan
QAPp	Quality Assurance Project Plan
RF	Resin Flow
RTI	Research Triangle Institute
RW	Resin weight
SC	Styrene Content
SU	Spray-Up
TH	Thickness
THA	Total hydrocarbon analyzer
TTE	Temporary total enclosure
VOC	Volatile organic compound

Executive Summary

The CFA sponsored *Open Molding Styrene Emissions Test Project* is the most extensive research conducted to date on this subject. The scope, details and data quality produced by this project have provided a fundamental understanding of styrene emissions measurement techniques, and the factors contributing to styrene emissions. In addition, the EPA Category II Quality Assurance Project Plan qualification provides a level of recognition and confidence in this work which is unprecedented by any other study or emissions test project.

Phase I of this project is a Baseline Study of the hand lay-up, gel coating, and spray-up (chopping) processes. In the baseline study, no attempt was made to reduce or control emissions. The application practices employed are considered typical for uncontrolled processing. The parameters of the experimental variables (i.e. styrene content, gel time, thickness, air flow and material flow) are again typical of what may be found in the industry. However, the range of these variables does not approximate the range that might be found across the scope of the industry. For example, the mold used for these experiments is a male mold with a surface area of approximately 37 square feet. Molds which are larger or smaller, and in both male and female configuration, can be found throughout the industry. These data represent an accurate picture of styrene emissions within the parameters of this project, and form the foundation for understanding a larger scope of the industry.

The data presented in this Phase I Study indicates emissions levels higher than current EPA AP-42 factors for uncontrolled processing. However, it has been shown that substantial reductions in emissions are available through relatively minor resin/gel coat formulation changes, and straightforward refinements in application techniques. Some of these material formulation changes are explored with the use of high and low styrene content resin/gel coats, or in the fast and slow gel times represented in the experimental design. The subsequent *Gel Coat/Spray-Up Optimization Study* explores modifications to application technique which resulted in substantial and easily attainable reductions in emissions.¹

The Open Molding Styrene Emissions Test Project - Phase I Study experimental runs were conducted by the Composites Fabricators Association, at a Dow Chemical applications laboratory facility in Freeport, Texas, between September 19, 1995 and December 14, 1995. A total of 60 valid experimental runs were made during this time period. The follow-up *Gel Coat/Spray-Up Optimization Study* was conducted from February 21, 1996 to March 7, 1996. Phase II of the Project, which is specifically exploring source reduction and pollution prevention methods was initiated in May, 1996 and is expected to be finalized in the 3rd quarter of, 1996.

An extensive pilot program preceded this study, in which the operation of the temporary total enclosure, exhaust stack air flow, measurement equipment, and experimental procedure was established and refined. The test set-up was then transferred to another building in the Dow complex, where final improvements were incorporated for the "official" experimental runs. The sophisticated data acquisition system incorporated in this study has provided unprecedented data resolution, and correlation of data to operating conditions.

The Baseline experiments were conducted using an orthophthalic polyester resin and a polyester gel coat with styrene as the sole monomer. Hand lay-up laminates were fabricated using chopped

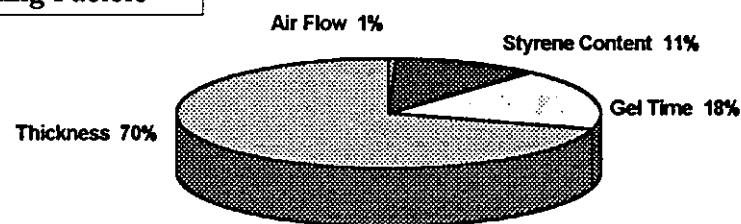
strand mat, while the spray-up laminates used continuous strand roving. For gel coating and spray-up, an air-assist airless (AAA) spray unit, which is common throughout the industry, was used.

Statistical analysis of the resulting data has shown a high level of confidence in validity, and the repeatability of replicate experiments has proven to be very accurate. Resulting emissions are expressed in a number of forms in the data tables. This includes: % emissions by resin weight (%RW); % emissions by available styrene (%AS); grams of emission per square foot (g/ft^2); grams of emission per square meter (g/m^2); and Normalized Surface Area Emissions ($\text{g}/\text{ft}^2/\text{kg}$); and pounds of emission per ton of resin (lbs/Ton). The test results as discussed in this document are expressed as percent emissions of available styrene (AS). Available styrene can also be expressed as percent emissions per resin styrene content. Analysis of the data based on each of the various expressions yields a slightly different view of the results. For example, the analysis of surface area emissions vs. emissions based on weight of resin, yields a different ranking of test results. This analytic flexibility allows a better understanding of the emissions mechanism, and will contribute to the construction of more accurate modeling of emissions.

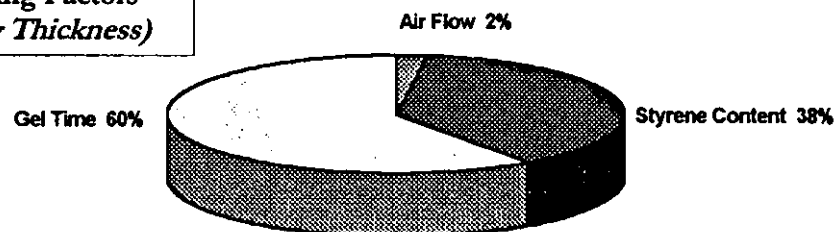
Hand Lay-up Summary

The major factors contributing to styrene emissions in the hand lay-up process are: Laminate thickness; Gel time; Styrene content. Air flow, in the range of 50 -100 fpm, over the mold surface is a insignificant factor. An average of 14.1% emissions (AS) was produced for all experimental runs. Emissions ranged from 9.8% to 21.1% (AS). The combination of a thick laminate, low styrene content, fast gel time and low air flow produced the lowest emissions at 9.8% AS. At the high end of the range, a thin laminate, high styrene content, slow gel time and high air flow produced 21.1% (AS) emissions. Approximately 50% of total emissions were produced during the resin application phase of the process (transferring resin from the bucket to the laminate with a paint roller). 25% of total emissions were produced during the laminate roll-out sequence and the remaining 25% emissions were produced in the post roll-out curing stage.

**Hand Lay-Up Emissions -
Contributing Factors**

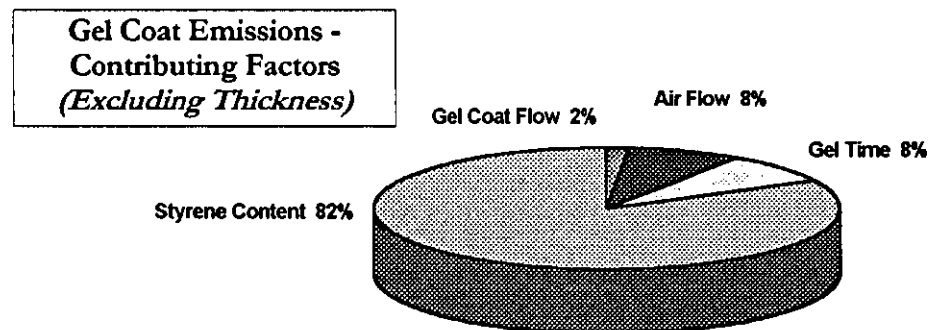
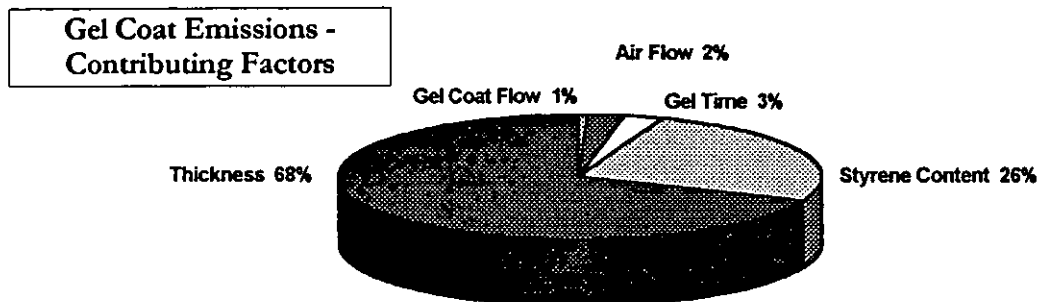


**Hand Lay-Up Emissions -
Contributing Factors
(Excluding Thickness)**



Gel Coat Summary

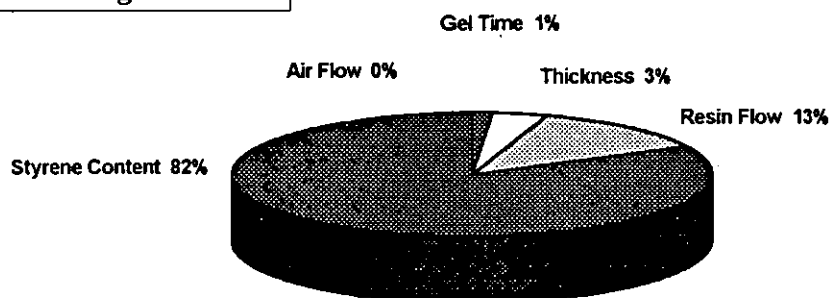
The major factors contributing to styrene emissions in the gel coat process are: Film thickness and Styrene content. Gel time and air flow over the mold are minor factors, while gel coat flow rate is an insignificant factor. An average of 51.4% emissions (AS) was produced for all experimental runs. Emissions ranged from 43.5% to 61.8% (AS). The combination of thick film, low styrene, fast gel time, high gel coat flow and low air flow produced the lowest emissions at 43.5% (AS). At the high end of the range, a thin film, high styrene, slow gel time, high gel coat flow and low air flow produced 61.8% (AS) emissions. Approximately 50% of total emissions were produced during the spray application and 50% during the curing stage.



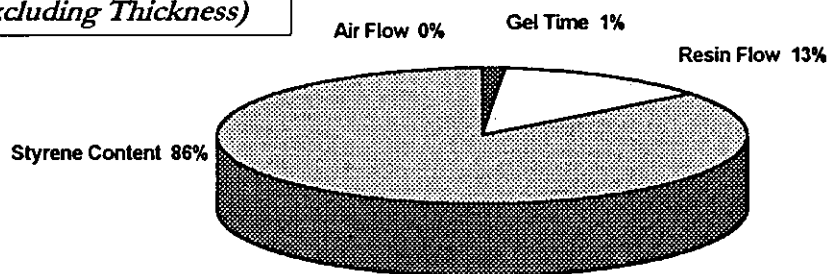
Spray-up Summary

The major factors contributing to styrene emissions in the spray-up process are: Styrene content and resin flow rate. Thickness was a smaller contributor, and a two factor interaction of styrene content + resin flow is a significant factor. Air flow was an insignificant factor. An average of 25.0% emissions (AS) was produced for all experimental runs. Emissions ranged from 17.1% to 38.0% (AS). The combination of thick laminate, low styrene, fast gel time, low resin flow and high air flow produced the lowest emissions at 17.1% (AS). At the high end of the range, a thick laminate, high styrene, slow gel time, low resin flow and high air flow produced 38.0% (AS) emissions. Approximately 50% of total emissions were produced during the spray application, 25% during the laminate roll-out, and 25% during the post roll-out curing stage.

Spray-Up Emissions - Contributing Factors



Spray-Up Emissions - Contributing Factors (Excluding Thickness)



Conclusion of Phase I Baseline Studies

In all three studies, styrene content was consistently a major factor. Laminate or film thickness, gel time and resin flow rate are emissions contributors in varying degrees. Air flow over the mold was an insignificant factor in all cases. The combination of styrene content and resin flow, in the spray-up study, was the only significant two factor interaction in all the studies. The combination of thick laminate/film, low styrene content and fast gel time is consistent in producing the lowest emissions in all three studies.

Significance of Effects of Contributing Emissions Factors
Table ES-1

Factor	Hand Lay-Up	Gel Coat	Spray-Up
Thickness	Major	Major	Minor
Styrene %	Major	Major	Major
Gel Time	Major	Minor	Minor
Resin Flow	N/A	Insignificant	Major
Air Flow	Insignificant	Minor	Insignificant

Optimization Study

The objective of the Optimization Study was to explore the effects of optimizing the spraying process for both gel coat and spray-up resin application. Whereas in the Baseline studies no attempt was made to control emissions, this study sought to quantify the effects of changes to the spray gun and application technique. The Optimization Study was carried out under the same rigorous Category II Quality Plan parameters as the Baseline study. (Refer to appendix for full text of Optimization Study Final Report).

The results of this study indicate that the reduction of overspray, through optimized spray gun set-up and controlled spraying technique, makes major contribution to reduced styrene emissions. Gel coat emissions were reduced by over 40%, and spray-up emissions by over 20% with controlled spraying techniques. Extrapolating these reductions to the range of emissions from the Baseline Studies finds the potential to reduce gel coat emissions to between 25.4% and 36%. While spray-up emissions can be reduced to between 13.4% and 29.8%. This brings the gel coat emissions within the range of current EPA AP-42¹ emissions factors, and spray-up emissions within the upper range of the AP-42 factors.

Optimization Study Conclusions

Optimization of spray gun set-up and spraying technique can have a highly significant impact in reducing emissions. These methods provide substantial pollution prevention opportunities in the form of source reduction and bring emission factors within, or in proximity to, AP-42 emission factors. Recommendations are outlined in the Optimization Study Report, and include comments on proper spray gun set-up, tip pressure, operator training, spraying technique and overspray capture. It is recommended that these optimization methods be considered a primary form of pollution prevention and source reduction for all polyester/vinyl ester resin and gel coat spraying operations.

¹ AP-42, U.S. EPA, Office of Air Quality Planning and Standards, *Compilation of Air Pollutant Factors (AP-42)*, Research Triangle Park, NC, September 1988

Section 1.0

Introduction

1.1 Background

The industries using unsaturated polyester and vinyl ester resins process an estimated 1.4 billion pounds of resin per year. Various industry estimates indicate a range of 40% to 70% of this resin is used in the open molding processing category. A wide and diverse range of products are produced through open molding, including: corrosion control and pollution prevention products; transportation products; marine products; architectural products; sports and leisure products; and custom molded products.

Because of the versatility of composites, including the fact that many companies manufacture composites as a component of other products, it is difficult to ascertain the absolute size and scope of the industry. Recent surveys estimate that between 3,000 and 5,000 companies are engaged in composites production. These operations may range in size from literal "mom and pop" two person operations, to facilities employing nearly 1000 workers. It is estimated that at least 150,000 workers are employed by the U.S. composites industry, and that the industry contributes over \$16 billion annually to the U.S. economy.²

As a result of the 1990 Clean Air Act Amendment, the USEPA is developing a maximum available control technology (MACT) standard for the open molding composites industry. This standard is focused on styrene emissions from the molding process. Currently EPA's *Compilation of Air Pollutant Emission Factors (AP-42)* is the primary source of styrene emission factors for both the agency and the industry. A series of unrelated emissions tests conducted by EPA contractors and other sources have shown a wide range of emission factors. The purpose of the CFA Open Molding Styrene Emissions Test Project is to identify and quantify contributing factors to styrene emissions, and to establish baseline emission levels from the open molding process.

The open molding industry uses the hand lay-up, spray-up and gel coating processes. Gel coat is used to provide a cosmetic and weatherable exterior surface for composite products. Both the hand lay-up and spray-up processes use thermoset resin and a reinforcement fiber to create the structural laminate. Polyester or vinyl ester resins, and glass fiber reinforcement are most commonly used by a vast majority of the industry.

The hand lay-up process is defined as the manual application of resin to the (glass) fiber reinforcement. The resin and initiator are mixed in a container and applied to the laminate using a brush, paint roller, squeegee or similar tool. Following saturation of the fiber reinforcement a "roll out" sequence takes place, where an FRP roller is used to remove entrapped air and consolidate the laminate.

The resin spray-up application is defined as the use of a "chopper gun" to apply a laminate. The chopper gun dispenses resin, catalyst and chopped glass fibers. Continuous strand fiberglass roving is fed to a chopper unit mounted on the spray gun and is cut into chopped short fiber lengths. The chopped fiber is ejected from the chopper unit and is captured by the resin fan pattern a short distance from the spray gun. The mixture of the catalyzed resin and chopped fiber is deposited on the mold by the spraying action.

Gel coat application uses a spray gun. The gel coat and initiator are mixed during the spraying process, and the "catalyzed" gel coat is deposited on the mold surface in a uniform film. In the fabrication of composites parts using gel coat, the gel coating process is identical for both the hand lay-up and spray-up laminating process.

This project was initiated to provide to the aforementioned baseline data on styrene emissions and to serve as the foundation for a follow-on project which will seek to document emission reduction or pollution prevention techniques.

² Composites Fabrication, April 1996, *Developing the Demographics of the Composites Industry*, Joseph McDermott, Composites Fabricators Association, Arlington, Virginia, 1996.

1.2 Purpose

This study has several major objectives which define the purpose of the endeavor. The first goal was to learn how to measure styrene emissions from the open molding process accurately, with repeatability and with scientific verification of the results. The second goal is to identify the contribution of various factors to styrene emissions and to collect data on the effects. These factors include items such as thickness, gel time, styrene content, air flow, and spray gun flow rate. The third goal is to establish baseline emission levels from the open molding process, which can be used to determine the effectiveness of pollution prevention techniques. The fourth objective is to provide the industry and government agencies accurate and reliable information on styrene emissions. To this extent, this project has been certified under an EPA Category II Quality Assurance Plan, which provides a high level of confidence in the experimental plan and data collection.

1.3 Approach

It has been determined that the use of an orthophthalic formulation polyester resin is representative of a large portion of the open molding industry. The styrene content of the resin formulated for the test project is also representative of many other formulations of unsaturated polyester or vinyl ester resins. A majority of companies reported using air-assisted airless (AAA) spray equipment in the 1994 CFA Benchmarking survey, therefore this type of application equipment was selected as the "baseline" for the industry. The air flows, gel times, laminate thickness, spray gun flow rates and environmental conditions used are considered typical within industry norms. The application technique, for the spraying experiments in the initial baseline study, is termed "uncontrolled". In this context, uncontrolled spraying, uses typical methods found in most fabrication facilities, where overspray is the result of spraying off the edge of the mold. A study of video tapes provided data on the distance and time of "off-mold" spraying. This study attempted to reproduce the typical amount of overspray which results from uncontrolled spraying.

The molding process is housed in a temporary total enclosure (TTE) and analytical equipment measures styrene concentration in the TTE exhaust stack. Styrene concentrations are measured in parts per million (ppm), and expressed in grams of emissions. Total grams of emissions will be expressed as: Emissions percent per weight of available styrene (%AS); Emissions percent per resin weight (%RW); Emissions per unit surface area (g/ft²; g/m²; g/ft²/kg normalized); And pounds of emissions per ton of resin (lbs/Ton).

Section 2.0

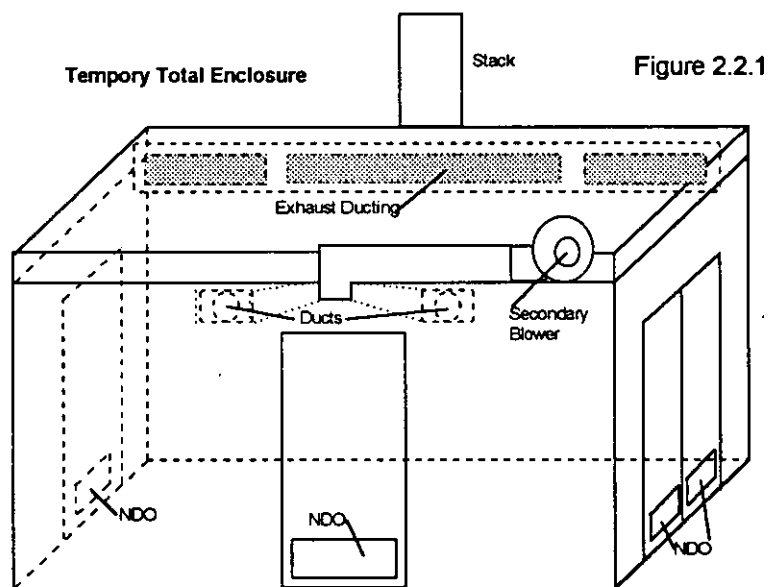
Facility and Experimental Setup

2.1 Laboratory Facility

The project was conducted in the Composites Applications Laboratory, B-1603, Dow Chemical Company, Freeport, Texas. The laboratory is temperature controlled and is used exclusively during experimental runs to minimize background VOC concentrations. An analytical laboratory is also located within the facility, with equipment and personnel to analyze resin properties and modify resin or gel coat formulations as required. The facility is ISO 9001 certified. The measurement and analytical equipment used in the project is registered and maintained under ISO certification.

2.2 Temporary Total Enclosure

The temporary total enclosure (TTE) consists of an 8' high x 12.5' wide x 15' long four sided room covered by a 12.5' x 15' exhaust hood. (See figure 2.2.1). The enclosure is within the temperature controlled applications laboratory. The walls of the enclosure are constructed of wood studs covered by clear mylar™ sheeting, with access doors on three sides. Natural draft openings (NDO's) are arranged in accordance with EPA Method 204. The NDO's are baffled to prevent the incoming air from flowing over the mold surface, while still providing the required 200 fpm flow through the openings, as required by Method 204.



2.3 Exhaust System and Enclosure Air Flow

The exhaust hood contains a plenum approximately 14' wide with louvered openings across width. The plenum connects to two "Y" ducts which join the single exhaust stack outside the laboratory. The air movement is accomplished with a centrifugal blower which joins the horizontal section of stack on the roof to the vertical stack. A total airflow of approximately 1400 cfm will be maintained through the enclosure with an electronic airflow traverse probe utilizing a VorTek™ velocity sensing system and Camille® Data Collection System. (See Appendix - Quality Assurance

Project Plan for description of air flow velocity sensor). The air velocity sensing system monitors and adjusts air flow within the stack to maintain the required air flow throughout the experimental run. A Dwyer™ manometer is connected to the exhaust stack as a back-up to the VorTek™ system and a quality assurance check at the initiation of each experimental run. There is 100% capture efficiency of air in the temporary total enclosure.

A secondary blower provides a known air flow over the mold surface. This blower is mounted outside of the test enclosure and draws air from within the test area, returning it through two (2) ducts which direct a uniform flow of air across the mold surface. The air flow across the mold is calibrated to high and low velocities of 100 fpm and 50 fpm, respectively.

The innovation of baffling the NDO's and using the secondary blower allows the use of EPA Method 204, requiring a minimum of 200 fpm through the enclosure, while retaining the ability to control the air flow over the mold surface at various rates less than 200 fpm.

2.4 Measurement Equipment

Two instruments have been employed simultaneously to measuring styrene concentrations in the exhaust stack. The primary measurement instrument is a total hydrocarbon analyzer, used according to EPA Method 25A, as described in the Code of Federal Regulations, Chapter 40, Part 60. The Thermo Environmental Instruments, Inc. Model 51 heated Total Hydrocarbon Analyzer (THA) uses a flame ionization detector (FID) that converts hydrocarbons in proportion to the to the number of atoms transiting the detector. The THA provides continuous data output, which in this case is cycled in one second intervals, with a two second interval signal output to the data acquisition system.

The secondary measurement instrument is a Varian 3700 gas chromatograph (GC), equipped with a flame ionization detector. The gas chromatograph is configured to cycle samples every 120 seconds, with the signal output to a Hewlett-Packard Integrator, which provides a print copy of data during the 120 second sample cycle.

The THA recognizes any hydrocarbon compound, whereas the gas chromatograph indicates the presence of styrene with a unique peak response. If extraneous hydrocarbons are present during a test, the THA would record a higher peak than the gas chromatograph. It was not known during the original pre-trials if other hydrocarbons would be present. There have been no hydrocarbons other than styrene detected in the course of the study.

Both analytical units will use sample probes in the form of pitot tubes in the enclosure exhaust duct. The THA sample probe is a "rake" type pitot tube having three (3) sample points. The sample points are a hole located in the center of the duct and two holes located 10% of the duct diameter from the edge of the duct. The GC sample point is a "S" type pitot tube located in the center of the duct.

2.5 Emission Sampling Location

Calibrated pitot tubes for the total hydrocarbon analyzer and the gas chromatograph are located in the horizontal section of the stack, upstream from the exhaust blower..

2.6 Data Acquisition System

A Dow Camille® Data Acquisition System is used to display real time data inputs, record data and control exhaust air flow. The computer based Camille® system receives data from the THA at two second intervals and from the GC at 120 second intervals; monitors and continually adjusts stack exhaust flow; continuously records temperature; records digital output from the resin weight balance; and records the trigger position of the spray gun. Data is displayed on screen and is written to the internal hard disk and to a floppy disk. Following is a sample of the Camille® data stream which is both written to storage and displayed graphically on the system monitor:

SAMPLE OF CAMILE DATA STREAM Raw Data Display

Raw Data Display

Total Hydrocarbon Analyzer Output - Styrene Stack Concentration. Emissions Calculations Based on this Data

Enclosure Temperature

Spray Gun Trigger Sensor - Gun On/Off

Gas Chromatograph Output - Styrene Stack Concentration. Data Points at 120 Second Intervals

Actual Time: Data Points in 2 Second Intervals

Stack Air Flow Monitored and Adjusted By Camile System

Running Resin Weight as Applied

THA Internal Running Averages

THA Internal Time

GC Internal Time

Camile System Internal Time

Date (d-m-y)	Time (hh:mm:ss)	THA (ppm)	Air Flow (cfm)	Temp °F	Resin Wt. (g)	THA Serial Avg.	Gun (0=off/1=on)	THA High Avg.	THA Low Avg.	THA Serial Time	GC Time	GC (ppm)	GC Sample #	Camile Time
15-Nov-95	15:45:53	22.263	1466.01	72.4	-0.9453	1.2	0	1.2	1.2	60120	56587	16.698	254	56753
15-Nov-95	15:45:55	34.194	1471.24	72.4	-0.9790	1.2	0	1.2	1.2	60120	56587	16.698	254	56755
15-Nov-95	15:45:57	40.335	1470.36	72.4	-0.9790	1.2	0	1.2	1.2	60120	56587	16.698	254	56757
15-Nov-95	15:45:59	61.936	1473.15	72.4	-0.9790	1.2	0	1.2	1.2	60120	56587	16.698	254	56759
15-Nov-95	15:46:01	66.711	1470.11	72.4	-0.9800	1.2	0	1.2	1.2	60120	56587	16.698	254	56761
15-Nov-95	15:46:03	62.511	1467.59	72.4	-0.9838	1.2	1	1.2	1.2	60120	56587	16.698	254	56763
15-Nov-95	15:46:05	73.428	1470.78	72.4	-1.0540	1.2	1	1.2	1.2	60120	56587	16.698	254	56765
15-Nov-95	15:46:07	80.252	1470.28	72.4	-1.0560	1.2	1	1.2	1.2	60120	56587	16.698	254	56767
15-Nov-95	15:46:09	80.145	1474.78	72.4	-1.0880	1.2	1	1.2	1.2	60120	56707	16.698	255	56769
15-Nov-95	15:46:11	86.946	1482.21	72.4	-1.2178	1.2	1	1.2	1.2	60120	56707	16.698	255	56771
15-Nov-95	15:46:13	108.563	1479.80	72.4	-1.2670	1.2	1	1.2	1.2	60120	56707	16.698	255	56773
15-Nov-95	15:46:15	112.662	1475.34	72.4	-1.2670	1.2	0	1.2	1.2	60120	56707	16.698	255	56775
15-Nov-95	15:46:17	124.262	1466.28	72.4	-1.2660	1.2	1	1.2	1.2	60120	56707	16.698	255	56777
15-Nov-95	15:46:19	126.309	1467.75	72.4	-1.2660	1.2	0	1.2	1.2	60120	56707	16.698	255	56779
15-Nov-95	15:46:21	126.560	1470.26	72.4	-1.2660	1.2	0	1.2	1.2	60120	56707	16.698	255	56781
15-Nov-95	15:46:23	122.116	1476.63	72.4	-1.2660	1.2	0	1.2	1.2	60120	56707	16.698	255	56783
15-Nov-95	15:46:25	112.566	1480.99	72.4	-1.2660	1.2	0	1.2	1.2	60120	56707	16.698	255	56785
15-Nov-95	15:46:27	109.496	1478.31	72.4	-1.2660	1.2	0	1.2	1.2	60120	56707	16.698	255	56787
15-Nov-95	15:46:29	102.674	1471.86	72.4	-1.2660	1.2	0	1.2	1.2	60120	56707	16.698	255	56789
15-Nov-95	15:46:31	100.628	1466.16	72.4	-1.2660	1.2	0	1.2	1.2	60120	56707	16.698	255	56791

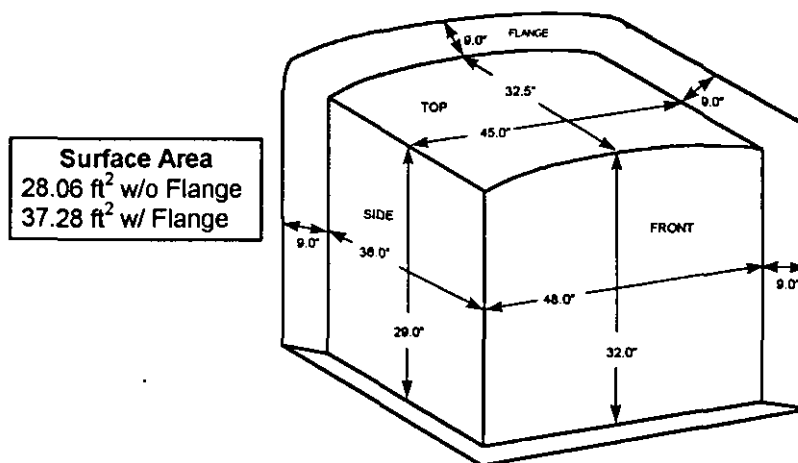
Spray-Up Runs May Log Between 4000 and 7000 Data Points

Table 2.6.1

2.7 Mold Configuration and Size

The mold used for these experiments is a three sided male mold constructed of steel and mounted on a wheeled dolly. The mold has a 9" angular flange on the three primary planes, designed to catch overspray during controlled spraying experiments. Mold dimensions are as follows:

Figure 2.7.1
TEST MOLD

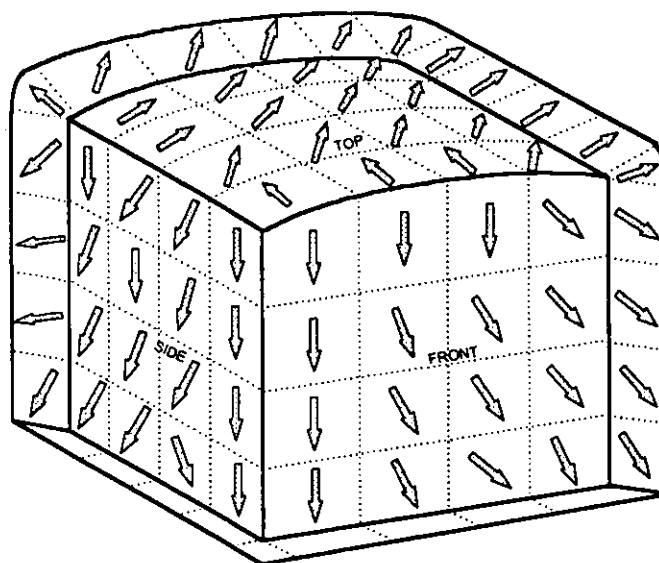


2.8 Air Flow Over Mold Surface

Outside air drawn into the TTE is baffled, so as to eliminate general exhaust flow over the mold. A secondary blower draws air from within the enclosure and is ducted to create a direct flow over the mold surface. This air flow can be adjusted to various flow rates including 50 fpm and 100 fpm as used during the experiments. Air velocity at the mold was measured with a hot wire anemometer to calibrate and document flow rate. Prior to beginning the experiments, a handheld bulb type smoke generator was used to map the direction of laminar air flow within 1/4" (6mm) of the mold surface. The general "aim point" of the air flow is the corner intersecting the front, top and side of the mold.

Figure 2.8.1

Laminar Air Flow Over Mold Surface



2.9 Application Equipment

Spray equipment consists of an air-assisted airless plural component spray unit capable of being set-up to spray gel coat, resin or be fitted with a chopper unit. The fluid pump is a 14.5 to 1 air over fluid pump, with a piston driven catalyst slave pump. The fluid pump is capable of producing spray gun tip pressures that range from 435 psi as the lowest workable pressure to over 1400 psi at a maximum pump input pressure of 100 psi. Over the range of testing, pump pressures ranged from 45 psi to 67 psi to produce the required flow rates dictated by the experimental plan. Air assist pressures ranged from 45 psi to 55 psi for various gun setups.

The spray unit was retro-fitted with several devices to assist in calibrations and measurements: A graduated cylinder catalyst reservoir replaced the standard catalyst container and was used to calibrate and measure catalyst flows; An air flow rotameter was placed in the chopper air source line and used to calibrate the chopper unit glass output; And a magnetic proximity switch was mounted on the spray gun trigger to report the trigger position to the Camille data acquisition system.

2.10 Resin and Gel Coat Application Procedure

2.10.1 Uncontrolled vs. Controlled Spraying

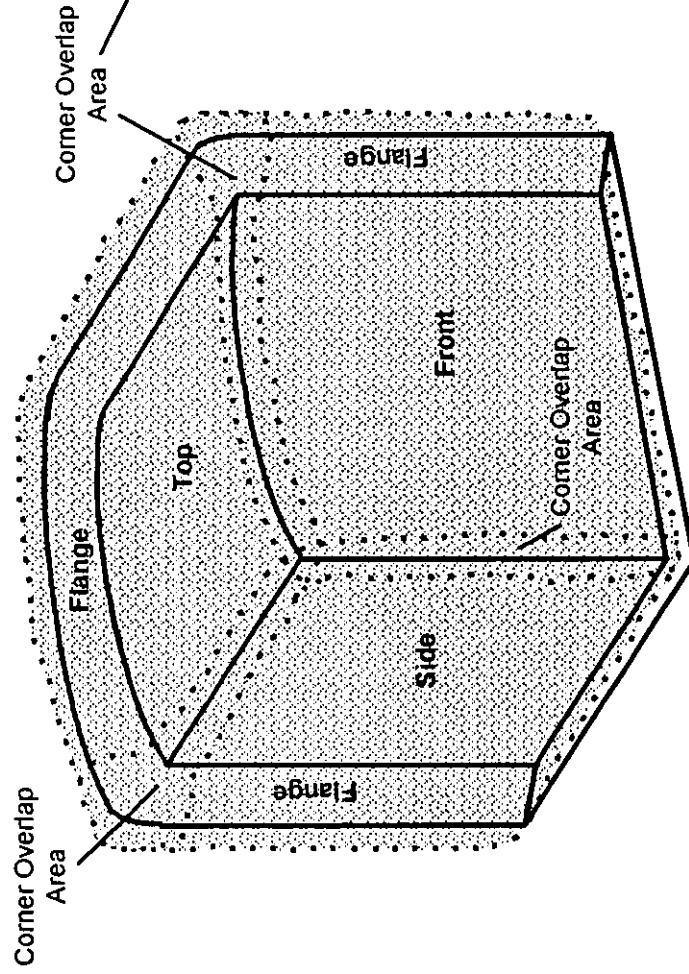
The Baseline Study was conducted using an uncontrolled spraying technique. This involves producing overspray which would be considered typical or normal for application of this type and configuration mold. A study of video tapes was conducted to determine the distance and duration of overspray off the edge of various molds. It was determined that carrying the spray gun stroke approximately 6" off the edge of the mold, would produce conditions considered typical of uncontrolled spraying. In addition, fan pattern intercept angles were used which would represent a typical industry application.

The controlled spraying technique used in subsequent Optimization Studies contains the overspray to the greatest extent possible within the flange of the mold. In this case the fan pattern intercept angles and maintained as close to 90° to the surface as possible.

The ramifications of surface area coverage become apparent when taking overspray into account. As illustrated in Figure 2.10.1.1 , the effective surface area of the uncontrolled application is 53.94 ft², while the controlled technique has an effective area of 34.58 ft².

Figure 2.10.1.1
 Spray Area Coverage - Spray-Up & Gel Coating

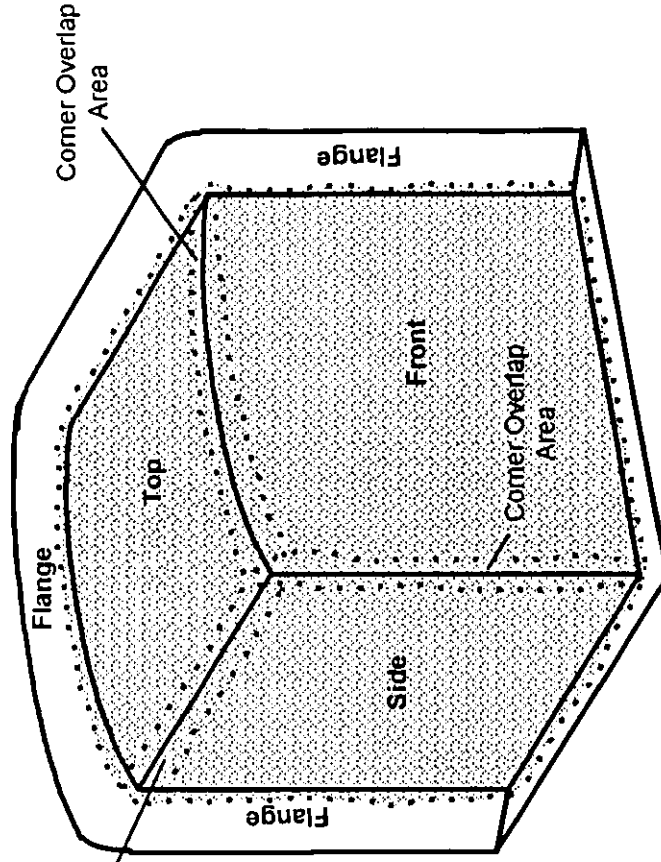
Uncontrolled Spray Technique
 Overspray Approx. 6" Off Mold Flange



Mold Surface Area
 37.28 ft² inc. Flange

Effective Spray Coverage:
 53.94 ft² inc. Overspray Area

Controlled Spray Technique
 Overspray Contained By Flange

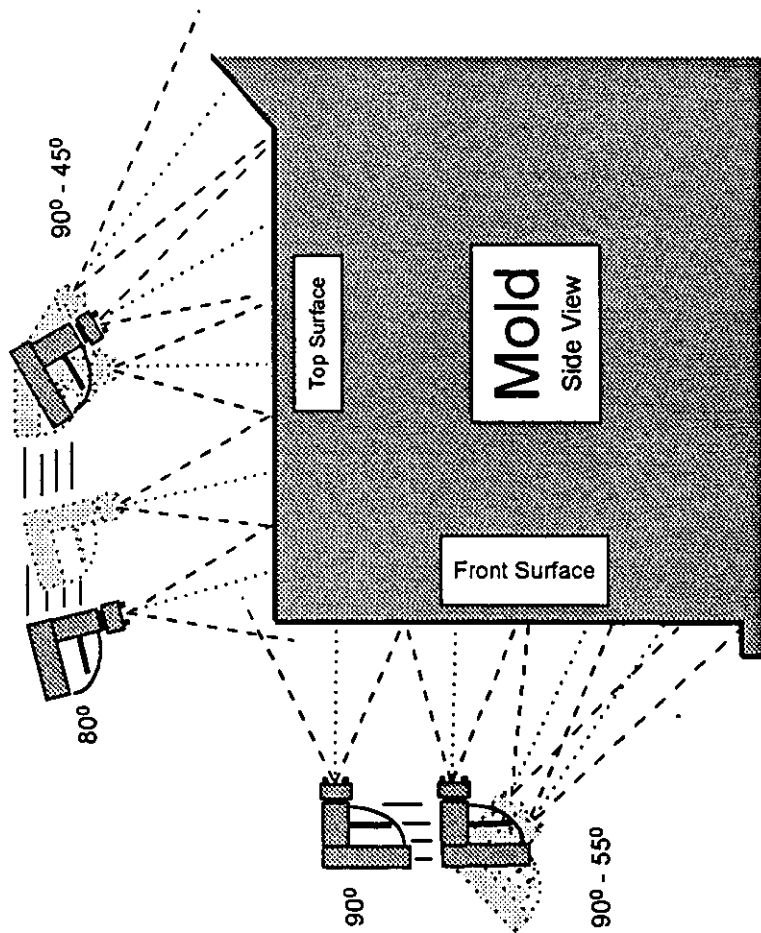


Mold Surface Area
 28.06 ft² without Flange

Effective Spray Coverage:
 34.58 ft² inc. Overspray Area

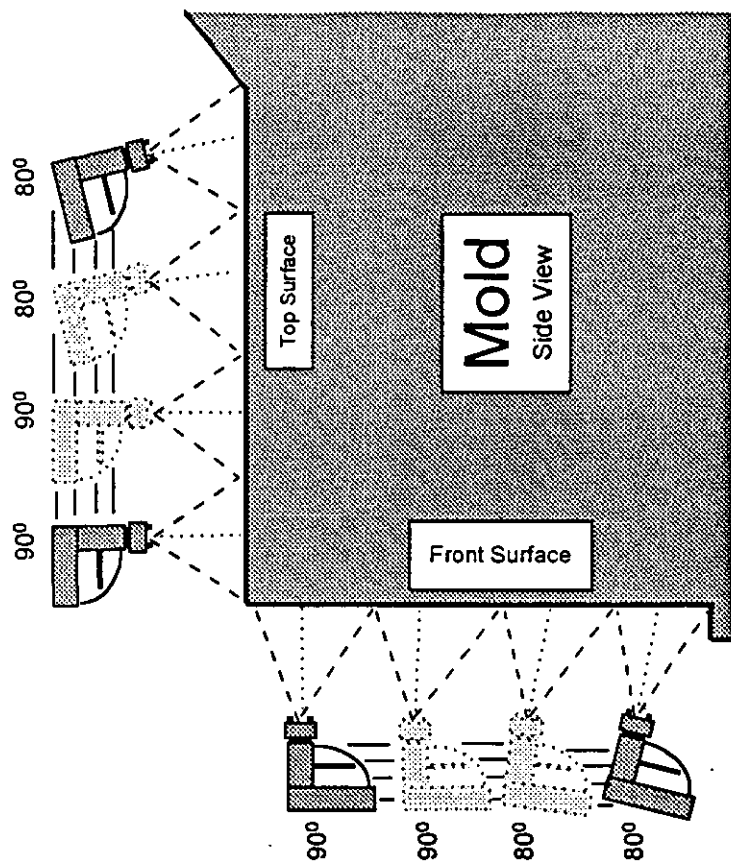
Figure 2.10.1.2
Fan Pattern Intercept Angles
Side View

Uncontrolled Spraying Technique



Spray Tip Approx. 18"-20"
From Mold Surface

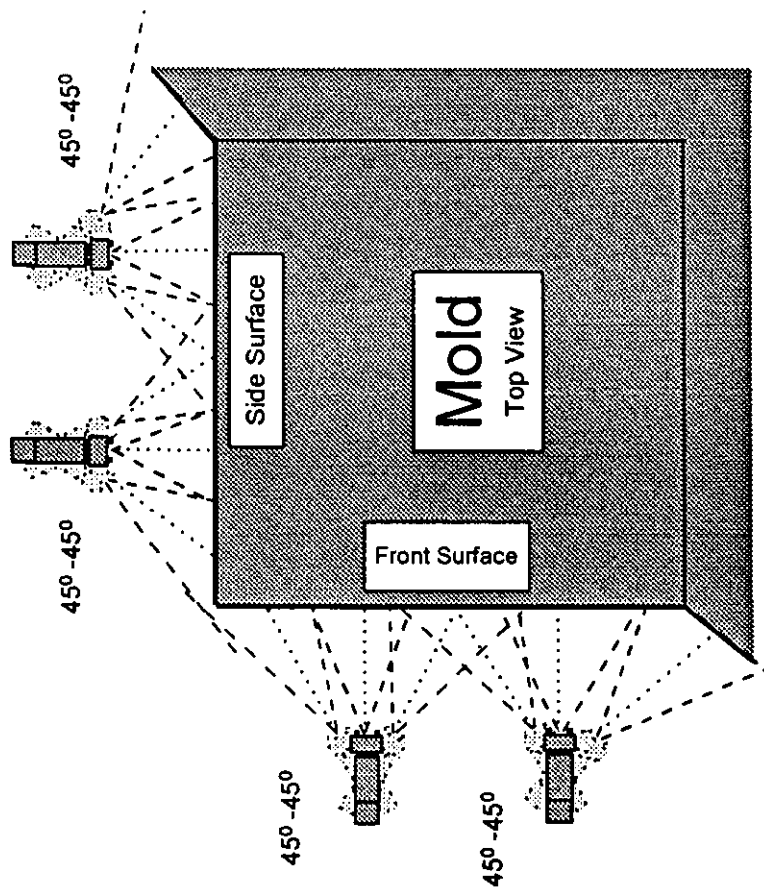
Controlled Spraying Technique



Spray Tip Approx. 12"
From Mold Surface

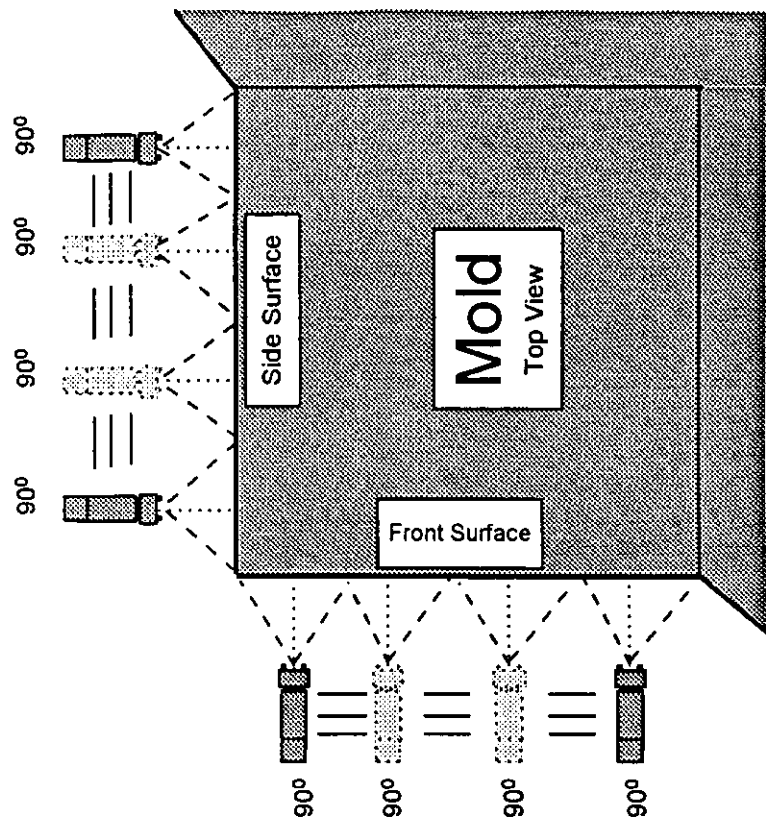
Figure 2.10.1.3
Fan Pattern Intercept Angles
Top View

Uncontrolled Spraying Technique



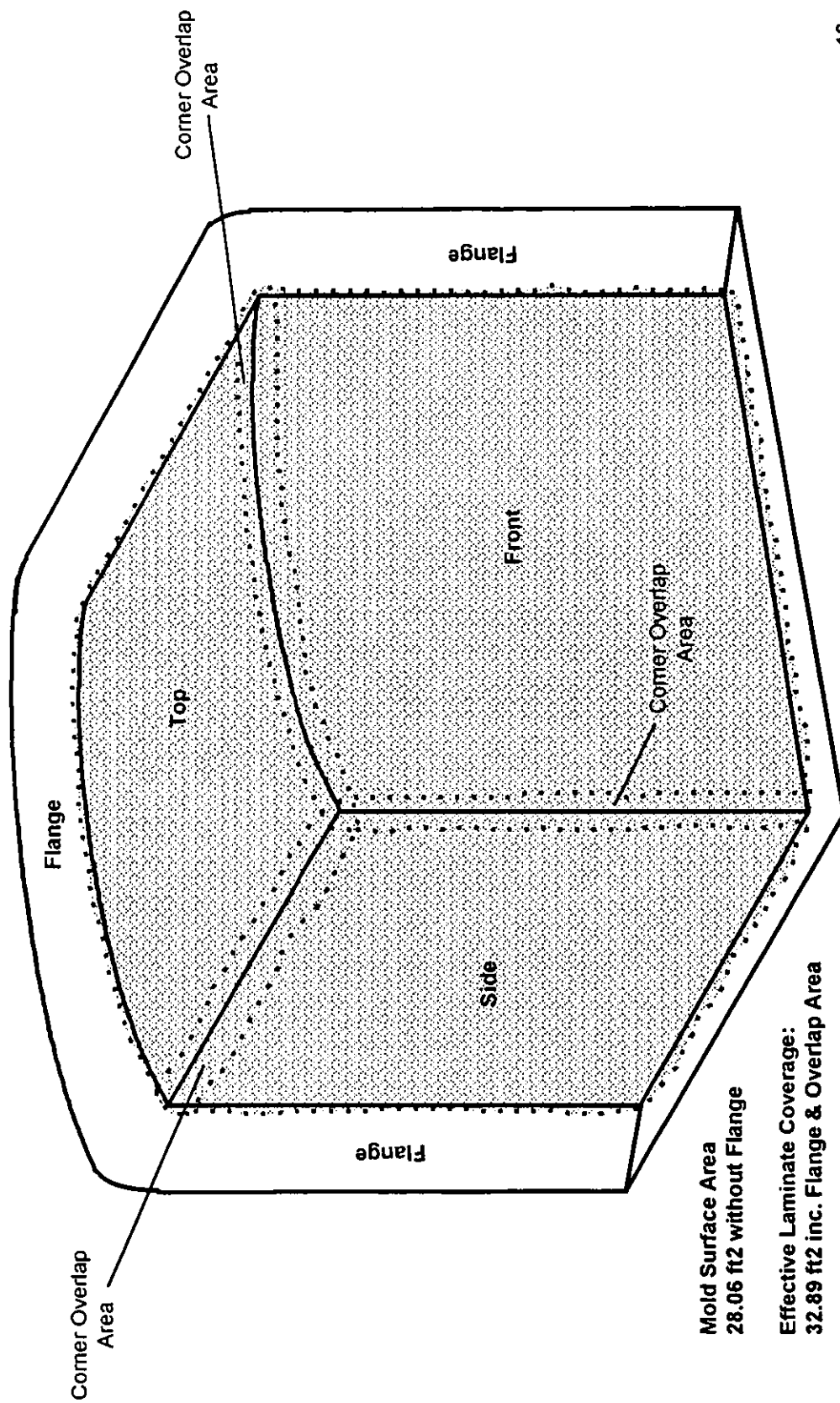
Spray Tip Approx. 18"-20"
From Mold Surface

Controlled Spraying Technique



Spray Tip Approx. 12"
From Mold Surface

Figure 2.10.1.4
Hand Lay-Up Laminated
Coverage Area



2.10.2 Application Techniques

Through the course of the test project it has become obvious that the detailed application technique of applying laminating resin and gel coat has an impact on the emissions profile. This description is offered in order to provide an understanding of the shape of the emissions profiles. These application procedures are representative of typical practices in the industry. They encompass necessary elements of production, such as mil gauge measurements, wet-out of multiple plies of chopped strand mat, and roll-out sequence as would be found in an actual production setting.

2.10.3 Detailed Hand Lay-Up Procedure

1. Resin is mixed in container
2. Resin is applied to chopped strand mat (CSM) with a paint roller
 - a. Top of mold wet-out
 - b. CSM positioned on top
 - c. Additional resin applied to CSM
 - d. Front of mold wet-out
 - e. CSM positioned on front
 - f. Additional resin applied to CSM
 - g. Side of mold wet-out
 - h. CSM positioned on side
 - i. Additional resin applied to CSM
 - j. Three sides rolled with paint roller
 - k. Three sides rolled with FRP roller
3. Laminate thickness measured - top, front, side

This procedure has produced an emissions profile in which micro-events involving the wet-out and placement of CSM are clearly visible.

2.10.4 Detailed Gel Coat Procedure

Gel coat is applied while monitoring weight of material being sprayed. The pre-calculated weights for each section of the mold are called out to the operator as an indication of approaching end of spray cycle. The gel coat is applied in three (3) continuous passes, to the required mil thickness, on each facet of the mold.

1. Top of mold sprayed in three passes.
2. Operator re-positions
3. Front of mold sprayed in three passes.
4. Operator re-positions
5. Side of mold sprayed in three passes.
6. Gel Coat thickness measured - top, front, side

This procedure has produced emissions with a distinct three peaked profile. Each "prong" of the profile represents the emissions peak for each facet of the mold. Emissions are shown to immediately drop when spraying is stopped.

2.10.5 Detailed Spray-Up Procedure

The spray-up laminate (chop) is applied while monitoring weight of material being sprayed. The pre-calculated weights for each section of the mold are called out to the operator as an indication of approaching end of spray cycle. The chop is applied in two (2) continuous passes, to the required laminate thickness, on each facet of the mold.

1. Top of mold sprayed in two passes.
2. Fast preliminary roll-out with FRP roller
3. Operator re-positions
4. Front of mold sprayed in two passes.
5. Fast preliminary roll-out with FRP roller
6. Operator re-positions
7. Side of mold sprayed in two passes.
8. Fast preliminary roll-out with FRP roller
9. Detailed roll of entire laminate with FRP roller
10. Laminate thickness measured - top, front, side

This procedure has produced emissions peaks which directly correlate with the spray time and roll-out time. Emissions are shown to immediately decline when spraying is stopped and to reach the "curing state" emissions quickly after roll-out is completed.

Section 3.0

Materials

3.1 Resins

An orthophthalic polyester resin was selected for these experiments as being representative of a type of resin widely used throughout the open molding composites industry. This formulation is relatively generic among all major resin manufacturers and is commonly used as a "general purpose" resin for many types of molded products. While the basic formulation of the resin is the same, four (4) variations of the base resin were used throughout the experiments. These variations are comprised of two (2) styrene levels and two (2) gel times. The high and low styrene resins contained 42% and 35% styrene respectively. Gel times were adjusted to 15 minutes and 30 minutes. Both styrene levels and gel times were "fine tuned" in the Dow laboratory to within the required specifications. The four resins are specified as follows:

Table 3.1.1

Resin Designation	Styrene Content	Gel Time
RP-1091	35	15
RP-1092	35	30
2985-09A	42	30
2985-09B	42	15

3.2 Gel Coats

A polyester gel coat was selected for these experiments as being representative of a type of gel coat widely used throughout the open molding composites industry. This formulation is relatively generic among all major gel coat manufacturers and is commonly used as a "general purpose" gel coat for many types of molded products. This particular gel coat was formulated with styrene as the sole monomer, excluding the co-monomer methyl methacrylate (MMA). Many gel coats include MMA as a portion of the monomer to enhance weatherability. For the purpose of these experiments it was felt that the inclusion of MMA might complicate the styrene emissions measurements, by adding a second VOC to the emissions stream. A gel coat with a MMA co-monomer would require less styrene monomer, and therefore would be expected to produce lower styrene emissions, in conjunction with methyl methacrylate emissions.

While the basic formulation of the gel coats is the same, four (4) variations of the base resin were used throughout the experiments. These variations are comprised of two (2) styrene levels and two (2) gel times. The high and low styrene resins contained 40% and 35% styrene respectively. Gel times were adjusted to 10 minutes and 20 minutes. Both styrene levels and gel times were "fine tuned" in the Dow laboratory to within the required specifications. The four gel coats are specified as follows:

Table 3.2.1

Gel Coat Designation	Styrene Content	Gel Time
944WJ026	35	10
944WJ027	35	20
944BJ009	40	10
944BJ010	40	20

3.3 Glass Fiber Reinforcement

For the hand lay-up experiments 1.5 oz/ft² chopped strand mat was used in either 1 or 2 ply combinations according to the required thickness. Continuous strand roving of 207 yield was used for the spray-up experiments. The chopper unit was set-up to produce a 1.5" chopped fiber length. Resin to glass ratio was calculated to produce a 28% glass loading, which is typical of these types of reinforcements.

3.4 Initiator

Methyl Ethyl Ketone Peroxide (MEKP) initiator (catalyst) was used for both the polyester resin and polyester gel coat. This initiator is specified at 50% active oxygen content, with dimethyl phthalate as a plasticizer vehicle.

Section 4.0

General Experimental Procedure

4.1 General Procedure

The experimental procedure was as follows:

1. Mold, materials and spray unit moved into TTE.
2. The instrumentation is calibrated.
3. Baseline measurements established.
4. Initial weight of resin or gel coat recorded.
5. Resin or gel coat was applied to the mold.
6. Final weight of resin or gel coat recorded.
7. GC and THA readings were discontinued when styrene levels reached previously established baseline levels.
8. Data recovered and stored.
9. Test area, mold and spray unit were prepared for subsequent experiment.

Pretrial experiments were conducted to determine the capture efficiency of the exhaust system. An open pan, with an absorbent media, containing measured amount of styrene was placed in direct air flow in the enclosure in order to evaporate the contents. The known weight of evaporated styrene was then be compared to the results of the instrumentation readings. This mass balance calibration provides a capture efficiency benchmark for the experimental runs.

Section 5.0

Resin Property Testing Laboratory

5.1 Resin Specification Adjustments

A Dow Chemical resin analytical lab is located in the same building as the test site. Lab personnel determined and adjusted the styrene content and gel time of the resins and gel coats to conform to the project specifications. Styrene content and gel time testing procedures are located in the appendix.

Section 6.0

Critical and Non-Critical Measurements

6.1 Explanation of Measurements

Critical measurements provide primary data effect or may effect the overall objectives of the project. Non-critical measurements are used to provide supplementary data to verify critical measurements. There were two types of critical measurements in this project. First was the direct measurement of styrene emissions, using the total hydrocarbon analyzer and EPA Method 25A. Second was measurements of the process which must be controlled in order to derive the necessary resolution from the collected data. These measurements included wet laminate/film thickness, resin/gel coat styrene content, gel time, resin/gel flow rate, air flow over mold, and ambient temperature. Non-critical measurements include the gas chromatograph, which was used as secondary measurement system to verify total hydrocarbon analyzer data.

6.2 Laminate/Gel Coat Thickness

In the spray-up laminate experiments, a chop mil gauge was used during the application to determine the rate of build-up and extent of thickness. A special continuous strand gun roving with red tracer strands was employed to give the operator a visual indication of the general laminate thickness and distribution across the mold surface. During the course of spray application the operator checked the thickness at three specified locations on the laminate with the chop mil gauge while building the laminate to the specified thickness.

The mean thickness was calculated from the measurements and compared against each other with a one-tail test at the $\alpha = 0.05$ confidence level for 2 degrees of freedom for which the student's $t_{0.05,2} = 2.760$. The estimated standard deviation required for the hypothesis $H_0: m_1 = m_2$ and either, $H_1: m_1 < m_2$ or $H_1: m_1 > m_2$ is estimated to be $\pm 0.010''$ with the tolerance around the factor levels being $\pm 0.0012''$.

For the gel coat experiments a standard gel coat mil gauge was used to measure the thickness build-up during the application and to record the final gel coat wet film thickness. Mil gauge readings were taken in a specified location in the center of each of the three panels of the mold surface and averaged. The wet film thickness was recorded on the experiment report sheet. Based on the hypothesis treatment as given above, the specified tolerance (by standard deviation) was $\pm 0.002''$.

In the hand lay-up laminate experiments the primary thickness control was the thickness of the chopped strand mat reinforcement. One (1) ply of 1.5 oz/ft^2 mat was used for the thin laminate and two (2) plies of 1.5 oz/ft^2 mat was used for the thick laminate. Typical overlaps and build-ups were expected in corner areas of the mold.

6.3 Styrene Content

The styrene content of the polyester resin and polyester gel coat used in these experiments was to be formulated to the specified styrene content of $\pm 1.5\%$ by the suppliers of the materials. The low styrene requirement was 35 wt%, and the high styrene content was 42 wt%. A QA

certification analysis of styrene content was provided for each formulation of material. A measurement of the styrene content was performed according to the method, Determination Of Non-Volatile Content, prior to the initiation of each of the individual studies. The determinations were made using Dow work instructions and with calibrated equipment according to an approved written procedure (see section 3.5.2). The stated 95% confidence interval of the method is $\pm 0.34\%$ which sufficiently resolved the styrene content levels for this study. If the styrene values obtained did not meet the criteria of the required styrene content, the styrene content of the resin or gel coat was adjusted. The adjusted resin or gel coat was then analyzed for styrene content to ensure the accuracy of the styrene determinations.

6.4 Gel Time

The interval from catalyzation to gelation was determined by introducing into the resin or gel coat the percentage of methyl ethyl ketone peroxide (MEKP) catalyst specified as used on the products certificate of analysis. This test was performed on a 100 g mass of the sample with a Sunshine Gel Timer and thermal control according to specified work instructions (see section 3.5.4) and calibration procedures prior to the individual studies.

The gel times required for the resins were 15 and 30 minutes; the gel times required for the gel coats were 10 and 20 minutes. The MEKP catalyst level was adjusted and an accelerator added, N,N-dimethylaniline (DMA), to obtain the specified gel times within ± 1.5 minutes. The accelerator was added to the resin or gel coat prior to the catalyzation with MEKP. The accelerator was measured on a calibrated analytical balance with calibration documentation available. The gel time checks on incoming resin and gel coat, as well the necessary adjustments made are shown in Appendix ???.

The spray equipment was adjusted to deliver the percent catalyst required to achieve the specified gel time. The resin/gel coat to catalyst ratio of the spray gun was determined through a standard weight calibration of the spray gun output. The catalyst formulation remained consistent throughout the individual study.

In the case of the Resin Batch Application, the specified amount of catalyst was measured on a calibrated analytical balance with calibration documentation available. The catalyst was then manually mixed with the resin immediately prior to application. The catalyst formulation remained consistent throughout the individual study.

6.5 Resin Flow

The output of the spray gun was determined during the standard calibration of the spray equipment. The output was controlled by a combination of spray tip orifice size and pump pressure setting. Standard calibration consisted of spraying the resin into a container three times for 15 seconds intervals and weighing the output from each spray. Based on the confidence limit criteria as shown in Section 6.1.1, the measured output then requires that the mean of the three measurements is ± 0.15 lb(68 g) of the target level with any one measurement ± 0.125 lb(57 g) of the mean value. The mean weight was then converted into a flow rate in pounds per minute (lbs/min).

Table 6.5.1

Flow Rate	Target Resin Mass for 15 seconds	Acceptable Mean of 3 Samples	Acceptable Measured Values
2 lb/min	0.5 lb	± 0.15 lb	± 0.13 lb
4 lb/min	1.0 lb	± 0.15 lb	± 0.13 lb

6.6 Air Flow Over the Mold

Air flow velocity over the mold surface was controlled by the auxiliary blower and duct system, which was configured to extract air from within the test enclosure and return the air through ducts and outlets directed to provide an uniform air flow across the mold surface. The air flow over the mold surface had been measured in three (3) specific locations (the center of each corner adjoining panels of the mold) using a hot wire anemometer (Cole-Parmer Trisense Model No. 37000-00). The dampers in the ducts had been adjusted to specified settings to provide a low air velocity of 50 fpm and a high air velocity of 100 fpm at 2 inches from the center of each corner adjoining panels. The flow rate was verified prior to the start of the individual studies.

6.7 TTE Temperature Probe Calibration

A type J thermocouple located approximately three feet above the floor level reports to the Camille Data System. This thermocouple read out was checked against a NIST traceable thermometer on a weekly basis

6.8 Listing of Critical and Non-Critical Measurements

Critical and non-critical measurements are listed in Table 6.8.1 Critical measurements are those which must meet measurement frequency, precision, and accuracy requirements for an experimental run to be deemed valid. Non-critical measurements involved additional means of measuring styrene emissions, including emissions measurements with the gas chromatograph. These measurements were used to support the THA measurements, verify the function of the testing set-up and validate the quality of data collected. Table 6.8.2 is a summary of physical measurements conducted for the study.

Table 6.8.1
Quality Assurance Objectives for
Critical and Non-Critical Measurements

Measurement	Measurement Designation	Measurement Frequency	Precision Range	Required Accuracy	Completeness
Styrene Emissions (IHA)	Stack -EPA Method 25A	Continuous (2 second interval data points)	± 2 ppm	10%	>1200 data points per run and when measurement reaches original baseline
Styrene Emissions (GC)	Stack - GC Measurement	120 Second Interval	± 2 ppm	$\pm 10\%$	>30 data points per run and when measurement reaches original baseline
Wet Laminate Thickness	Wet Mil Gauge	Each Experiment	$\pm 0.010''$	$\pm 0.012''$	3 measurements per run
Wet Film Thickness	Wet Mil Gauge	Each Experiment	$\pm 0.002''$	$\pm 10\%$ Specified Thickness	3 measurements per run
Styrene Content	Dow Work Instructions	Each Resin/Gel Coat Batch	$\pm 0.34\%$ w/w at 95% confidence level	$\pm 1.5\%$ Specified Styrene Content	2 measurements of each resin prior to a study
Gel Time	Dow Work Instructions	Each Resin/Gel Coat Batch	$\pm 4\%$ absolute deviation from mean	± 1.5 min. Specified Gel Time	2 measurements of each resin prior to a study
Resin Flow Rate	Spray Gun Calibration	Each Experimental Run	± 3 lb/min.	± 3 lb/min. Specified Flow Rate	2 measurements per run
Air Flow	Velocity at Mold Surface	Prior to Each Experimental Study	$\pm 20\%$	$\pm 20\%$ Specified Air Flow	Six Readings per minute for three minutes
Temperature	Within Enclosure	During Each Experiment	$\pm 2^\circ\text{F}$	$75 \pm 4^\circ\text{F}$	> 1200 data points per run
Air Flow Through TTE	Vent Stack Air Flow	Continuous (1 second interval data points)	± 25 cfm	± 100 cfm	> 1200 data points per run
Mass Balance - Styrene Recovery Check	EPA Method 25A/Weight	Before Each Emission Study	$\pm 4\%$	$\pm 10\%$	Two measurements prior to each study
Resin/Gel Coat Weights	Precision Balance	During Each Experiment	± 0.002 lb	± 0.004 lb	Two Measurements per run

Table 6.8.2
Summary of Physical Measurements for
Styrene Emission Study

Measurement	Measurement Classification	Measurement Designation	Measurement Frequency	Measurement Site
Styrene Emissions (THA)	Critical	Stack -EPA Method 25A	Continuous (2 second interval data points)	Vent Hood Stack
Styrene Emissions (GC)	Non-critical	Stack - GC Measurement	120 Second Interval	Vent Hood Stack
Wet Laminate Thickness	Critical	Wet Mil Gauge	Each Experimental Run	Mold Surface on center of each panel
Wet Film Thickness	Critical	Wet Mil Gauge	Each Experimental Run	Mold Surface on center of each panel
Styrene Content	Critical	Dow Work Instructions	Each Emission Study	Laboratory analysis
Gel Time	Critical	Dow Work Instructions	Each Emission Study	Laboratory analysis
Resin Flow Rate	Critical	Spray Gun Calibration	Each Experimental Run	Chopper gun
Air Flow Over Mold	Critical	Hot Wire Anemometer	Prior to Each Experimental Study	Velocity at Mold Surface
Temperature	Critical	Thermocouple	During Each Experiment	Within TTE
Mass Balance-Styrene Recovery Check	Critical	EPA Method 25A/Weight	Prior to Each Study	Within TTE
Air Flow Through TTE	Critical	Velocity Sensor	Continuous (1 second interval data points)	Vent Hood Stack
Resin/Gel Coat Weight	Critical	Precision Balance	Each Experimental Run	Spray Unit Outside TTE

Section 7.0

Experimental Design

7.1 Experimental Design for Spray Applications (Gel Coating & Spray-Up)

The experimental programs described in Tables 7.2.3 and 7.2.4 are called blocked, 5 factor, 2 level, half fractional experiments. This experiment scheme is a class of screening designs for estimating the relative magnitude of the factors response. Screening designs assume that the response (Y) is a linear function of the factors.

$$Y = \beta_0 + \sum_{i=1}^5 \beta_i X_i + \sum_{i=1}^4 \sum_{j=2}^5 \beta_{ij} X_{ij} + \sum_{i=1}^3 \sum_{j=2}^4 \sum_{k=3}^5 \beta_{ijk} X_{ijk} + \sum_{i=1}^2 \sum_{j=2}^3 \sum_{k=3}^4 \sum_{l=4}^5 \beta_{ijkl} X_{ijkl} + \beta_{12345} X_{12345}$$

In the experimental programs listed, the use of blocking will cause the two-factor interactions (the product of the two effects) to be confounded with each other. Confounding is the overlapping of terms such that two or more effects cannot be distinguished from each other. Although the three factor interactions would be negligible compared to the main effects. If necessary, the interactive effects may be resolved from each other with a follow-up study called a reflective design. Blocking is a term for accommodating the possible effects for day-to-day changes in uncontrolled environmental factors. Four runs were repeated in order to estimate the variance of the measurement system and also estimate the lack-of-fit for the model. The column labeled "Pattern" is the coding system of the signs of the coefficients typically used to designate the low (-1) and high (+1) values in the design. Refer to Table 7.1.1 for the designation key for factor levels.

Table 7.1.1

	Laminate/Film Thickness	Styrene %	Gel Time	Resin Flow	Air Flow
Low Values (-)	Thin	Low	Slow	Low	Low
High Values (+)	Thick	High	Fast	High	High

7.2 Hand Lay-Up Application Study

The design for the Hand Lay-Up Application study is listed in Table 7.2.2. This screening study is a blocked 4-factor, 2 level full factorial design. Sixteen (16) experiments with a 4-factor design will allow all effects and interactions to be fully resolved from one another. The same assumption of linearity applies to this study and four runs were repeated to estimate the experimental variance and lack-of-fit.

$$Y = \beta_0 + \sum_{i=1}^5 \beta_i X_i + \sum_{i=1}^4 \sum_{j=2}^5 \beta_{ij} X_{ij} + \sum_{i=1}^3 \sum_{j=2}^4 \sum_{k=3}^5 \beta_{ijk} X_{ijk} + \sum_{i=1}^2 \sum_{j=2}^3 \sum_{k=3}^4 \sum_{l=4}^5 \beta_{ijkl} X_{ijkl} + \beta_{12345} X_{12345}$$

Table 7.2.2
Resin Spray Application Emission Study

Block (Day)	Run No.	Pattern	Laminate Thickness (in.) X ₁	Styrene % X ₂	Gel Time (min.) X ₃	Resin Flow (lb/min) X ₄	Air Flow (fpm) X ₅
1	1	—++	.040	35	30	.4	100
1	2	+++—	.080	42	15	2	50
2	3A	—++—	.040	42	15	2	50
2	4A	+—++	.080	35	30	4	100
3	5	—+—+	.040	42	30	2	100
3	6	+—++—	.080	35	15	4	50
4	4B	+—++	.080	35	30	4	100
4	3B	—++—	.040	42	15	2	50
5	7	—++—	.040	35	15	4	50
5	8	++—+	.080	42	30	2	100
6	9	—+—+	.040	35	15	2	100
6	10	+++—	.080	42	30	4	50
7	11A	—+—+	.040	42	30	4	50
7	12A	+—++	.080	35	15	2	100
8	13	+—	.080	35	30	2	50
8	14	+++++	.040	42	15	4	100
9	11B	—+—+	.040	42	30	4	50
9	12B	+—++	.080	35	15	2	100
10	15	—	.040	35	30	2	50
10	16	+++++	.080	42	15	4	100

Table 7.2.3
Gel Coat Spray Application Emission Study

Block (Day)	Run No.	Pattern	Laminate Thickness (in.)	Styrene %	Gel Time (min.)	Resin Flow (lb/min)	Air Flow (fpm)
			X ₁	X ₂	X ₃	X ₄	X ₅
1	1	—++	.018	35	20	4	100
1	2	+++—	.024	40	10	2	50
2	3A	—++—	.018	40	10	2	50
2	4A	+—++	.024	35	20	4	100
3	5	++—+	.024	40	20	2	100
3	6	+—++—	.024	35	10	4	50
4	4B	+—++	.024	35	20	4	100
4	3B	—++—	.018	40	10	2	50
5	7	—++—	.018	35	10	4	50
5	8	—+—+	.018	40	20	2	100
6	9	—+—+	.018	35	10	2	100
6	10	++—+—	.024	40	20	4	50
7	11A	—+—+	.018	40	20	4	50
7	12A	+—+—+	.024	35	10	2	100
8	13	+—	.024	35	20	2	50
8	14	—+++++	.018	40	10	4	100
9	11B	—+—+	.018	40	20	4	50
9	12B	+—+—+	.024	35	10	2	100
10	15	-----	.018	35	20	2	50
10	16	++++++	.024	40	10	4	100

Table 7.3.4
Resin Batch Application Emission Study

Block (Day)	Run No.	Pattern	Laminate Thickness (in.)	Styrene %	Gel Time (min.)	Air Flow (fpm)
			X ₁	X ₂	X ₃	X ₄
1	1	—+	0.041	35	30	100
1	2	+++—	0.088	42	15	50
2	3A	-++-	0.041	42	15	50
2	4A	+—+	0.088	35	30	100
3	5	-+—	0.041	42	30	50
3	6	+—++	0.088	35	15	100
4	4B	+—+	0.088	35	30	100
4	3B	-++-	0.041	42	15	50
5	7	—++	0.041	35	15	100
5	8	++—	0.088	42	30	50
6	9	--+	0.041	35	15	50
6	10	++—+	0.088	42	30	100
7	11A	-+—+	0.041	42	30	100
7	12A	+—+-	0.088	35	15	50
8	13	+---	0.088	35	30	50
8	14	-++++	0.041	42	15	100
9	11B	-+—+	0.041	42	30	100
9	12B	+—+-	0.088	35	15	50
10	15	---	0.041	35	30	50
10	16	+++++	0.088	42	15	100

Section 8.0

Emissions Testing Results

8.1 Hand Lay-up Summary

The major factors contributing to styrene emissions in the hand lay-up process are: Laminate thickness; Gel time; Styrene content. Air flow, in the range of 50 -100 fpm, over the mold surface is a insignificant factor. An average of 14.1% emissions (AS) was produced for all experimental runs. Emissions ranged from 9.8% to 21.1% (AS). The combination of a thick laminate, low styrene content, fast gel time and low air flow produced the lowest emissions at 9.8% AS. At the high end of the range, a thin laminate, high styrene content, slow gel time and high air flow produced 21.1% (AS) emissions. Approximately 50% of total emissions were produced during the resin application phase of the process (transferring resin from the bucket to the laminate with a paint roller). 25% of total emissions were produced during the laminate roll-out sequence and the remaining 25% emissions were produced in the post roll-out curing stage.

8.2 Gel Coat Summary

The major factors contributing to styrene emissions in the gel coat process are: Film thickness and Styrene content. Gel time and air flow over the mold are minor factors, while gel coat flow rate is an insignificant factor. An average of 51.4% emissions (AS) was produced for all experimental runs. Emissions ranged from 43.5% to 61.8% (AS). The combination of thick film, low styrene, fast gel time, high gel coat flow and low air flow produced the lowest emissions at 43.5% (AS). At the high end of the range, a thin film, high styrene, slow gel time, high gel coat flow and low air flow produced 61.8% (AS) emissions. Approximately 50% of total emissions were produced during the spray application and 50% during the curing stage.

8.3 Spray-up Summary

The major factors contributing to styrene emissions in the spray-up process are: Styrene content and resin flow rate. Thickness was a smaller contributor, and a two factor interaction of styrene content + resin flow is a significant factor. Air flow was an insignificant factor. An average of 25.0% emissions (AS) was produced for all experimental runs. Emissions ranged from 17.1% to 38.0% (AS). The combination of thick laminate, low styrene, fast gel time, low resin flow and high air flow produced the lowest emissions at 17.1% (AS). At the high end of the range, a thick laminate, high styrene, slow gel time, low resin flow and high air flow produced 38.0% (AS) emissions. Approximately 50% of total emissions were produced during the spray application, 25% during the laminate roll-out, and 25% during the post roll-out curing stage.

8.4 Conclusion of Phase I Baseline Studies

In all three studies, styrene content was consistently a major factor. Laminate or film thickness, gel time and resin flow rate are emissions contributors in varying degrees. Air flow over the mold was an insignificant factor in all cases. The combination of styrene content and resin flow, in the spray-up study, was the only significant two factor interaction in all the studies. The combination of thick laminate/film, low styrene content and fast gel time is consistent in producing the lowest emissions in all three studies.

8.5 Expression of Emissions Data

The emissions data in the following tables are expressed in a variety of modes. While the data remains constant, various expressions lend to a better understanding of the effects. These expressions allow for calculation of emissions in a number of different ways. For example, the surface area emissions take into account variations in the effect of laminate thickness, whereas projecting the results of emissions based on available styrene tend to obscure the importance in variations of styrene content. Calculations of emissions based on resin weight (RW) may provide the best overall determination of emissions, without masking the effects of individual variables. The expressions of emissions in the data tables is as follows:

Table 8.5.1a

Expression	Unit	Explanation
% Emissions of Available Styrene	% AS	Percent of resin styrene content lost to emissions (AP-42 emission factors are %AS)
% Emissions of Resin Weight	% RW	Percent of total resin weight lost to emissions
Grams of Emission per Square Foot	g/ft ²	Grams of emissions per square foot of mold surface (This mixed expression is used to allow for better understanding of those using U.S. measurement units)
Grams of Emission per Square Meter	g/m ²	Grams of emissions per square meter of mold surface (Metric units)
Normalized Surface Area Emissions	g/ft ² /kg Resin	The amount of resin used is "normalized" to 1000 grams or 1 kg and emissions are expressed as grams per unit of surface area (ft ²). (This mixed expression is used to allow for better understanding of those using U.S. measurement units.)
Pounds of Emissions per Ton of Resin	lbs/Ton	Pounds of emissions per Ton of resin used, where resin weight is normalized to 2000 lbs.

Hand Lay-Up Emissions Baseline Data

Table 8.1

Hand Lay-Up Experiment Data Table

Run Parameters					Data							Normalized	Emission	Emission
Run No.	Data ID	anhyd Thick- ess (in.)	Resin Styrene %	Gel Time (min.)	Air Flow (fpm)	Resin onsume (g)	Available Styrene (g)	Emission Weight (g)	Emission % of AS	Surface Area Emiss. (g/ft2)	Surface Area Emiss. (g/m2)	Surf. Area Emission (g/ft2/kg GC)	% of Resin (RW)	Lbs/Ton Resin Consumed
1	100295B	0.041	35	30	100	3168.00	1105.60	195.78	17.7%	6.97	75.04	2.20	6.2%	123.60
2	100295C	0.068	42	15	50	6050.00	2505.00	294.10	11.7%	10.47	112.73	1.73	4.9%	97.22
3A	092095A	0.041	42	15	50	2998.00	1287.00	214.38	16.7%	7.63	82.17	2.55	7.2%	143.02
4A	100395A	0.068	35	30	100	6054.00	2156.40	252.69	11.7%	9.00	96.85	1.49	4.2%	83.48
5	092595A	0.041	42	30	50	2815.00	1187.90	227.98	19.2%	8.12	87.38	2.88	8.1%	161.98
6	092695A	0.068	35	15	100	6028.00	2150.50	217.37	10.1%	7.74	83.32	1.28	3.6%	72.11
4B	092695C	0.068	35	30	100	6444.00	2248.96	295.44	13.1%	10.52	113.24	1.63	4.6%	91.69
3B	092695B	0.041	42	15	50	2980.00	1279.60	226.29	17.7%	8.08	86.73	2.70	7.6%	151.87
7	092795A	0.041	35	15	100	3421.00	1220.30	179.71	14.7%	6.40	68.88	1.87	5.3%	105.06
8	092795B	0.068	42	30	50	5799.00	2447.20	330.93	13.5%	11.78	126.84	2.03	5.7%	114.13
9	092795C	0.041	35	15	50	3302.00	1177.80	165.46	14.0%	5.89	63.42	1.78	5.0%	100.22
10	092895A	0.068	42	30	100	5582.00	2355.80	337.41	14.3%	12.01	129.33	2.15	6.0%	120.89
11A	092895B	0.041	42	30	100	2779.00	1172.70	248.62	21.2%	8.85	95.29	3.18	8.9%	178.93
12A	092895C	0.068	35	15	50	6274.00	2237.90	213.79	9.6%	7.61	81.94	1.21	3.4%	68.15
13	092995A	0.068	35	30	50	6032.00	2105.20	250.51	11.9%	8.92	96.02	1.48	4.2%	83.06
14	092995B	0.041	42	15	100	3153.00	1308.00	222.84	17.1%	7.93	85.41	2.52	7.1%	141.35
11B	092995C	0.041	42	30	100	2954.00	1246.80	262.12	21.0%	9.33	100.47	3.16	8.9%	177.47
12B	100295A	0.068	35	15	50	6287.00	2242.60	226.07	10.1%	8.05	86.65	1.28	3.6%	71.92
15	091995A	0.041	35	30	50	2735.00	974.20	171.64	17.6%	6.11	65.79	2.23	6.3%	125.51
16	091995B	0.068	42	15	100	6484.00	2784.00	320.20	11.5%	11.40	122.73	1.76	4.9%	98.77

CFA Open Molding Styrene Emissions Test Project
Hand Lay-Up Emissions Baseline Data

Table 8.2

Hand Lay-Up Experiment Master Table- Replicate Averages

Run Parameters												Normalized Surf. Area Emission (g/ft2/kg GC)	Emission % of Resin (RW)	Emission Lbs/Ton Resin Consumed
Run No.	Data ID	Laminate Thickness (in.)	Resin Styrene %	Gel Time (min.)	Air Flow (fpm)	Emission % of AS	Surface Area Emiss. (g/ft2)	Surface Area Emiss. (g/m2)						
1	100285B	0.041	35	30	100	17.7%	6.97	75.04	2.20	6.2%	123.60			
2	100285C	0.088	42	15	50	11.7%	10.47	112.73	1.73	4.9%	97.22			
3	Replicate Avg.	0.041	42	15	50	17.2%	7.84	84.45	2.62	7.4%	147.44			
4	Replicate Avg.	0.088	35	30	100	12.4%	9.76	105.05	1.56	4.4%	87.59			
5	092595A	0.041	42	30	50	19.2%	8.12	87.38	2.88	8.1%	161.98			
6	092695A	0.088	35	15	100	10.1%	7.74	83.32	1.28	3.6%	72.11			
7	092795A	0.041	35	15	100	14.7%	6.40	68.88	1.87	5.3%	105.06			
8	092795B	0.088	42	30	50	13.5%	11.78	126.84	2.03	5.7%	114.13			
9	092795C	0.041	35	15	50	14.0%	5.89	63.42	1.78	5.0%	100.22			
10	092895A	0.088	42	30	100	14.3%	12.01	129.33	2.15	6.0%	120.89			
11	Replicate Avg.	0.041	42	30	100	21.1%	9.09	97.88	3.17	8.9%	178.20			
12	Replicate Avg.	0.088	35	15	50	9.8%	7.83	84.30	1.25	3.5%	70.03			
13	092995A	0.088	35	30	50	11.9%	8.92	96.02	1.48	4.2%	83.06			
14	092995B	0.041	42	15	100	17.1%	7.93	85.41	2.52	7.1%	141.35			
15	091995A	0.041	35	30	50	17.6%	6.11	65.79	2.23	6.3%	125.51			
16	091995B	0.088	42	15	100	11.5%	11.40	122.73	1.76	4.9%	98.77			

Hand Lay-Up Emissions Baseline Data

Table 8.3

Emissions By % Of Available Styrene

Run Parameters												
Run No.	Data ID	Laminate Thickness (in.)	Resin Styrene %	Gel Time (min.)	Air Flow (fpm)	Data			Normalized Surf. Area Emission (g/ft2/kg GC)	Emission % of Resin (RW)	Emission Lbs/Ton Resin Consumed	
						Emission % of AS	Surface Area Emiss. (g/ft2)	Surface Area Emiss. (g/m2)				
12	Replicate Avg.	0.088	35	15	50							
6	092695A	0.088	35	15	100	9.8%	7.83	84.30	1.25	3.5%	70.03	
16	091995B	0.088	42	15	100	10.1%	7.74	83.32	1.28	3.6%	72.11	
2	100295C	0.088	42	15	50	11.5%	11.40	122.73	1.76	4.9%	98.77	
13	092995A	0.088	35	30	50	11.7%	10.47	112.73	1.73	4.9%	97.22	
4	Replicate Avg.	0.088	35	30	100	11.9%	8.92	96.02	1.48	4.2%	83.06	
8	092795B	0.088	42	30	50	12.4%	9.76	105.05	1.56	4.4%	87.59	
9	092795C	0.041	35	15	50	13.5%	11.78	126.84	2.03	5.7%	114.13	
10	092895A	0.088	42	30	100	14.0%	5.89	63.42	1.78	5.0%	100.22	
7	092795A	0.041	35	15	100	14.3%	12.01	129.33	2.15	6.0%	120.89	
14	092995B	0.041	42	15	100	14.7%	6.40	68.88	1.87	5.3%	105.06	
3	Replicate Avg.	0.041	42	15	50	17.1%	7.93	85.41	2.52	7.1%	141.35	
15	091995A	0.041	35	30	50	17.2%	7.84	84.45	2.62	7.4%	147.44	
1	100295B	0.041	35	30	100	17.6%	6.11	65.79	2.23	6.3%	125.51	
5	092595A	0.041	42	30	50	17.7%	6.97	75.04	2.20	6.2%	123.60	
11	Replicate Avg.	0.041	42	30	100	19.2%	8.12	87.38	2.88	8.1%	161.98	
						21.1%	9.09	97.88	3.17	8.9%	178.20	

CFA Open Molding Styrene Emissions Test Project
Hand Lay-Up Emissions Baseline Data

Table 8.4

Emissions By Normalized Surface Area

Run No.	Run Parameters					Data			Normalized Surf. Area Emission (g/m ² /kg GC)	Emission % of Resin (RW)	Emission Lbs/Ton Resin Consumed
	Data ID	Laminate Thickness (in.)	Resin Styrene %	Gel Time (min.)	Air Flow (fpm)	Emission % of AS	Surface Area Emiss. (g/m ²)	Surface Area Emiss. (g/m ²)			
12	Replicate Avg.	0.088	35	15	50	9.8%	7.83	84.30	1.25	3.5%	70.03
6	092695A	0.088	35	15	100	10.1%	7.74	83.32	1.28	3.8%	72.11
13	092895A	0.088	35	30	50	11.9%	8.92	96.02	1.48	4.2%	83.06
4	Replicate Avg.	0.088	35	30	100	12.4%	9.76	105.05	1.56	4.4%	87.59
2	100295C	0.088	42	15	50	11.7%	10.47	112.73	1.73	4.9%	97.22
16	091995B	0.088	42	15	100	11.5%	11.40	122.73	1.76	4.9%	98.77
9	092795C	0.041	35	15	50	14.0%	5.89	63.42	1.78	5.0%	100.22
7	092795A	0.041	35	15	100	14.7%	6.40	68.88	1.87	5.3%	105.08
8	092795B	0.088	42	30	50	13.5%	11.78	126.84	2.03	5.7%	114.13
10	092895A	0.088	42	30	100	14.3%	12.01	129.33	2.15	6.0%	120.89
1	100295B	0.041	35	30	100	17.7%	6.97	75.04	2.20	6.2%	123.60
15	091995A	0.041	35	30	50	17.6%	6.11	65.79	2.23	6.3%	125.51
14	092895B	0.041	42	15	100	17.1%	7.93	85.41	2.52	7.1%	141.35
3	Replicate Avg.	0.041	42	15	50	17.2%	7.84	84.45	2.52	7.4%	147.44
5	092595A	0.041	42	30	50	19.2%	8.12	87.38	2.88	8.1%	161.98
11	Replicate Avg.	0.041	42	30	100	21.1%	9.09	97.88	3.17	8.9%	178.20

Hand Lay-Up Emissions Baseline Data

Table 8.5

Emissions By % Resin Weight

Run Parameters											
Run No.	Data ID	Laminate Thickness (in.)	Resin Styrene %	Gel Time (min.)	Air Flow (fpm)	Data			Normalized Surf. Area Emission (g/ft2/kg GC)	Emission % of Resin (RW)	Emission Lbs/Ton Resin Consumed
						Emission % of AS	Surface Area Emiss. (g/ft2)	Surface Area Emiss. (g/m2)			
12	Replicate Avg.	0.088	35	15	50	9.8%	7.83	84.30	1.25	3.5%	70.03
6	092695A	0.088	35	15	100	10.1%	7.74	83.32	1.28	3.6%	72.11
13	092995A	0.088	35	30	50	11.9%	8.92	96.02	1.48	4.2%	83.06
4	Replicate Avg.	0.088	35	30	100	12.4%	9.76	105.05	1.56	4.4%	87.59
2	100295C	0.088	42	15	50	11.7%	10.47	112.73	1.73	4.9%	97.22
16	091995B	0.088	42	15	100	11.5%	11.40	122.73	1.76	4.9%	98.77
9	092795C	0.041	35	15	50	14.0%	5.89	63.42	1.78	5.0%	100.22
7	092795A	0.041	35	15	100	14.7%	6.40	68.88	1.87	5.3%	105.06
8	092795B	0.088	42	30	50	13.5%	11.78	126.84	2.03	5.7%	114.13
10	092895A	0.088	42	30	100	14.3%	12.01	129.33	2.15	6.0%	120.89
1	100295B	0.041	35	30	100	17.7%	6.97	75.04	2.20	6.2%	123.60
15	091995A	0.041	35	30	50	17.6%	6.11	65.79	2.23	6.3%	125.51
14	092995B	0.041	42	15	100	17.1%	7.93	85.41	2.52	7.1%	141.35
3	Replicate Avg.	0.041	42	15	50	17.2%	7.84	84.45	2.62	7.4%	147.44
5	092595A	0.041	42	30	50	19.2%	8.12	87.38	2.88	8.1%	161.98
11	Replicate Avg.	0.041	42	30	100	21.1%	9.09	97.88	3.17	8.9%	178.20

CFA Open Molding Styrene Emissions Test Project
Hand Lay-Up Emissions Baseline Data

Table 8.6

Emissions - Pounds (lbs) Per Ton of Resin Consumed

Run No.	Run Parameters					Data			Normalized Surf. Area Emission (g/m ² /kg GC)	Emission % of Resin (RW)	Emission Lbs/Ton Resin Consumed
	Data ID	Laminate Thickness (in.)	Resin Styrene %	Gel Time (min.)	Air Flow (fpm)	Emission % of AS	Surface Area Emiss. (g/m ²)	Surface Area Emiss. (g/m ²)			
12	Replicate Avg.	0.088	35	15	50	9.8%	7.83	84.30	1.25	3.5%	70.03
6	092695A	0.088	35	15	100	10.1%	7.74	83.32	1.28	3.6%	72.11
13	092995A	0.088	35	30	50	11.9%	8.92	96.02	1.48	4.2%	83.06
4	Replicate Avg.	0.088	35	30	100	12.4%	9.76	105.05	1.56	4.4%	87.59
2	100295C	0.088	42	15	50	11.7%	10.47	112.73	1.73	4.9%	97.22
16	091995B	0.088	42	15	100	11.5%	11.40	122.73	1.76	4.9%	98.77
9	092795C	0.041	35	15	50	14.0%	5.89	63.42	1.78	5.0%	100.22
7	092795A	0.041	35	15	100	14.7%	6.40	68.88	1.87	5.3%	105.08
8	092795B	0.088	42	30	50	13.5%	11.78	126.84	2.03	5.7%	114.13
10	092895A	0.088	42	30	100	14.3%	12.01	129.33	2.15	6.0%	120.89
1	100295B	0.041	35	30	100	17.7%	6.97	75.04	2.20	6.2%	123.60
15	091995A	0.041	35	30	50	17.6%	6.11	65.79	2.23	6.3%	125.51
14	092995B	0.041	42	15	100	17.1%	7.93	85.41	2.52	7.1%	141.35
3	Replicate Avg.	0.041	42	15	50	17.2%	7.84	84.45	2.62	7.4%	147.44
5	092595A	0.041	42	30	50	19.2%	8.12	87.38	2.88	8.1%	161.98
11	Replicate Avg.	0.041	42	30	100	21.1%	9.09	97.88	3.17	8.9%	178.20

Hand Lay-Up Emissions Baseline Data Table 8.7

Laminate Thickness Effects

Run Parameters												
Run No.	Data ID	Laminate Thickness (in.)	Resin Styrene %	Gel Time (min.)	Air Flow (fpm)	Data			Normalized Surf. Area Emission (g/ft2/kg GC)	Emission % of Resin (RW)	Emission Lbs/Ton Resin Consumed	
						Emission % of AS	Surface Area Emiss. (g/ft2)	Surface Area Emiss. (g/m2)				
Thin Laminate												
7	092795A	0.041	35	15	100	14.7%	6.40	68.88	1.87	5.3%	105.06	
9	092795C	0.041	35	15	50	14.0%	5.89	63.42	1.78	5.0%	100.22	
1	100295B	0.041	35	30	100	17.7%	6.97	75.04	2.20	6.2%	123.60	
15	091995A	0.041	35	30	50	17.6%	6.11	65.79	2.23	6.3%	125.51	
3	Replicate Avg.	0.041	42	15	50	17.2%	7.84	84.45	2.62	7.4%	147.44	
14	092995B	0.041	42	15	100	17.1%	7.93	85.41	2.52	7.1%	141.35	
5	092595A	0.041	42	30	50	19.2%	8.12	87.38	2.88	8.1%	161.98	
11	Replicate Avg.	0.041	42	30	100	21.1%	9.09	97.88	3.17	8.9%	178.20	
Thick Laminate												
6	092695A	0.088	35	15	100	10.1%	7.74	83.32	1.28	3.6%	72.11	
12	Replicate Avg.	0.088	35	15	50	9.6%	7.83	84.30	1.25	3.5%	70.03	
4	Replicate Avg.	0.088	35	30	100	12.4%	9.76	105.05	1.56	4.4%	87.59	
13	092995A	0.088	35	30	50	11.9%	8.92	96.02	1.48	4.2%	83.06	
2	100295C	0.088	42	15	50	11.7%	10.47	112.73	1.73	4.9%	97.22	
16	091995B	0.088	42	15	100	11.5%	11.40	122.73	1.76	4.9%	98.77	
8	092795B	0.088	42	30	50	13.5%	11.78	126.84	2.03	5.7%	114.13	
10	092895A	0.088	42	30	100	14.3%	12.01	129.33	2.15	6.0%	120.89	

79

	% Available Styrene	Norm. Surface Area	% Resin Weight	Lbs / Ton Resin
Avg. Emissions - Thin Laminate	17.3%	2.41	6.8%	135.42
Avg. Emissions - Thick Laminate	11.9%	1.65	4.6%	92.98

Avg. Emissions - Thin Laminate/High Styrene	18.6%	8.25	7.9%	157.24
Avg. Emissions - Thin Laminate/Low Styrene	16.0%	6.34	5.7%	113.60

Avg. Emissions - Thick Laminate/High Styrene	12.8%	11.73	5.4%	107.75
Avg. Emissions - Thick Laminate/Low Styrene	11.1%	9.24	3.9%	78.20

CFA Open Molding Styrene Emissions Test Project
Hand Lay-Up Emissions Baseline Data
Table 8.8

Available Styrene Effects

Run Parameters												
Run No.	Data ID	Run Parameters				Data				Normalized Surf. Area Emission (g/ft2/kg GC)	Emission % of Resin (RW)	Emission Lbs/Ton Resin Consumed
		Laminate Thickness (in.)	Resin Styrene %	Gel Time (min.)	Air Flow (fpm)	Emission % of AS	Surface Area Emiss. (g/ft2)	Surface Area Emiss. (g/m2)				
Low Styrene												
7	092795A	0.041	35	15	100	14.7%	6.40	68.88	1.87	5.3%	105.06	
9	092795C	0.041	35	15	50	14.0%	5.89	63.42	1.78	5.0%	100.22	
1	100295B	0.041	35	30	100	17.7%	6.97	75.04	2.20	6.2%	123.60	
15	091995A	0.041	35	30	50	17.6%	6.11	65.79	2.23	6.3%	125.51	
6	092695A	0.088	35	15	100	10.1%	7.74	83.32	1.28	3.6%	72.11	
12	Replicate Avg.	0.088	35	15	50	9.6%	7.83	84.30	1.25	3.5%	70.03	
4	Replicate Avg.	0.088	35	30	100	12.4%	9.76	105.05	1.56	4.4%	87.59	
13	092995A	0.088	35	30	50	11.9%	8.92	96.02	1.48	4.2%	83.06	
High Styrene												
3	Replicate Avg.	0.041	42	15	50	17.2%	7.84	84.45	2.62	7.4%	147.44	
14	092895B	0.041	42	15	100	17.1%	7.93	85.41	2.52	7.1%	141.35	
5	092595A	0.041	42	30	50	19.2%	8.12	87.38	2.88	8.1%	161.98	
11	Replicate Avg.	0.041	42	30	100	21.1%	9.09	97.88	3.17	8.9%	178.20	
2	100295C	0.088	42	15	50	11.7%	10.47	112.73	1.73	4.9%	97.22	
16	091995B	0.088	42	15	100	11.5%	11.40	122.73	1.76	4.9%	98.77	
8	092795B	0.088	42	30	50	13.5%	11.78	126.84	2.03	5.7%	114.13	
10	092895A	0.088	42	30	100	14.3%	12.01	129.33	2.15	6.0%	120.89	

	% Available Styrene	Norm. Surface Area	% Resin Weight	Lbs / Ton Resin
Avg. Emissions - High Styrene	13.5%	2.36	6.6%	132.50
Avg. Emissions - Low Styrene	15.7%	1.71	4.8%	95.90

Avg. Emissions - Low Styrene/Thin Laminat	16.0%	2.02	5.7%	113.60
Avg. Emissions - Low Styrene/Thick Laminat	11.1%	1.39	3.9%	78.20

Avg. Emissions - High Styrene/Thin Laminat	18.6%	2.80	7.9%	157.24
Avg. Emissions - High Styrene/Thick Laminat	12.8%	1.92	5.4%	107.75

Hand Lay-Up Emissions Baseline Data

Table 8.9

Gel Time Effects

Run Parameters												
Run No.	Data ID	Laminate Thickness (in.)	Resin Styrene %	Gel Time (min.)	Air Flow (fpm)	Data				Emission % of Resin (RW)	Normalized Surf. Area Emission (g/ft2/kg GC)	Emission Lbs/Ton Resin Consumed
						Emission % of AS	Surface Area Emiss. (g/ft2)	Surface Area Emiss. (g/m2)				
Fast Gel Time												
7	092795A	0.041	35	15	100	14.7%	6.40	68.88	1.87	5.3%	105.08	
9	092795C	0.041	35	15	50	14.0%	5.89	63.42	1.78	5.0%	100.22	
3	Replicate Avg.	0.041	42	15	50	17.2%	7.84	84.45	2.62	7.4%	147.44	
14	092995B	0.041	42	15	100	17.1%	7.93	85.41	2.52	7.1%	141.35	
6	092695A	0.088	35	15	100	10.1%	7.74	83.32	1.28	3.6%	72.11	
12	Replicate Avg.	0.088	35	15	50	9.8%	7.83	84.30	1.25	3.5%	70.03	
2	100295C	0.088	42	15	50	11.7%	10.47	112.73	1.73	4.9%	97.22	
16	091995B	0.088	42	15	100	11.5%	11.40	122.73	1.76	4.9%	98.77	
Slow Gel Time												
1	100295B	0.041	35	30	100	17.7%	6.97	75.04	2.20	6.2%	123.60	
15	091995A	0.041	35	30	50	17.6%	6.11	65.79	2.23	6.3%	125.51	
5	092595A	0.041	42	30	50	19.2%	8.12	87.38	2.88	8.1%	161.98	
11	Replicate Avg.	0.041	42	30	100	21.1%	9.09	97.88	3.17	8.9%	178.20	
4	Replicate Avg.	0.088	35	30	100	12.4%	9.76	105.05	1.56	4.4%	87.59	
13	092995A	0.088	35	30	50	11.9%	8.92	96.02	1.48	4.2%	83.08	
8	092795B	0.088	42	30	50	13.5%	11.78	126.84	2.03	5.7%	114.13	
10	092895A	0.088	42	30	100	14.3%	12.01	129.33	2.15	6.0%	120.89	

	% Available Styrene	Norm. Surface Area	% Resin Weight	Lbs / Ton Resin
Avg. Emissions - Slow Gel Time	16.0%	2.21	6.2%	124.37
Avg. Emissions - Fast Gel Time	13.3%	1.85	5.2%	104.03

Avg. Emissions - Fast Gel Time/Thin Laminat	15.3%	2.20	6.2%	123.52
Avg. Emissions -Fast Gel Time/Thick Lamina	12.2%	1.50	4.2%	84.53

Avg. Emissions - Slow Gel Time/Thin Lamina	18.9%	2.62	7.4%	147.32
Avg. Emissions - Slow Gel Time/Thick Lamin	13.0%	1.81	5.1%	101.42

CFA Open Molding Styrene Emissions Test Project
Hand Lay-Up Emissions Baseline Data

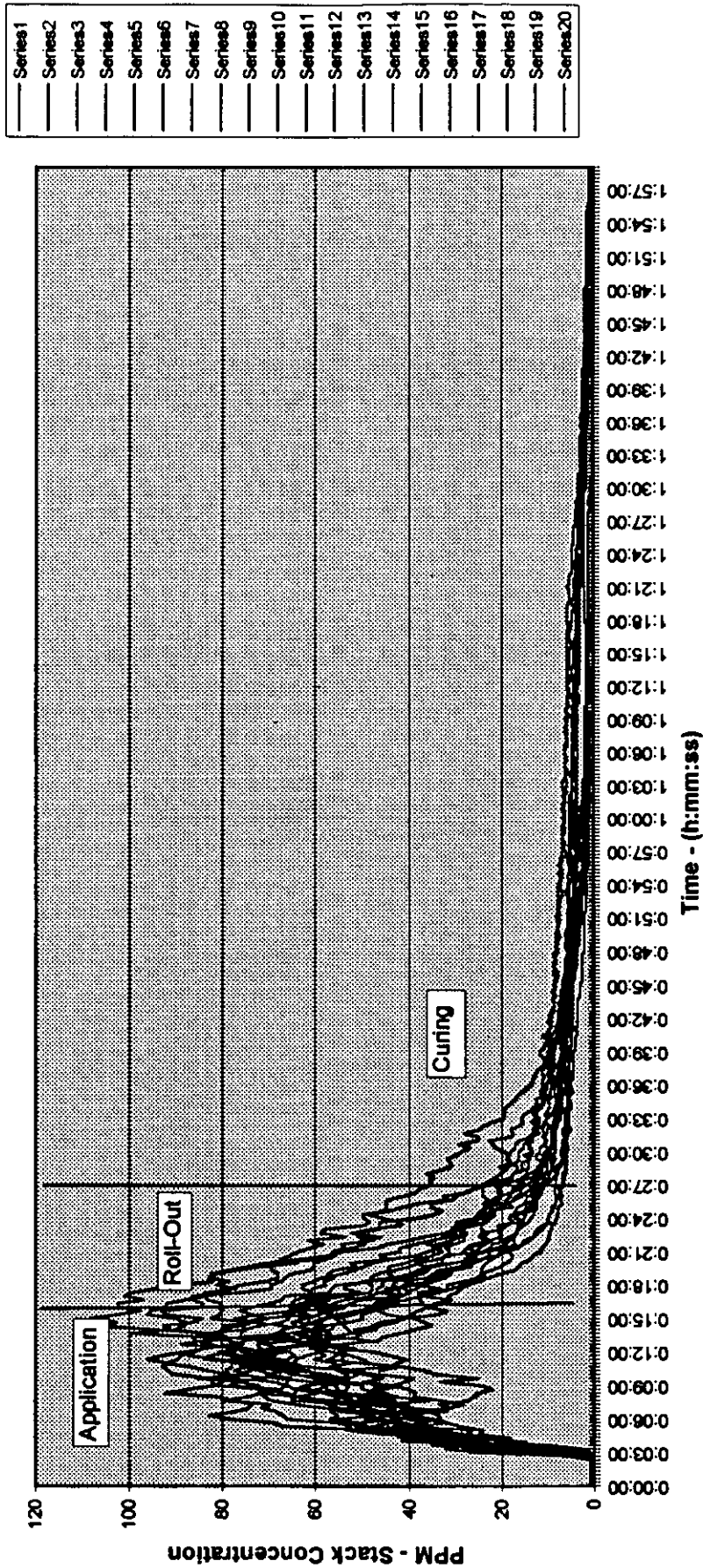
Table 8.10

Air Flow Effects

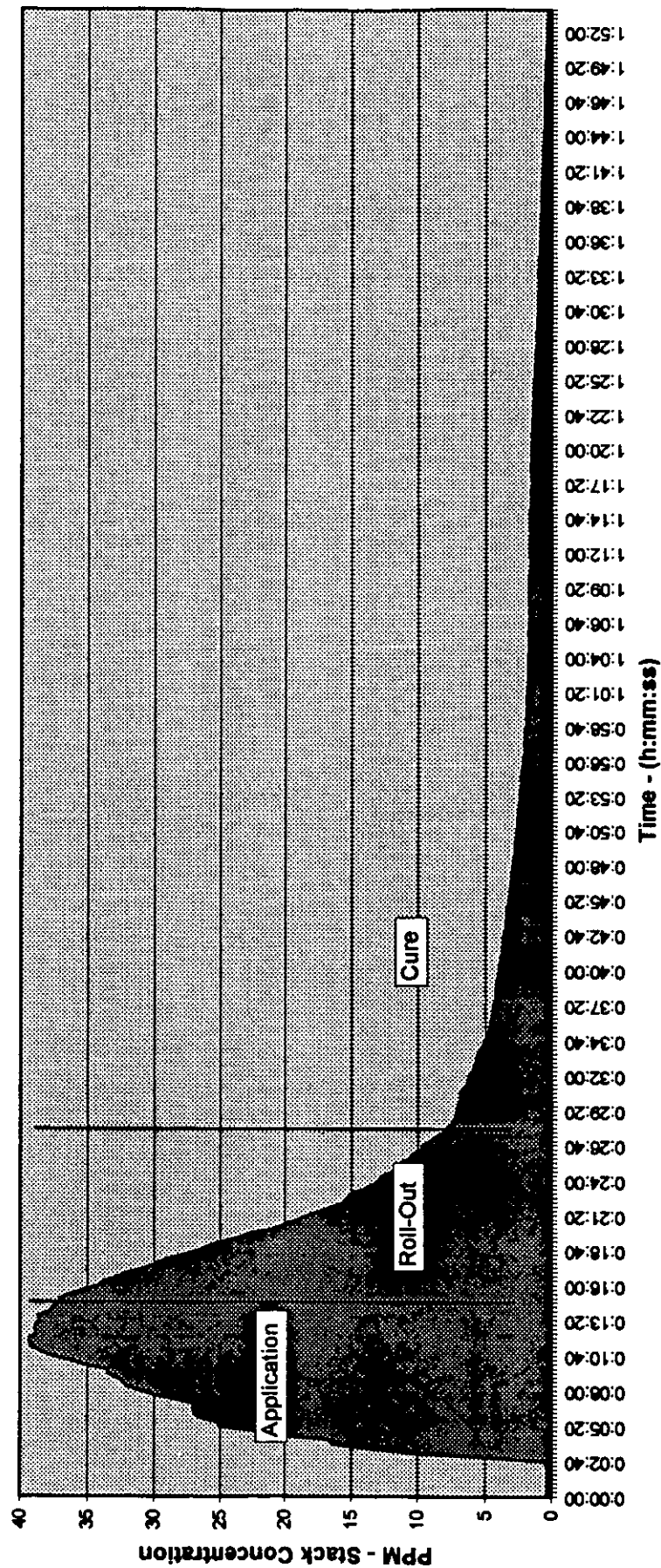
Run Parameters													Data			Normalized Surf. Area Emission (g/ft2/kg GC)	Emission % of Resin (RW)	Emission Lbs/Ton Resin Consumed
Run No.	Data ID	Laminatte Thickness (in.)	Resin Styrene %	Gel Time (min.)	Air Flow (fpm)	Emission % of AS	Surface Area Emiss. (g/ft2)	Surface Area Emiss. (g/m2)										
Low Flow																		
9	092795C	0.041	35	15	50	14.0%	5.89	63.42	1.78	5.0%			100.22					
15	091995A	0.041	35	30	50	17.6%	6.11	65.79	2.23	6.3%			125.51					
3	Replicate Avg.	0.041	42	15	50	17.2%	7.84	84.45	2.62	7.4%			147.44					
5	092595A	0.041	42	30	50	19.2%	8.12	87.38	2.88	8.1%			161.98					
12	Replicate Avg.	0.088	35	15	50	9.8%	7.83	84.30	1.25	3.5%			70.03					
13	092895A	0.088	35	30	50	11.9%	8.92	96.02	1.48	4.2%			83.06					
2	100295C	0.088	42	15	50	11.7%	10.47	112.73	1.73	4.9%			97.22					
8	092795B	0.088	42	30	50	13.5%	11.78	126.84	2.03	5.7%			114.13					
Igh Flow																		
1	100295B	0.041	35	30	100	17.7%	6.97	75.04	2.20	6.2%			123.60					
7	092795A	0.041	35	15	100	14.7%	6.40	68.88	1.87	5.3%			105.06					
11	Replicate Avg.	0.041	42	30	100	21.1%	9.09	97.88	3.17	6.9%			178.20					
14	092995B	0.041	42	15	100	17.1%	7.93	85.41	2.52	7.1%			141.35					
4	Replicate Avg.	0.088	35	30	100	12.4%	9.76	105.05	1.56	4.4%			87.59					
6	092695A	0.088	35	15	100	10.1%	7.74	83.32	1.28	3.6%			72.11					
10	092895A	0.088	42	30	100	14.3%	12.01	129.33	2.15	6.0%			120.89					
16	091995B	0.088	42	15	100	11.5%	11.40	122.73	1.76	4.9%			98.77					

	% Available Styrene	Norm. Surface Area	% Resin Weight	Lbs / Ton Resin
Avg. Emissions - High Air Flow	14.9%	2.06	5.9%	115.95
Avg. Emissions - Low Air Flow	14.4%	2.00	5.6%	112.45

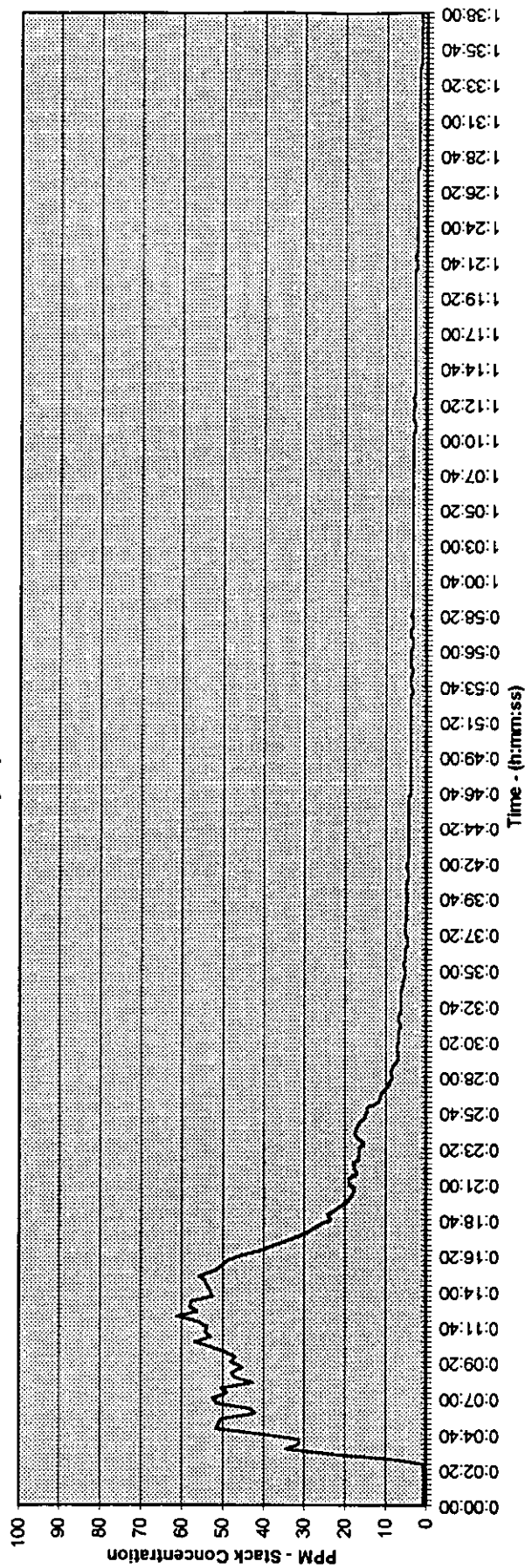
Composite Graph - Hand Lay-Up All Runs



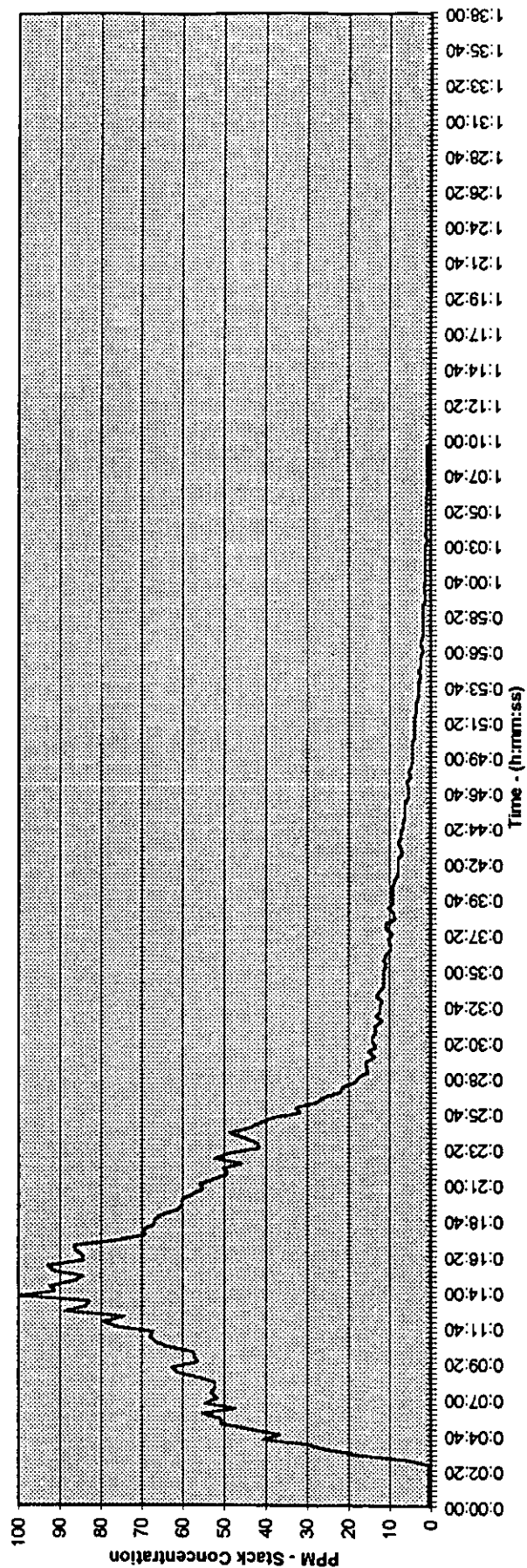
Average Emissions Profile - All Hand Lay-Up Runs



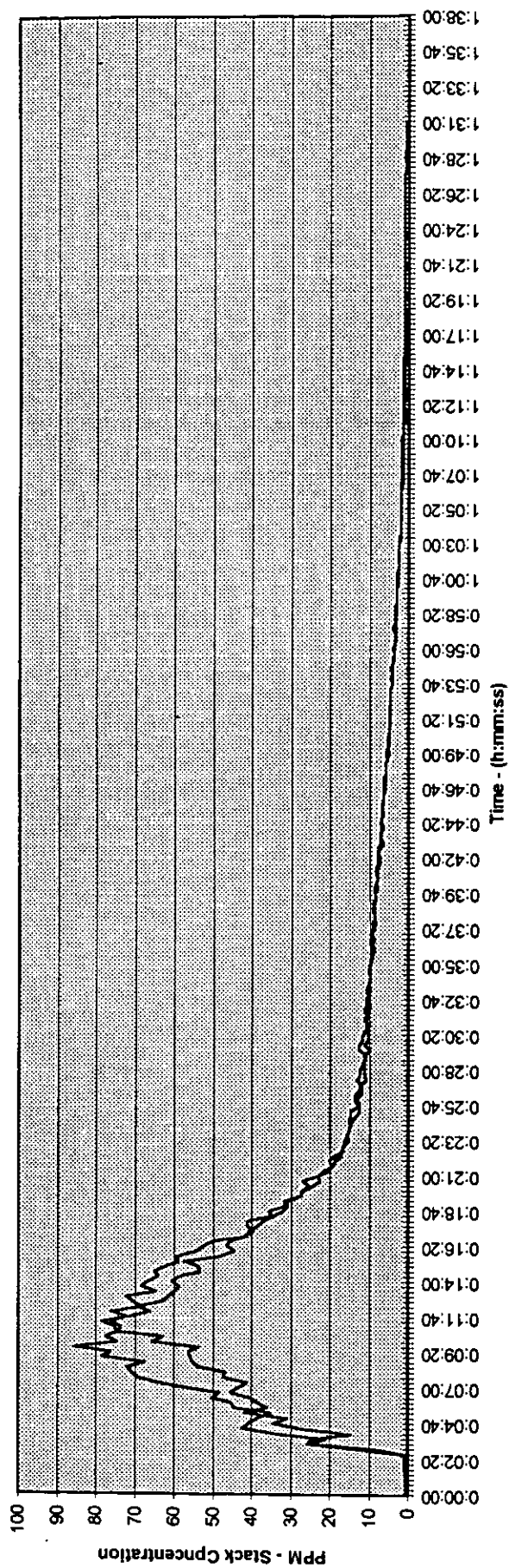
Hand Lay-Up - Run 1



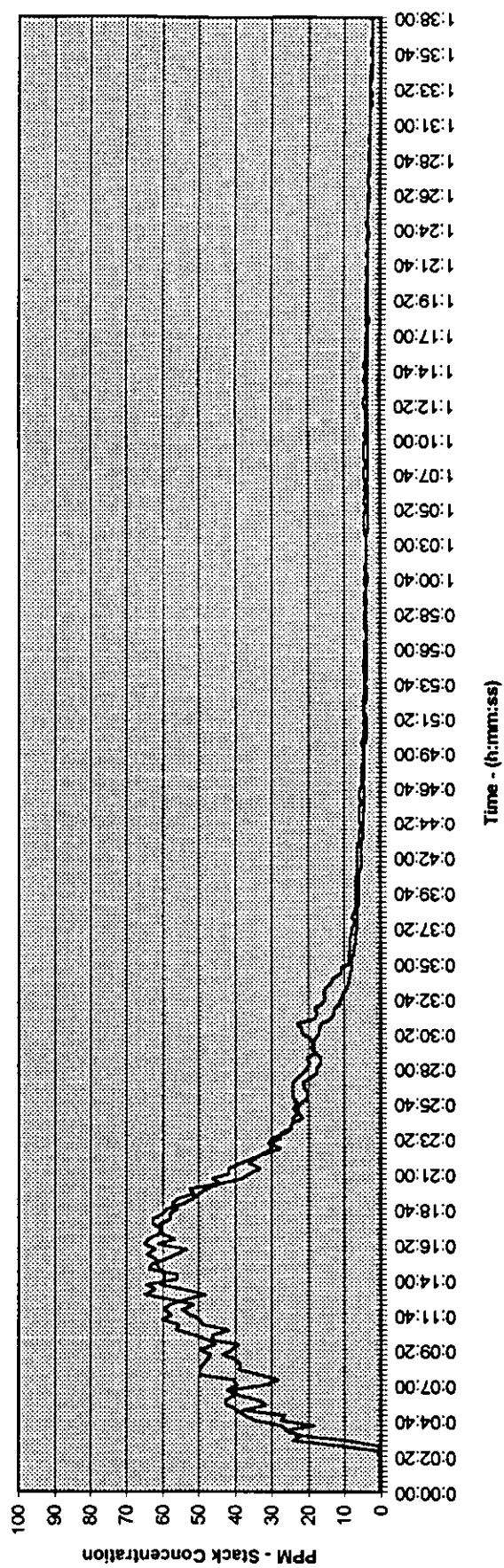
Hand Lay-Up - Run2



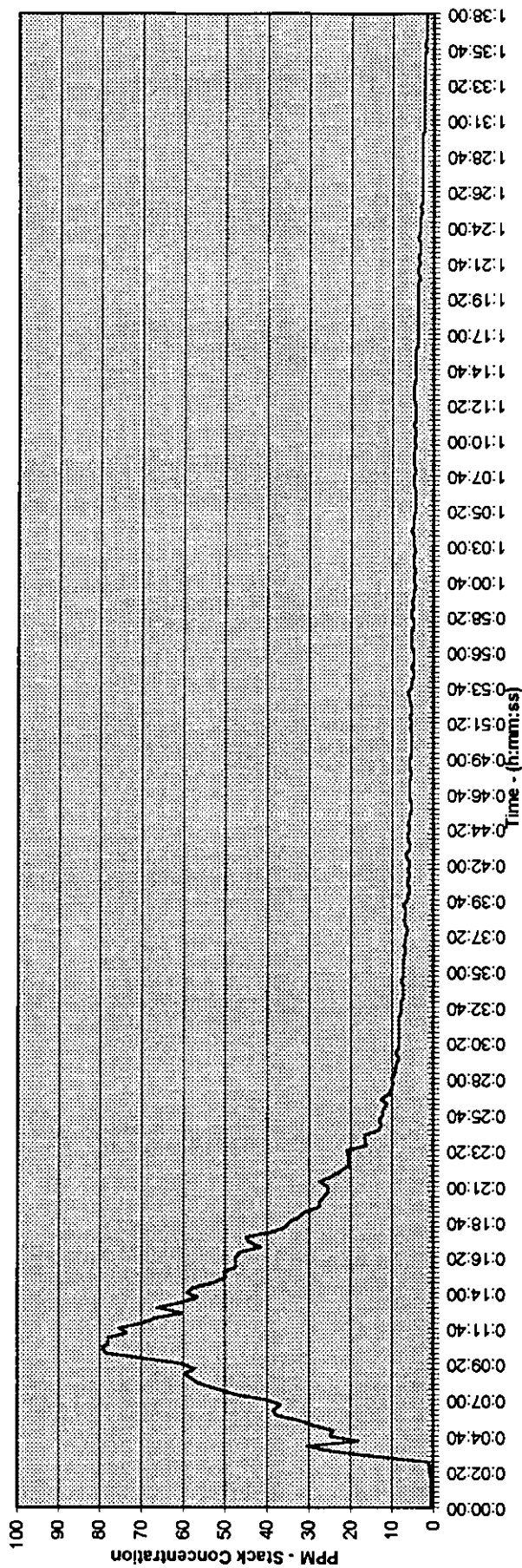
Hand Lay-Up - Runs 3A & 3B



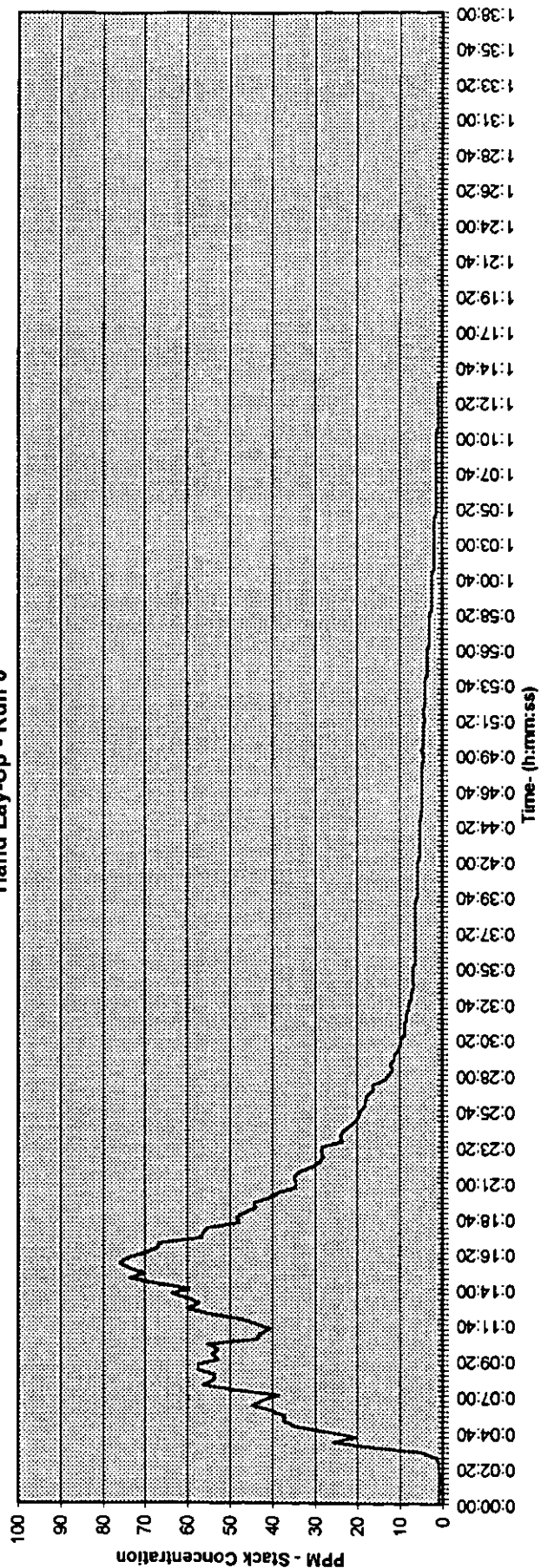
Hnad Lay-Up - Runs 4A & 4B



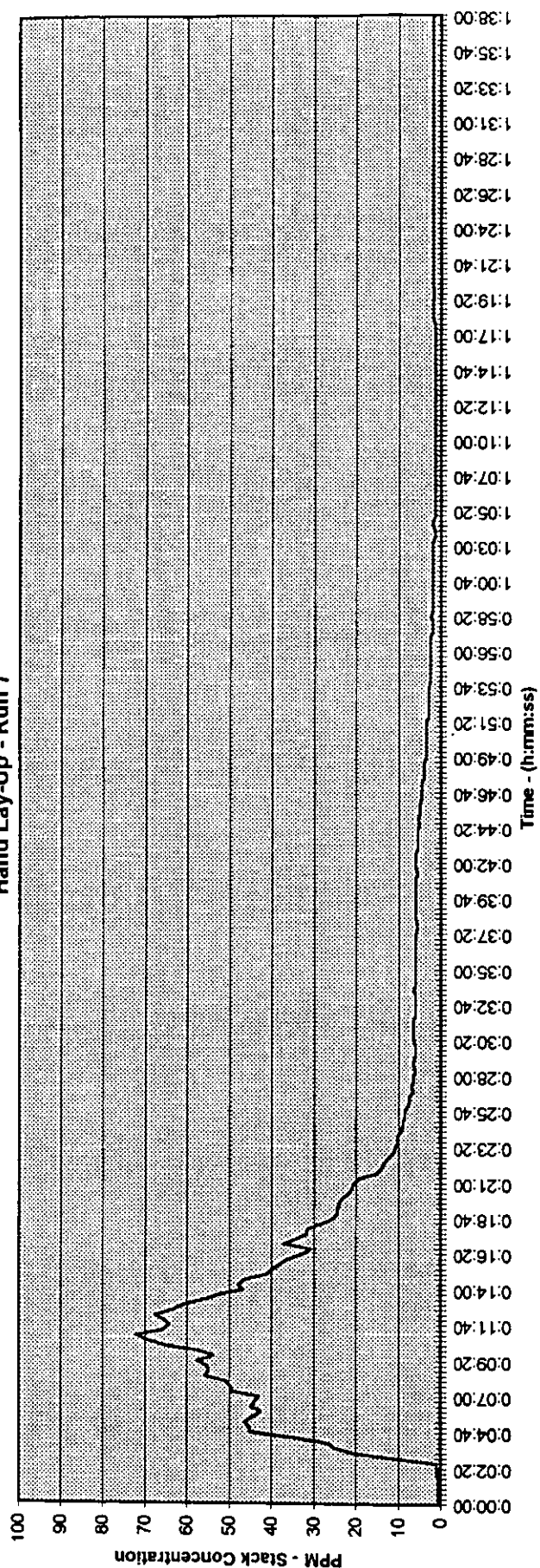
Hnad Lay-Up - Run 5



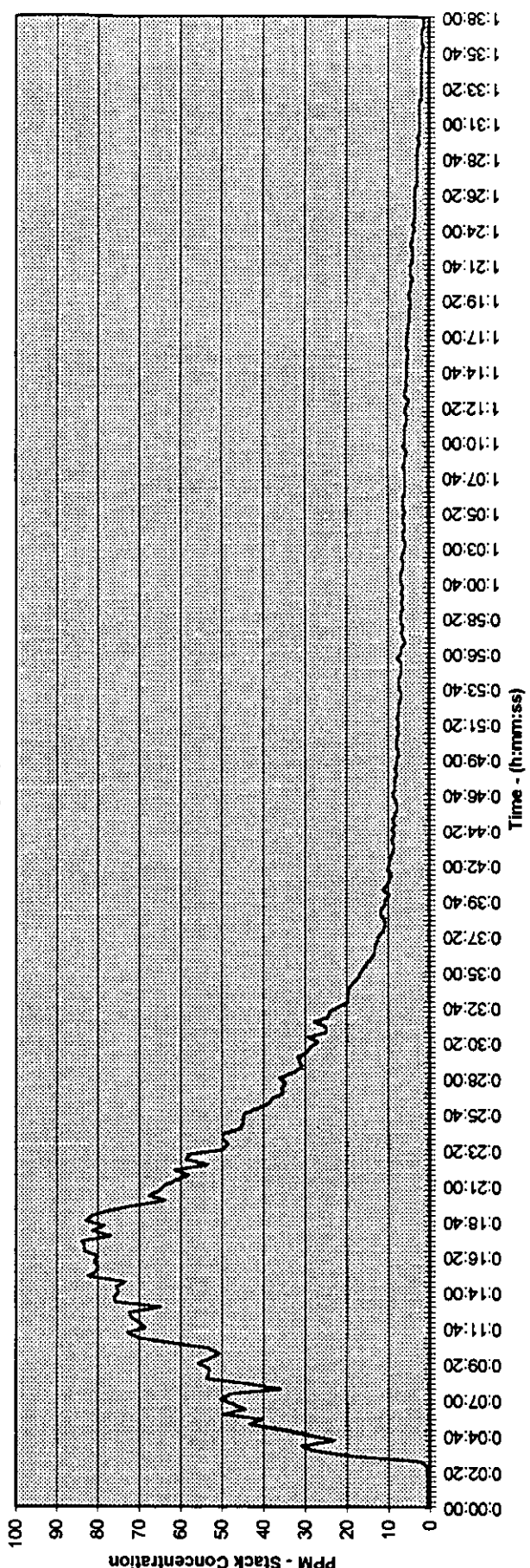
Hand Lay-Up - Run 6



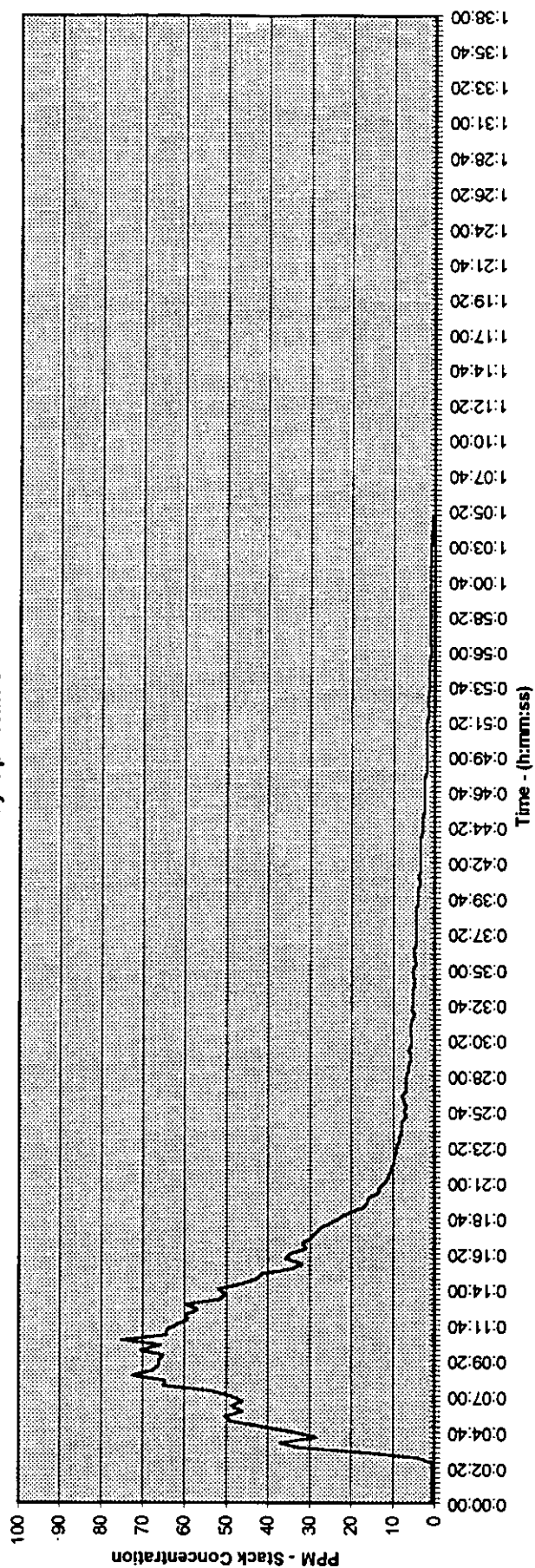
Hand Lay-Up - Run 7



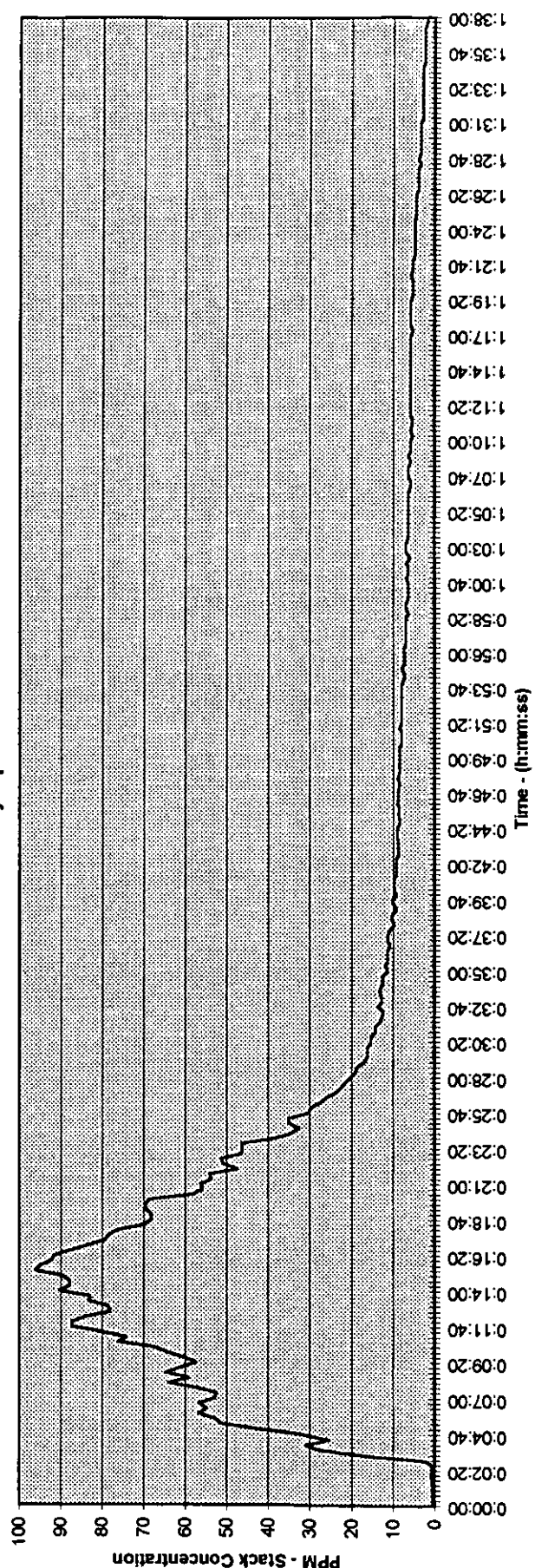
Hand Lay-Up - Run 8



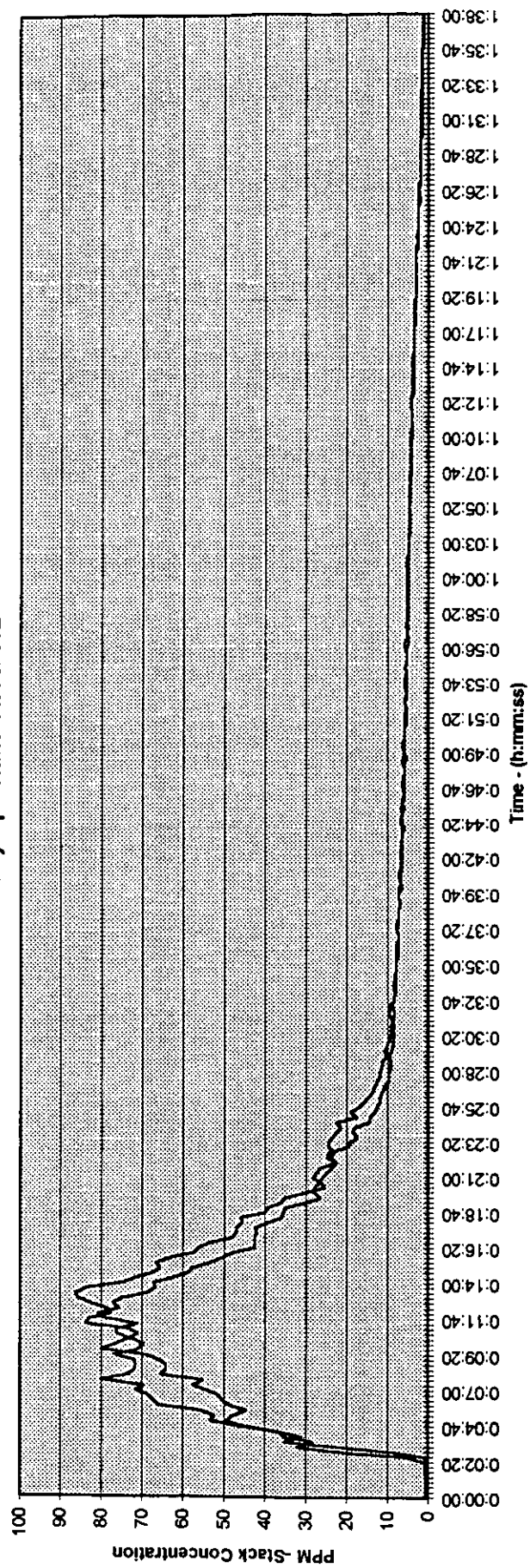
Hand Lay-Up - Run 9



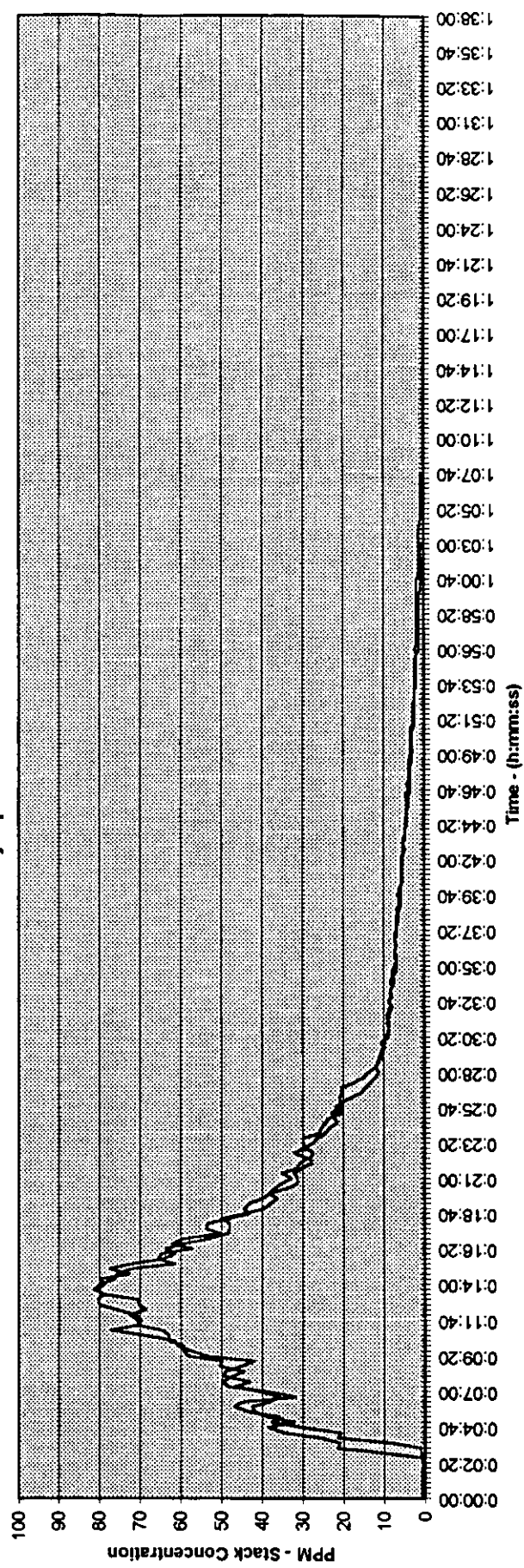
Hand Lay-Up - Run 10



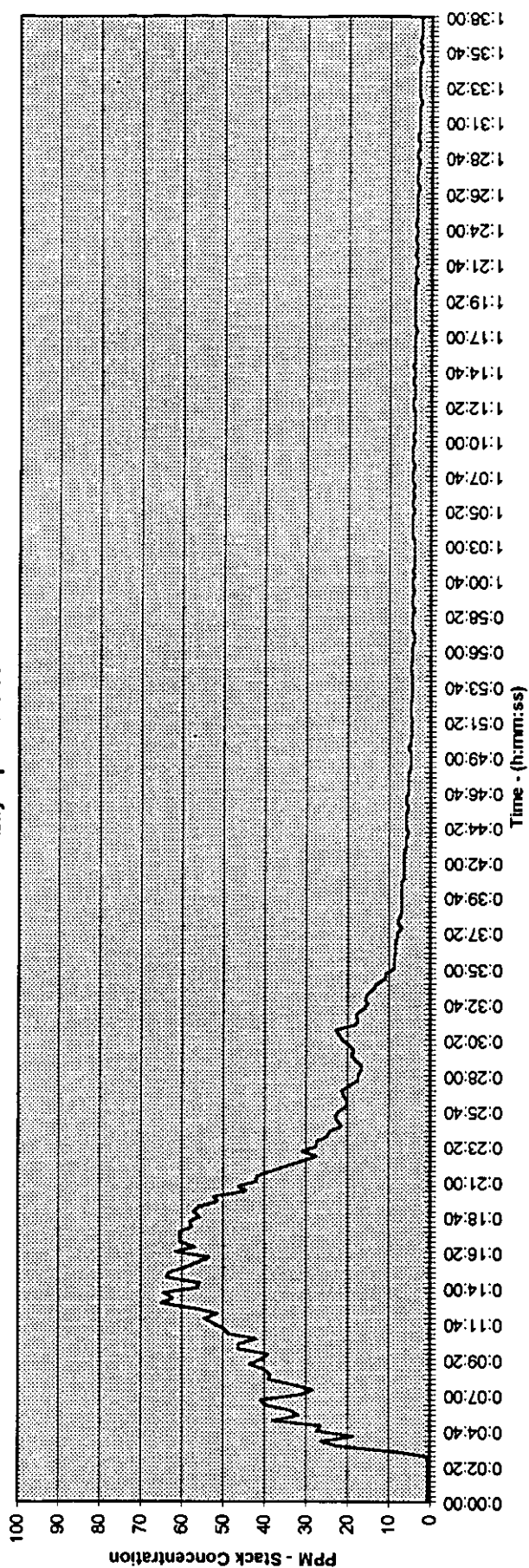
Hand Lay-Up - Runs 11A & 11B



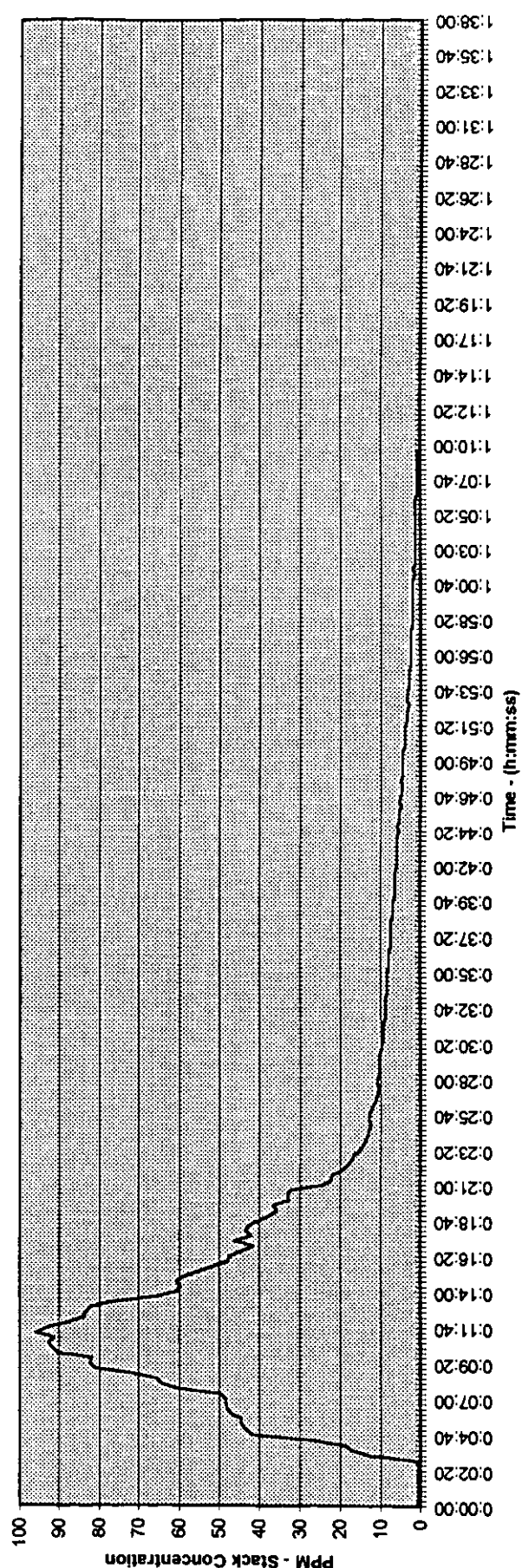
Hand Lay-Up - Runs 12A & 12B



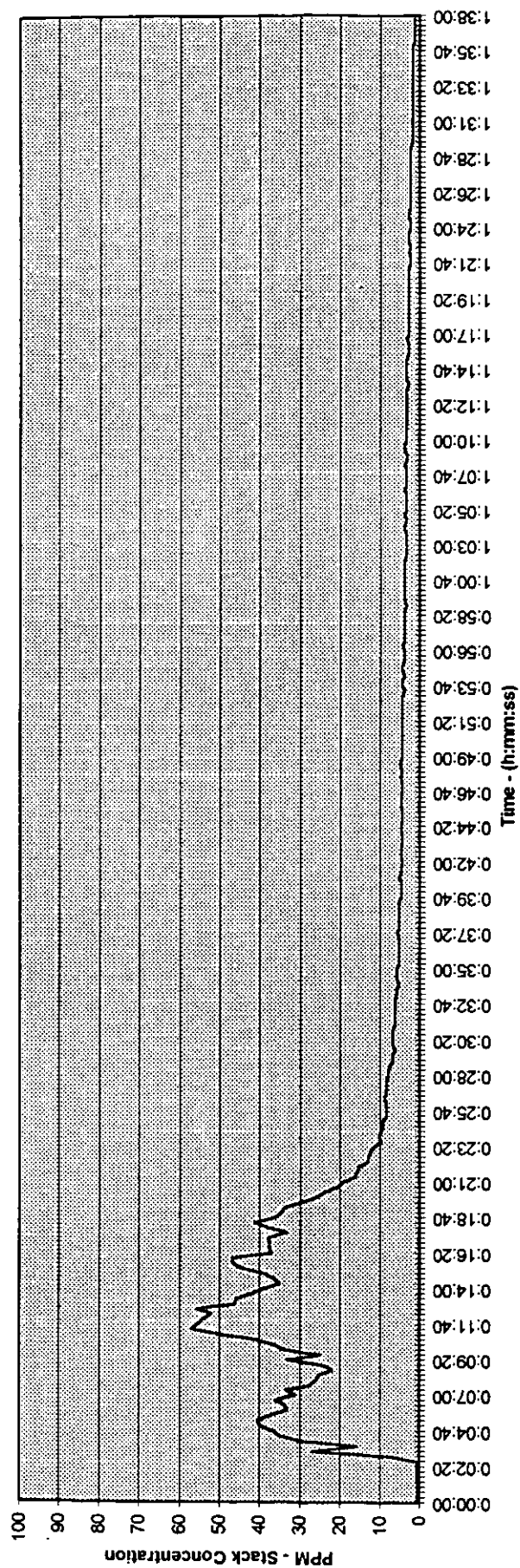
Hnad Lay-Up - Run 13



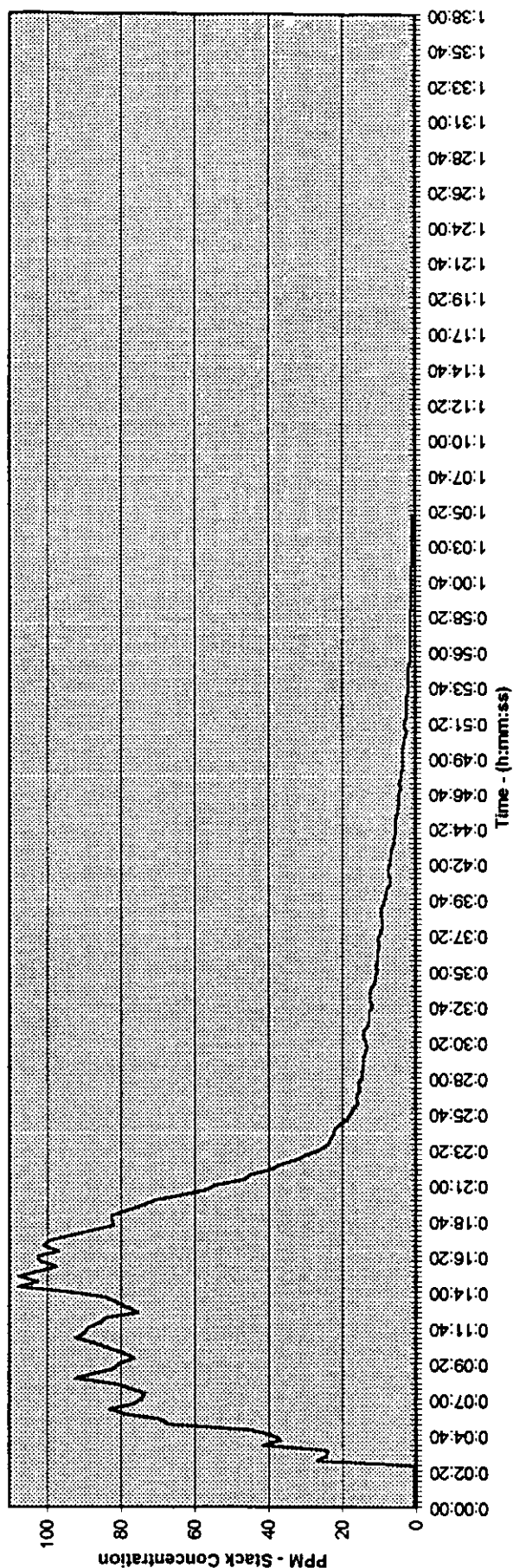
Hnad Lay-Up - Run 14



Hand Lay-Up - Run 15



Hand Lay-Up - Run 16



CFA Open Molding Styrene Emissions Test Project
Gel Coat Emissions Baseline Study

Table 8.11

Gel Coat Experiment Data Table

		Run Parameters					Data							Normalized Surf. Area Emission (g/1000g GC)	Emission % of Gel Resin (RW)	Emission Lbs/Ton Resin Consumed
Run No.	Data ID	GC Film Thick- ness (in.)	GC Styrene %	Gel Time (min.)	GC Flow (lb/min)	Air Flow (fpm)	Gel Coat Consumed (g)	Available Styrene (g)	Emission Weight (g)	Emission % of AS	Surface rea Emiss (g/ft2)	Surface Area Emiss. (g/m2)				
1	10195A	0.018	35	20	4	100	2510.00	864.90	465.32	53.8%	12.72	136.98	5.07	18.5%	370.77	
2	10195B	0.024	40	10	2	50	3110.00	1258.30	576.30	45.8%	15.76	169.65	5.07	18.5%	370.61	
3A	101295A	0.018	40	10	2	50	2359.00	954.50	507.79	53.2%	13.89	149.48	5.89	21.5%	430.52	
4A	101295B	0.024	35	20	4	100	3206.00	1104.80	539.14	48.8%	14.74	158.71	4.60	16.8%	336.33	
5	101395A	0.024	40	20	2	100	3134.00	1255.50	615.20	49.0%	16.82	181.10	5.37	19.6%	392.59	
6	101395B	0.024	35	10	4	50	3206.00	1113.80	484.50	43.5%	13.25	142.63	4.13	15.1%	302.25	
4B	101695A	0.024	35	20	4	100	3122.00	1075.80	449.68	41.8%	12.30	132.38	3.94	14.4%	288.07	
3B	101695B	0.018	40	10	2	50	2345.00	948.80	549.36	57.9%	15.02	161.72	6.41	23.4%	468.53	
7	101695C	0.018	35	10	4	50	2492.00	865.70	437.18	50.5%	11.95	128.70	4.80	17.5%	350.87	
8	101795A	0.018	40	20	2	100	2353.00	942.60	572.16	60.7%	15.65	168.43	6.65	24.3%	486.32	
9	101795B	0.018	35	10	2	100	2330.00	809.40	469.45	58.0%	12.84	138.20	5.51	20.1%	402.96	
10	101895A	0.024	40	20	4	50	3110.00	1245.90	652.85	52.4%	17.85	192.18	5.74	21.0%	419.84	
11A	101895B	0.018	40	20	4	50	2391.00	957.80	591.92	61.8%	16.19	174.25	6.77	24.8%	495.12	
12A	101995A	0.024	35	10	2	100	3124.00	1085.30	503.58	46.4%	13.77	148.24	4.41	16.1%	322.39	
13	101995B	0.024	35	20	2	50	3139.00	1081.70	491.09	45.4%	13.43	144.57	4.28	15.6%	312.90	
14	101995C	0.018	40	10	4	100	2310.00	934.60	523.38	56.0%	14.31	154.07	6.20	22.7%	453.14	
11B	102395A	0.018	40	20	4	50	2386.00	955.80	592.60	62.0%	16.20	174.45	6.79	24.8%	496.73	
12B	102395B	0.024	35	10	2	100	3137.00	1089.80	488.23	44.8%	13.35	143.72	4.26	15.6%	311.27	
15	102495A	0.018	35	20	2	50	2347.00	808.80	403.59	49.9%	11.04	118.81	4.70	17.2%	343.92	
16	102495B	0.024	40	10	4	100	3093.00	1251.40	641.97	51.3%	17.55	188.98	5.68	20.8%	415.11	

CFA Open Molding Styrene Emissions Test Project
Gel Coat Emissions Baseline Study

Table 8.12

Gel Coat Experiment Master Table- Replicate Averages

Run No.	Data ID	Run Parameters					Data			Normalized Surf. Area Emission g/ft ² /kg GC	Emission % of Gel Coat (RW)	Emission Lbs/Ton Gel Coat Consumed
		GC Film Thickness (in.)	GC Styrene %	Gel Time (min.)	GC Flow (lb/min)	Air Flow (fpm)	Emission % of AS	Surface Area Emiss. (g/ft ²)	Surface Area Emiss. (g/m ²)			
1	101195A	0.018	35	20	4	100	53.8%	12.72	136.98	5.07	18.5%	370.77
2	101195B	0.024	40	10	2	50	45.8%	15.76	169.65	5.07	18.5%	370.61
3	Replicate Avg.	0.018	40	10	2	50	55.6%	14.45	155.60	6.15	22.5%	449.52
4	Replicate Avg.	0.024	35	20	4	100	45.3%	13.52	145.54	4.27	15.8%	312.20
5	101395A	0.024	40	20	2	100	49.0%	16.82	181.10	5.37	19.6%	392.59
6	101395B	0.024	35	10	4	50	43.5%	13.25	142.63	4.13	15.1%	302.25
7	101695C	0.018	35	10	4	50	50.5%	11.95	128.70	4.80	17.5%	350.87
8	101795A	0.018	40	20	2	100	60.7%	15.65	168.43	6.65	24.3%	486.32
9	101795B	0.018	35	10	2	100	58.0%	12.84	138.20	5.51	20.1%	402.96
10	101895A	0.024	40	20	4	50	52.4%	17.85	192.18	5.74	21.0%	419.84
11	Replicate Avg.	0.018	40	20	4	50	61.8%	16.19	174.25	6.77	24.8%	495.93
12	Replicate Avg.	0.024	35	10	2	100	45.6%	13.56	145.98	4.33	15.8%	316.83
13	101995B	0.024	35	20	2	50	45.4%	13.43	144.57	4.28	15.6%	312.90
14	101995C	0.018	40	10	4	100	56.0%	14.31	154.07	6.20	22.7%	453.14
15	102495A	0.018	35	20	2	50	49.9%	11.04	118.81	4.70	17.2%	343.92
16	102495B	0.024	40	10	4	100	51.3%	17.55	188.98	5.68	20.8%	415.11

CFA Open Molding Styrene Emissions Test Project
Gel Coat Emissions Baseline Study

Table 8.13

Emissions % Of Available Styrene

Run Parameters												
Run No.	Data ID	GC Film Thickness (in.)	GC Styrene %	Gel Time (min.)	GC Flow (lb/min)	Air Flow (fpm)	Data			Normalized Surf. Area Emission g/ft2/kg GC	Emission % of Gel Coat (RW)	Emission Lbs/Ton Gel Coat Consumed
							Emission % of AS	Surface Area Emiss. (g/ft2)	Surface Area Emiss. (g/m2)			
6	101395B	0.024	35	10	4	50				4.13	15.1%	302.25
4	Replicate Avg.	0.024	35	20	4	100				4.27	15.6%	312.20
13	101995B	0.024	35	20	2	50				4.28	15.6%	312.90
12	Replicate Avg.	0.024	35	10	2	100				4.33	15.8%	316.83
2	101195B	0.024	40	10	2	50				5.07	18.5%	370.61
5	101395A	0.024	40	20	2	100				5.37	19.6%	392.59
15	102495A	0.018	35	20	2	50				4.70	17.2%	343.92
7	101695C	0.018	35	10	4	50				4.80	17.5%	350.87
16	102495B	0.024	40	10	4	100				5.68	20.8%	415.11
10	101895A	0.024	40	20	4	50				5.74	21.0%	419.84
1	101195A	0.018	35	20	4	100				5.07	18.5%	370.77
3	Replicate Avg.	0.018	40	10	2	50				6.15	22.5%	449.52
14	101995C	0.018	40	10	4	100				6.20	22.7%	453.14
9	101795B	0.018	35	10	2	100				5.51	20.1%	402.96
8	101795A	0.018	40	20	2	100				6.65	24.3%	486.32
11	Replicate Avg.	0.018	40	20	4	50				6.77	24.8%	495.93

CFA Open Molding Styrene Emissions Test Project
Gel Coat Emissions Baseline Study

Table 8.14

Emissions By Normalized Surface Area

Run No.	Data ID	Run Parameters					Data			Normalized Surf. Area Emission g/ft2/kg GC	Emission % of Gel Coat (RW)	Emission Lbs/Ton Gel Coat Consumed
		GC Film Thickness (in.)	GC Styrene %	Gel Time (min.)	GC Flow (lb/min)	Air Flow (fpm)	Emission % of AS	Surface Area Emiss. (g/ft2)	Surface Area Emiss. (g/m2)			
15	102495A	0.018	35	20	2	50	49.9%	11.04	118.81	4.70	17.2%	343.92
7	101695C	0.018	35	10	4	50	50.5%	11.95	128.70	4.80	17.5%	350.87
1	101195A	0.018	35	20	4	100	53.8%	12.72	136.98	5.07	18.5%	370.77
9	101795B	0.018	35	10	2	100	58.0%	12.84	138.20	5.51	20.1%	402.96
6	101395B	0.024	35	10	4	50	43.5%	13.25	142.63	4.13	15.1%	302.25
13	101995B	0.024	35	20	2	50	45.4%	13.43	144.57	4.28	15.6%	312.90
4	Replicate Avg.	0.024	35	20	4	100	45.3%	13.52	145.54	4.27	15.6%	312.20
12	Replicate Avg.	0.024	35	10	2	100	45.6%	13.56	145.98	4.33	15.8%	316.83
14	101995C	0.018	40	10	4	100	56.0%	14.31	154.07	6.20	22.7%	453.14
3	Replicate Avg.	0.018	40	10	2	50	55.6%	14.45	155.60	6.15	22.5%	449.52
8	101795A	0.018	40	20	2	100	60.7%	15.65	168.43	6.65	24.3%	486.32
2	101195B	0.024	40	10	2	50	45.8%	15.76	169.65	5.07	18.5%	370.61
11	Replicate Avg.	0.018	40	20	4	50	61.8%	16.19	174.25	6.77	24.8%	495.93
5	101395A	0.024	40	20	2	100	49.0%	16.82	181.10	5.37	19.6%	392.59
16	102495B	0.024	40	10	4	100	51.3%	17.55	188.98	5.68	20.8%	415.11
10	101895A	0.024	40	20	4	50	52.4%	17.85	192.18	5.74	21.0%	419.84

CFA Open Molding Styrene Emissions Test Project
Gel Coat Emissions Baseline Study

Table 8.15

Emissions By % Gel Coat Weight

Run No.	Data ID	Run Parameters					Data			Normalized Surf. Area Emission g/ft ² /kg GC	Emission % of Gel Coat (RW)	Emission Lbs/Ton Gel Coat Consumed
		GC Film Thickness (in.)	GC Styrene %	Gel Time (min.)	GC Flow (lb/min)	Air Flow (fpm)	Emission % of AS	Surface Area Emiss. (g/ft ²)	Surface Area Emiss. (g/m ²)			
6	101395B	0.024	35	10	4	50	43.5%	13.25	142.63	4.13	15.1%	302.25
4	Replicate Avg.	0.024	35	20	4	100	45.3%	13.52	145.54	4.27	15.6%	312.20
13	101995B	0.024	35	20	2	50	45.4%	13.43	144.57	4.28	15.6%	312.90
12	Replicate Avg.	0.024	35	10	2	100	45.6%	13.56	145.98	4.33	15.8%	316.83
15	102495A	0.018	35	20	2	50	49.9%	11.04	118.81	4.70	17.2%	343.92
7	101895C	0.018	35	10	4	50	50.5%	11.95	128.70	4.80	17.5%	350.87
2	101195B	0.024	40	10	2	50	45.8%	15.76	169.65	5.07	18.5%	370.61
1	101195A	0.018	35	20	4	100	53.8%	12.72	136.98	5.07	18.5%	370.77
5	101395A	0.024	40	20	2	100	49.0%	16.82	181.10	5.37	19.6%	392.59
9	101795B	0.018	35	10	2	100	58.0%	12.84	138.20	5.51	20.1%	402.96
16	102495B	0.024	40	10	4	100	51.3%	17.55	188.98	5.68	20.8%	415.11
10	101895A	0.024	40	20	4	50	52.4%	17.85	192.18	5.74	21.0%	419.84
3	Replicate Avg.	0.018	40	10	2	50	55.6%	14.45	155.60	6.15	22.5%	449.52
14	101995C	0.018	40	10	4	100	56.0%	14.31	154.07	6.20	22.7%	453.14
8	101795A	0.018	40	20	2	100	60.7%	15.65	168.43	6.65	24.3%	486.32
11	Replicate Avg.	0.018	40	20	4	50	61.8%	16.19	174.25	6.77	24.8%	495.93

CFA Open Molding Styrene Emissions Test Project
Gel Coat Emissions Baseline Study

Table 8.16

Emissions - Pounds (lbs) Per Ton Resin Consumed

Run Parameters													
Run No.	Data ID	GC Film Thickness (in.)	GC Styrene %	Gel Time (min.)	GC Flow (lb/min)	Air Flow (fpm)	Data				Normalized Surf. Area Emission g/ft2/kg GC	Emission % of Gel Coat (RW)	Emission Lbs/Ton Gel Coat Consumed
							Emission % of AS	Surface Area Emiss. (g/ft2)	Surface Area Emiss. (g/m2)				
6	101395B	0.024	35	10	4	50							
4	Replicate Avg.	0.024	35	20	4	100							
13	101995B	0.024	35	20	2	50							
12	Replicate Avg.	0.024	35	10	2	100							
15	102495A	0.018	35	20	2	50							
7	101695C	0.018	35	10	4	50							
2	101195B	0.024	40	10	2	50							
1	101195A	0.018	35	20	4	100							
5	101395A	0.024	40	20	2	100							
9	101795B	0.018	35	10	2	100							
16	102495B	0.024	40	10	4	100							
10	101895A	0.024	40	20	4	50							
3	Replicate Avg.	0.018	40	10	2	50							
14	101995C	0.018	40	10	4	100							
8	101795A	0.018	40	20	2	100							
11	Replicate Avg.	0.018	40	20	4	50							

Gel Coat Emissions Baseline Study

Table 8.17

Film Thickness Effects

Run No.		Data ID	Run Parameters					Data			Normalized Surf. Area Emission g/ft2/kg GC	Emission % of Gel Coat (RW)	Emission Lbs/Ton Gel Coat Consumed
			GC Film Thickness (in.)	GC Styrene %	Gel Time (min.)	GC Flow (lb/min)	Air Flow (fpm)	Emission % of AS	Surface Area Emiss. (g/ft2)	Surface Area Emiss. (g/m2)			
Thin Film													
7		101695C	0.018	35	10	4	50	50.5%	11.95	128.70	4.80	17.5%	350.87
9		101795B	0.018	35	10	2	100	58.0%	12.84	138.20	5.51	20.1%	402.96
1		101195A	0.018	35	20	4	100	53.8%	12.72	136.98	5.07	18.5%	370.77
15		102495A	0.018	35	20	2	50	49.9%	11.04	118.81	4.70	17.2%	343.92
3		Replicate Avg.	0.018	40	10	2	50	55.6%	14.45	155.60	6.15	22.5%	449.52
14		101995C	0.018	40	10	4	100	56.0%	14.31	154.07	6.20	22.7%	453.14
8		101795A	0.018	40	20	2	100	60.7%	15.65	168.43	6.65	24.3%	486.32
11		Replicate Avg.	0.018	40	20	4	50	61.8%	16.19	174.25	6.77	24.8%	495.93
Thick Film													
6		101395B	0.024	35	10	4	50	43.5%	13.25	142.63	4.13	15.1%	302.25
12		Replicate Avg.	0.024	35	10	2	100	45.6%	13.56	145.98	4.33	15.8%	316.83
4		Replicate Avg.	0.024	35	20	4	100	45.3%	13.52	145.54	4.27	15.6%	312.20
13		101995B	0.024	35	20	2	50	45.4%	13.43	144.57	4.28	15.6%	312.90
2		101195B	0.024	40	10	2	50	45.8%	15.76	169.65	5.07	18.5%	370.61
16		102495B	0.024	40	10	4	100	51.3%	17.55	188.98	5.68	20.8%	415.11
5		101395A	0.024	40	20	2	100	49.0%	16.82	181.10	5.37	19.6%	392.59
10		101895A	0.024	40	20	4	50	52.4%	17.85	192.18	5.74	21.0%	419.84

	% Available Styrene	Norm. Surface Area	% Gel Coat Weight	Lbs/ Ton Gel Coat
Avg. Emissions - Thin Film	55.8%	5.73	21.0%	419.18
Avg. Emissions - Thick Film	47.3%	4.86	17.8%	355.29

Avg. Emissions - Thin Film/High Styrene	58.5%	6.44	23.6%	471.23		
Avg. Emissions - Thin Film/Low Styrene	53.1%	5.02	18.4%	367.13		

Avg. Emissions - Thick Film/High Styrene	49.6%	5.47	20.0%	399.54		
Avg. Emissions - Thick Film/Low Styrene	45.0%	4.25	15.6%	311.05		

CFA Open Molding Styrene Emissions Test Project
Gel Coat Emissions Baseline Study

Table 8.18

Available Styrene Effects

		Run Parameters										Data		Normalized	Emission	Emission
Run No.	Data ID	GC Film Thickness (in.)	GC Styrene %	Gel Time (min.)	GC Flow (lb/min)	Air Flow (fpm)	Emission % of AS	Surface Area Emiss. (g/ft2)	Surface Area Emiss. (g/m2)		Surf. Area Emission g/ft2/kg GC	% of Gel Coat (RW)	Lbs/Ton Gel Coat Consumed			
Low Styrene																
7	101695C	0.018	35	10	4	50	50.5%	11.95	128.70		4.80	17.5%	350.87			
9	101795B	0.018	35	10	2	100	58.0%	12.84	138.20		5.51	20.1%	402.96			
1	101195A	0.018	35	20	4	100	53.8%	12.72	136.98		5.07	18.5%	370.77			
15	102495A	0.018	35	20	2	50	49.9%	11.04	118.81		4.70	17.2%	343.92			
6	101395B	0.024	35	10	4	50	43.5%	13.25	142.63		4.13	15.1%	302.25			
12	Replicate Avg.	0.024	35	10	2	100	45.6%	13.56	145.98		4.33	15.8%	316.83			
4	Replicate Avg.	0.024	35	20	4	100	45.3%	13.52	145.54		4.27	15.6%	312.20			
13	101995B	0.024	35	20	2	50	45.4%	13.43	144.57		4.28	15.6%	312.90			
High Styrene																
3	Replicate Avg.	0.018	40	10	2	50	55.6%	14.45	155.60		6.15	22.5%	449.52			
14	101995C	0.018	40	10	4	100	56.0%	14.31	154.07		6.20	22.7%	453.14			
8	101795A	0.018	40	20	2	100	60.7%	15.65	168.43		6.65	24.3%	486.32			
11	Replicate Avg.	0.018	40	20	4	50	61.8%	16.19	174.25		6.77	24.8%	495.93			
2	101195B	0.024	40	10	2	50	45.8%	15.76	169.65		5.07	18.5%	370.61			
16	102495B	0.024	40	10	4	100	51.3%	17.55	188.98		5.68	20.8%	415.11			
5	101395A	0.024	40	20	2	100	49.0%	16.82	181.10		5.37	19.6%	392.59			
10	101895A	0.024	40	20	4	50	52.4%	17.85	192.18		5.74	21.0%	419.84			

	% Available Styrene	Norm. Surface Area	% Gel Coat Weight	Lbs/Ton Gel Coat
Avg. Emissions - Low Styrene	49.0%	4.64	17.0%	339.09
Avg. Emissions - High Styrene	54.1%	5.95	21.8%	435.38

Avg. Emissions - Low Styrene/Thick Film	45.0%	4.25	15.6%	311.05
Avg. Emissions - Low Styrene/Thin Film	53.1%	5.02	18.4%	367.13

Avg. Emissions - High Styrene/Thick Fil	49.6%	5.47	20.0%	399.54
Avg. Emissions - High Styrene/Thin Film	58.5%	6.44	23.6%	471.23

CFA Open Molding Styrene Emissions Test Project
Gel Coat Emissions Baseline Study

Table 8.19

Gel Time Effects

Run Parameters												
Run No.	Data ID	GC Film Thickness (in.)	GC Styrene %	Gel Time (min.)	GC Flow (lb/min)	Air Flow (fpm)	Data			Normalized Surf. Area Emission g/ft2/kg GC	Emission % of Gel Coat (RW)	Emission Lbs/Ton Gel Coat Consumed
							Emission % of AS	Surface Area Emiss. (g/ft2)	Surface Area Emiss. (g/m2)			
Fast Gel Time												
7	101695C	0.018	35	10	4	50	50.5%	11.95	128.70	4.80	17.5%	350.87
9	101795B	0.018	35	10	2	100	58.0%	12.84	138.20	5.51	20.1%	402.96
3	Replicate Avg.	0.018	40	10	2	50	55.6%	14.45	155.60	6.15	22.5%	449.52
14	101995C	0.018	40	10	4	100	56.0%	14.31	154.07	6.20	22.7%	453.14
6	101395B	0.024	35	10	4	50	43.5%	13.25	142.63	4.13	15.1%	302.25
12	Replicate Avg.	0.024	35	10	2	100	45.6%	13.56	145.98	4.33	15.8%	316.83
2	101195B	0.024	40	10	2	50	45.8%	15.76	169.65	5.07	18.5%	370.61
16	102495B	0.024	40	10	4	100	51.3%	17.55	188.98	5.68	20.8%	415.11
Slow Gel Time												
1	101195A	0.018	35	20	4	100	53.8%	12.72	136.98	5.07	18.5%	370.77
15	102495A	0.018	35	20	2	50	49.9%	11.04	118.81	4.70	17.2%	343.92
8	101795A	0.018	40	20	2	100	60.7%	15.65	168.43	6.65	24.3%	486.32
11	Replicate Avg.	0.018	40	20	4	50	61.8%	16.19	174.25	6.77	24.8%	495.93
4	Replicate Avg.	0.024	35	20	4	100	45.3%	13.52	145.54	4.27	15.6%	312.20
13	101995B	0.024	35	20	2	50	45.4%	13.43	144.57	4.28	15.6%	312.90
5	101395A	0.024	40	20	2	100	49.0%	16.82	181.10	5.37	19.6%	392.59
10	101895A	0.024	40	20	4	50	52.4%	17.85	192.18	5.74	21.0%	419.84

	% Available Styrene	Norm. Surface Area	% Gel Coat Weight	Lbs./Ton Gel Coat
Avg. Emissions - Fast Gel Time	50.8%	5.23	19.1%	382.66
Avg. Emissions - Slow Gel Time	52.3%	5.36	19.6%	391.81

Avg. Emissions - Fast Gel Time/Thick Fil	46.6%	4.80	17.6%	351.20
Avg. Emissions - Fast Gel Time/Thin Fil	52.7%	5.66	20.7%	414.12

Avg. Emissions - Slow Gel Time/Thick Fil	48.0%	4.91	18.0%	359.38
Avg. Emissions - Slow Gel Time/Thin Fil	56.6%	5.80	21.2%	424.23

CFA Open Molding Styrene Emissions Test Project
Gel Coat Emissions Baseline Study

Table 8.20

Gel Coat Flow Rate Effects

		Run Parameters					Data			Normalized	Emission	Emission
Run No.	Data ID	GC Film Thickness (in.)	GC Styrene %	Gel Time (min.)	GC Flow (lb/min)	Air Flow (fpm)	Emission % of AS	Surface Area Emiss. (g/ft2)	Surface Area Emiss. (g/m2)	Surf. Area Emission g/ft2/kg GC	% of Gel Coat (RW)	Lbs/Ton Gel Coat Consumed
Low Flow Rate												
9	101795B	0.018	35	10	2	100	58.0%	12.84	138.20	5.51	20.1%	402.96
15	102495A	0.018	35	20	2	50	49.9%	11.04	118.81	4.70	17.2%	343.92
3	Replicate Avg.	0.018	40	10	2	50	55.6%	14.45	155.60	6.15	22.5%	449.52
8	101795A	0.018	40	20	2	100	60.7%	15.65	168.43	6.65	24.3%	486.32
12	Replicate Avg.	0.024	35	10	2	100	45.6%	13.56	145.98	4.33	15.8%	316.83
13	101995B	0.024	35	20	2	50	45.4%	13.43	144.57	4.28	15.6%	312.90
2	101195B	0.024	40	10	2	50	45.8%	15.76	169.65	5.07	18.5%	370.61
5	101395A	0.024	40	20	2	100	49.0%	16.82	181.10	5.37	19.6%	392.59
High Flow Rate												
1	101195A	0.018	35	20	4	100	53.8%	12.72	136.98	5.07	18.5%	370.77
7	101695C	0.018	35	10	4	50	50.5%	11.95	128.70	4.80	17.5%	350.87
11	Replicate Avg.	0.018	40	20	4	50	61.8%	16.19	174.25	6.77	24.8%	495.93
14	101995C	0.018	40	10	4	100	56.0%	14.31	154.07	6.20	22.7%	453.14
4	Replicate Avg.	0.024	35	20	4	100	45.3%	13.52	145.54	4.27	15.6%	312.20
6	101395B	0.024	35	10	4	50	43.5%	13.25	142.63	4.13	15.1%	302.25
10	101895A	0.024	40	20	4	50	52.4%	17.85	192.18	5.74	21.0%	419.84
16	102495B	0.024	40	10	4	100	51.3%	17.55	188.98	5.68	20.8%	415.11

	% Available Styrene	Norm. Surface Area	% Gel Coat Weight	Lbs/Ton Gel Coat
Avg. Emissions - Low Flow Rate	51.2%	5.26	19.2%	384.46
Avg. Emissions - High Flow Rate	51.8%	5.33	19.5%	390.01

Avg. Emissions - Low Flow Rate/Thick	46.5%	4.76	17.4%	348.23
Avg. Emissions - Low Flow Rate/Thin	56.0%	5.75	21.0%	420.68

Avg. Emissions- High Flow Rate/Thick	48.1%	4.95	18.1%	362.35
Avg. Emissions - High Flow Rate/Thin	55.5%	5.71	20.9%	417.68

CFA Open Molding Styrene Emissions Test Project
Gel Coat Emissions Baseline Study

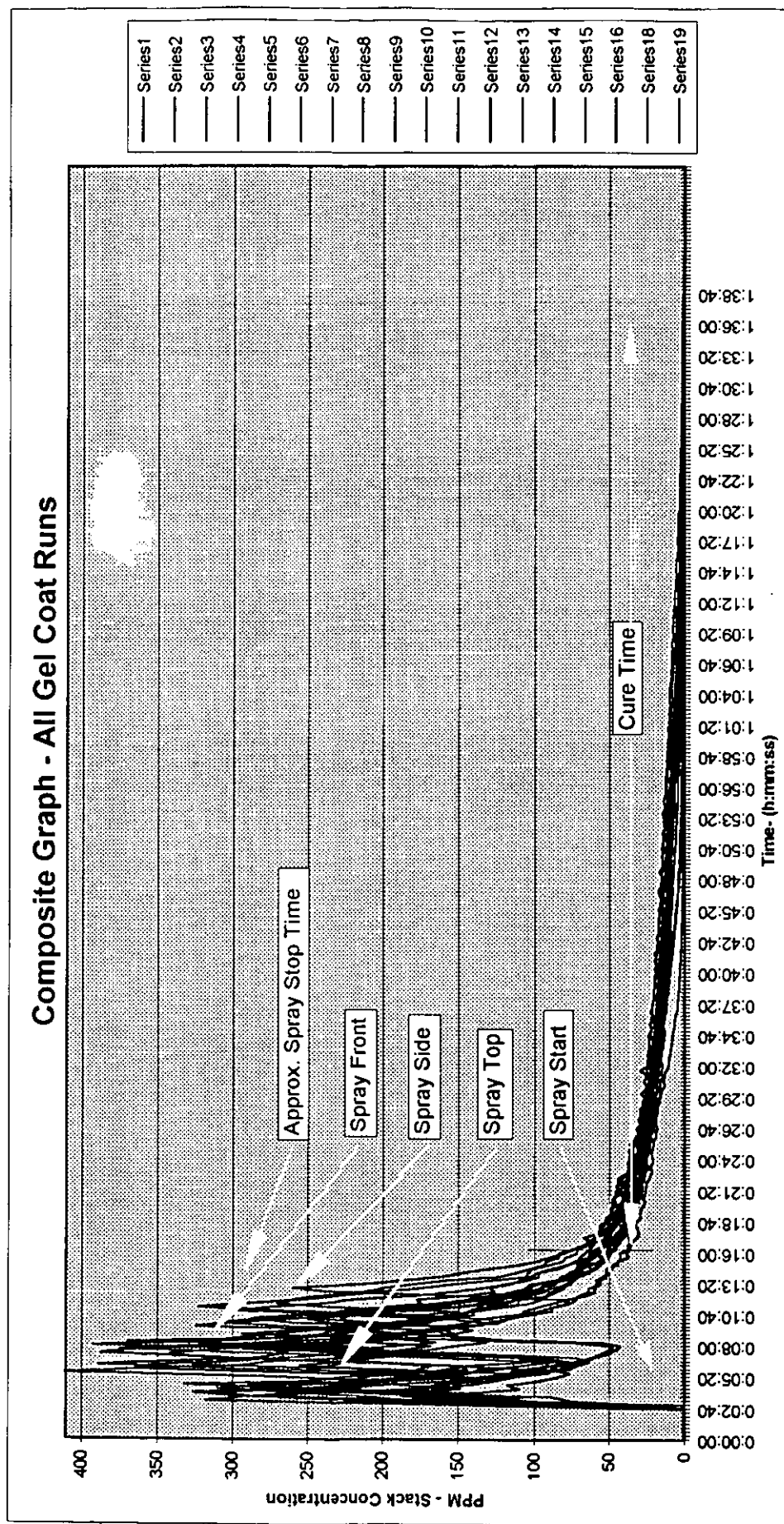
Table 8.21

Air Flow Effects

Run Parameters													
Run No.	Data ID	GC Film Thickness (in.)	GC Styrene %	Gel Time (min.)	GC Flow (lb/min)	Air Flow (fpm)	Data			Normalized Surf. Area Emission g/ft2/kg GC	Emission % of Gel Coat (RW)	Emission Lbs/Ton Gel Coat Consumed	
							Emission % of AS	Surface Area Emiss. (g/ft2)	Surface Area Emiss. (g/m2)				
Low Air Flow													
15	102495A	0.018	35	20	2	50	49.9%	11.04	118.81	4.70	17.2%	343.92	
7	101695C	0.018	35	10	4	50	50.5%	11.95	128.70	4.80	17.5%	350.87	
3	Replicate Avg.	0.018	40	10	2	50	55.6%	14.45	155.60	6.15	22.5%	449.52	
11	Replicate Avg.	0.018	40	20	4	50	61.8%	16.19	174.25	6.77	24.8%	495.93	
13	101995B	0.024	35	20	2	50	45.4%	13.43	144.57	4.28	15.6%	312.90	
6	101395B	0.024	35	10	4	50	43.5%	13.25	142.63	4.13	15.1%	302.25	
2	101195B	0.024	40	10	2	50	45.8%	15.76	169.65	5.07	18.5%	370.61	
10	101895A	0.024	40	20	4	50	52.4%	17.85	192.18	5.74	21.0%	419.84	
High Air Flow													
9	101795B	0.018	35	10	2	100	58.0%	12.84	138.20	5.51	20.1%	402.96	
1	101195A	0.018	35	20	4	100	53.8%	12.72	136.98	5.07	18.5%	370.77	
8	101795A	0.018	40	20	2	100	60.7%	15.65	168.43	6.65	24.3%	486.32	
14	101995C	0.018	40	10	4	100	56.0%	14.31	154.07	6.20	22.7%	453.14	
12	Replicate Avg.	0.024	35	10	2	100	45.6%	13.56	145.98	4.33	15.8%	316.83	
4	Replicate Avg.	0.024	35	20	4	100	45.3%	13.52	145.54	4.27	15.6%	312.20	
5	101395A	0.024	40	20	2	100	49.0%	16.82	181.10	5.37	19.6%	392.59	
16	102495B	0.024	40	10	4	100	51.3%	17.55	188.98	5.68	20.8%	415.11	

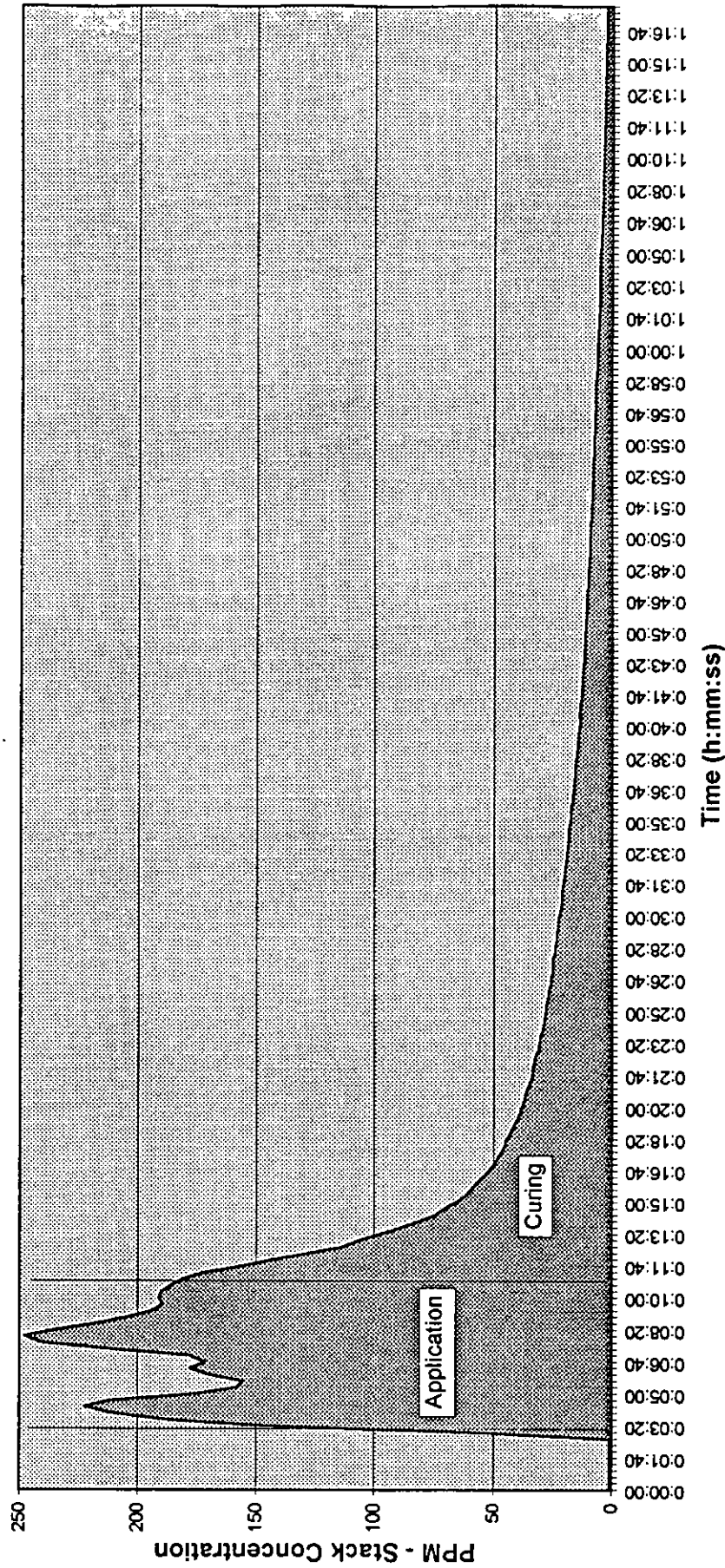
	% Available Styrene		Norm. Surface Area		% Gel Coat Weight		Lbs/Ton Gel Coat	
Avg. Emissions - Low Air Flow Rate	50.6%		5.20		19.0%		380.73	
Avg. Emissions - High Air Flow Rate	52.5%		5.39		19.7%		393.74	

CFA Open Molding Styrene Emissions Test Project
Gel Coat Emissions Baseline Study

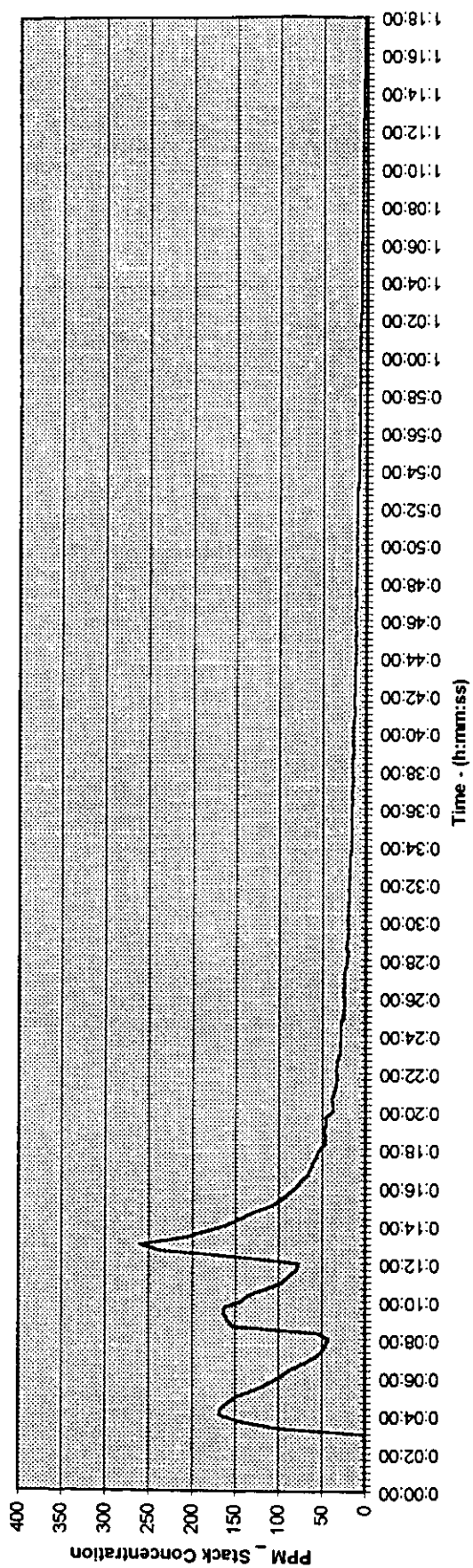


CFA Open Molding Styrene Emissions Test Project
Gel Coat Emissions Baseline Study

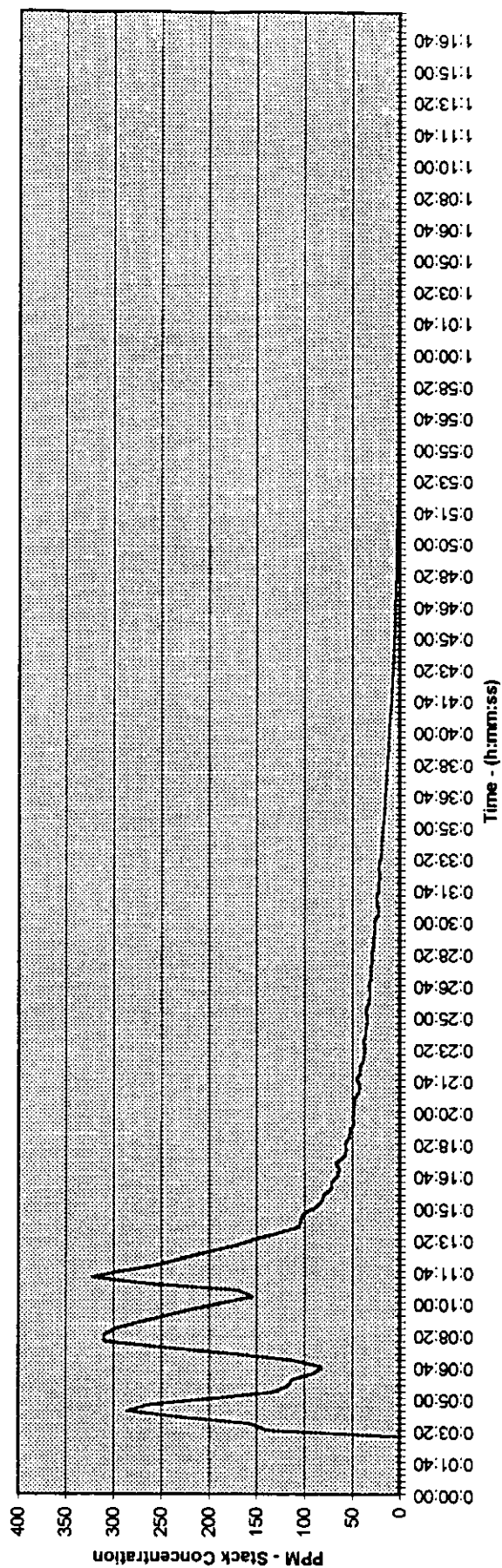
Average Emissions Profile - All Gel Coat Runs



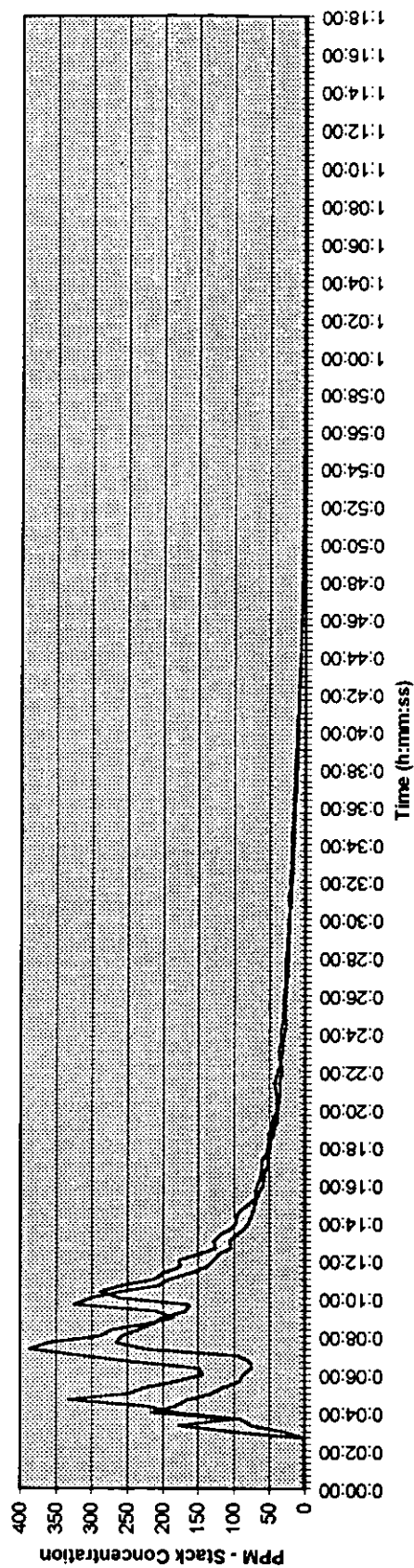
Gel Coat - Run 1



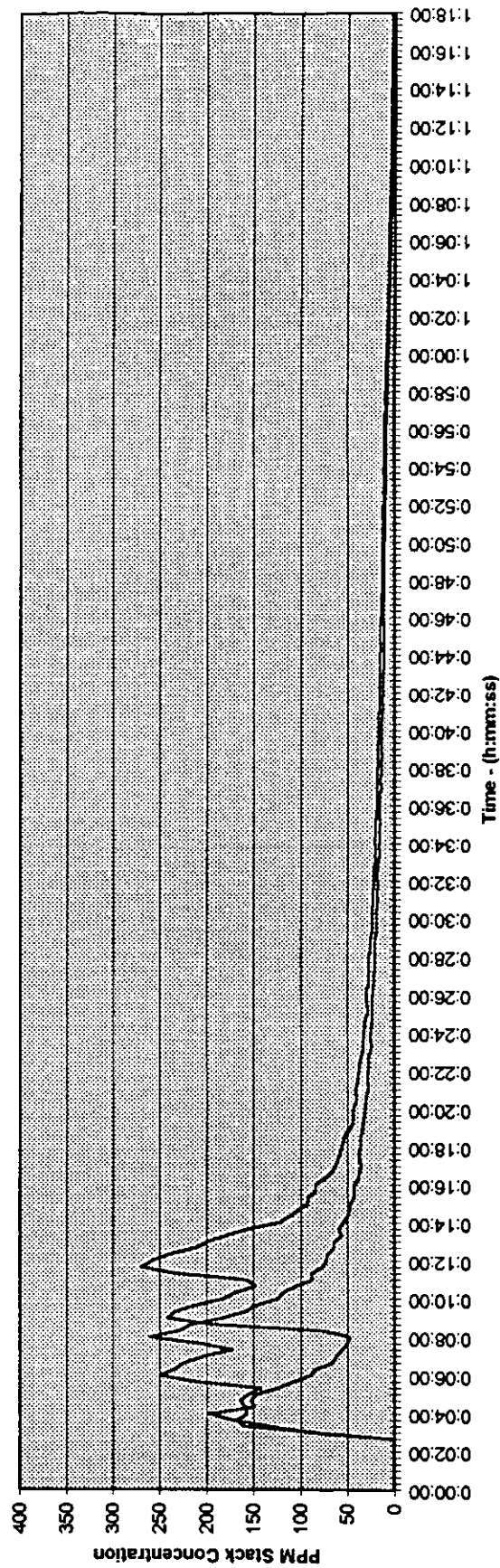
Gel Coat - Run 2



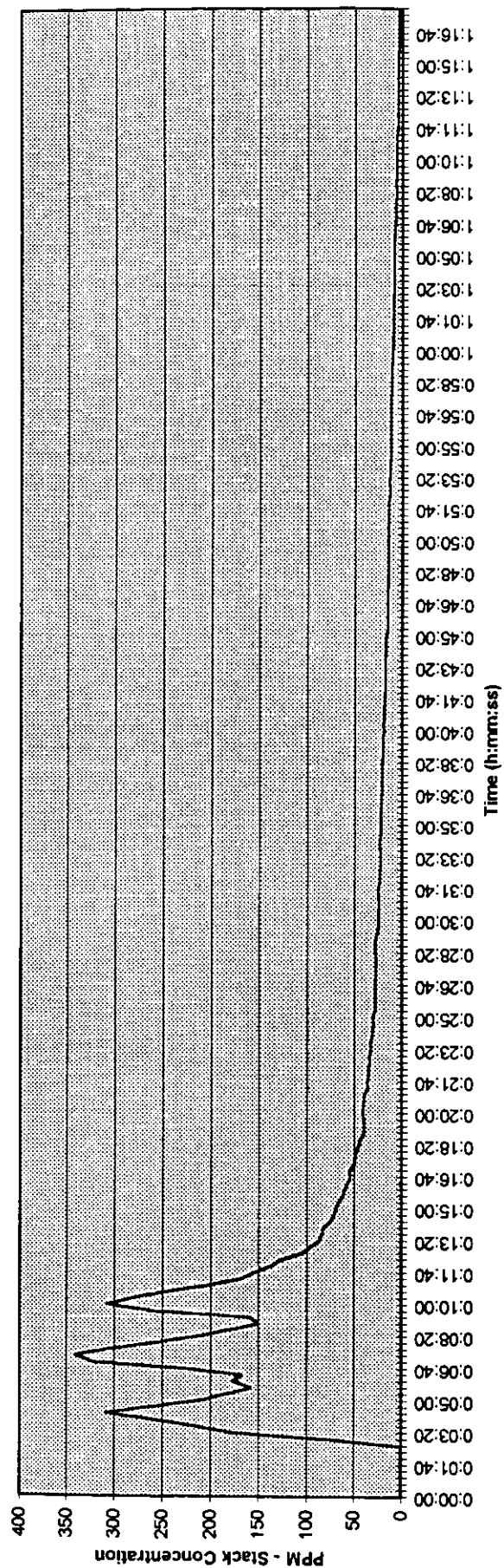
Gel Coat - Runs 3A & 3B



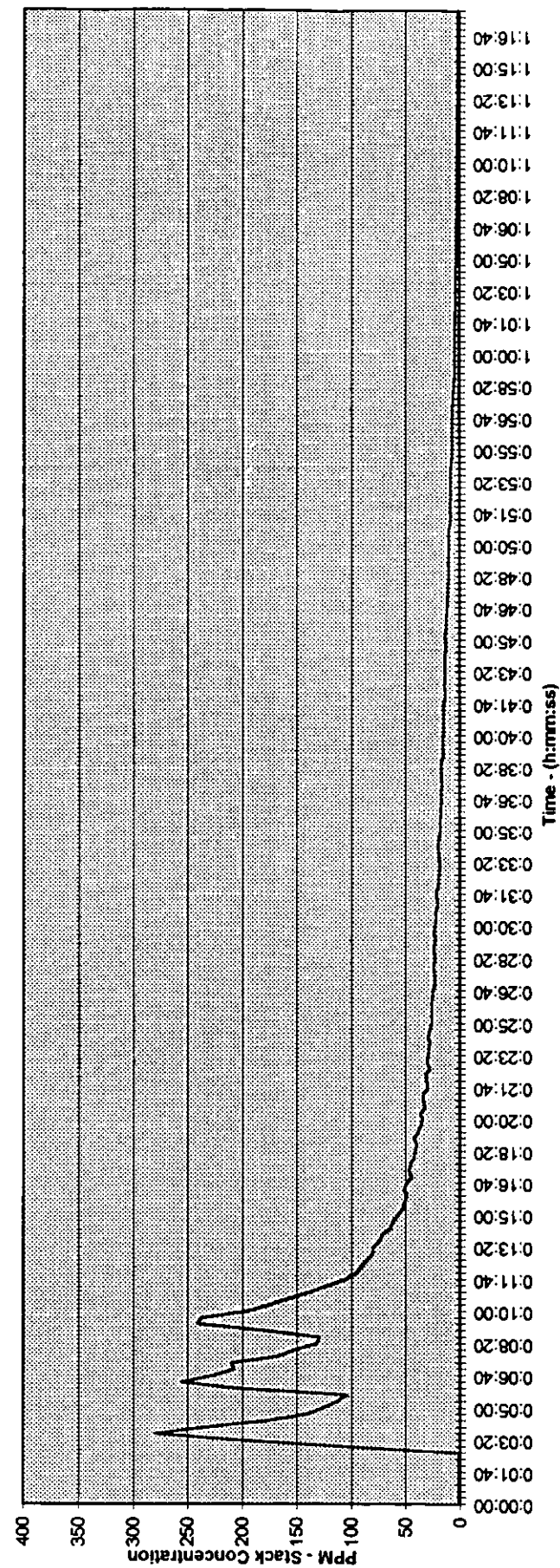
Gel Coat - Runs 4A & 4B



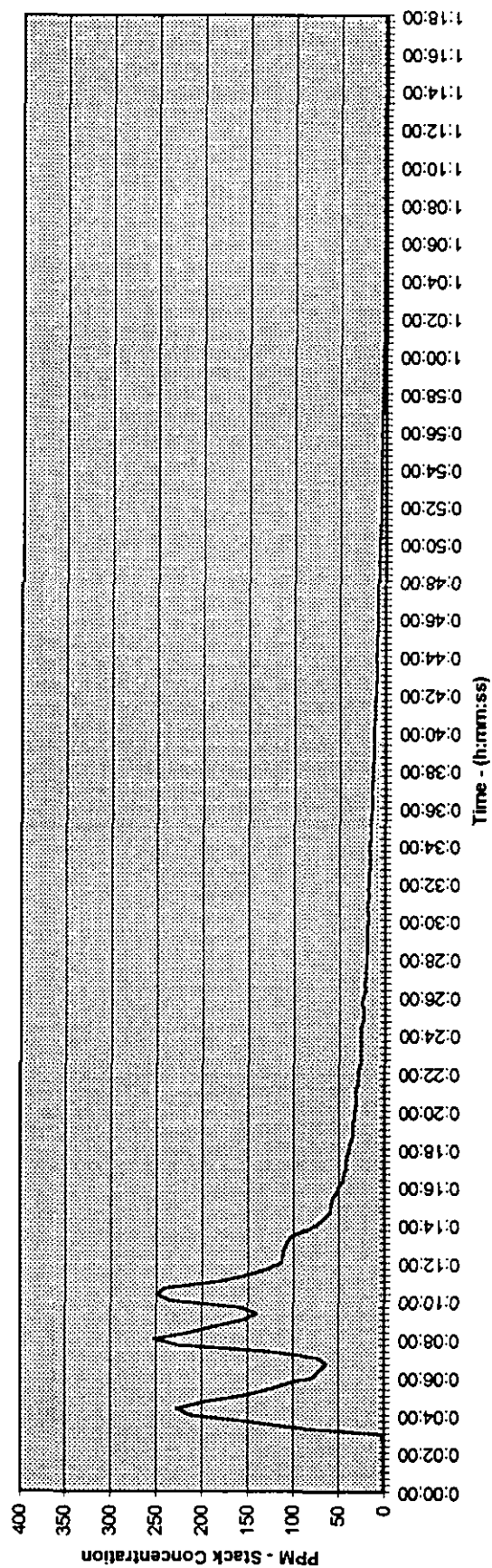
Gel Coat - Run 5



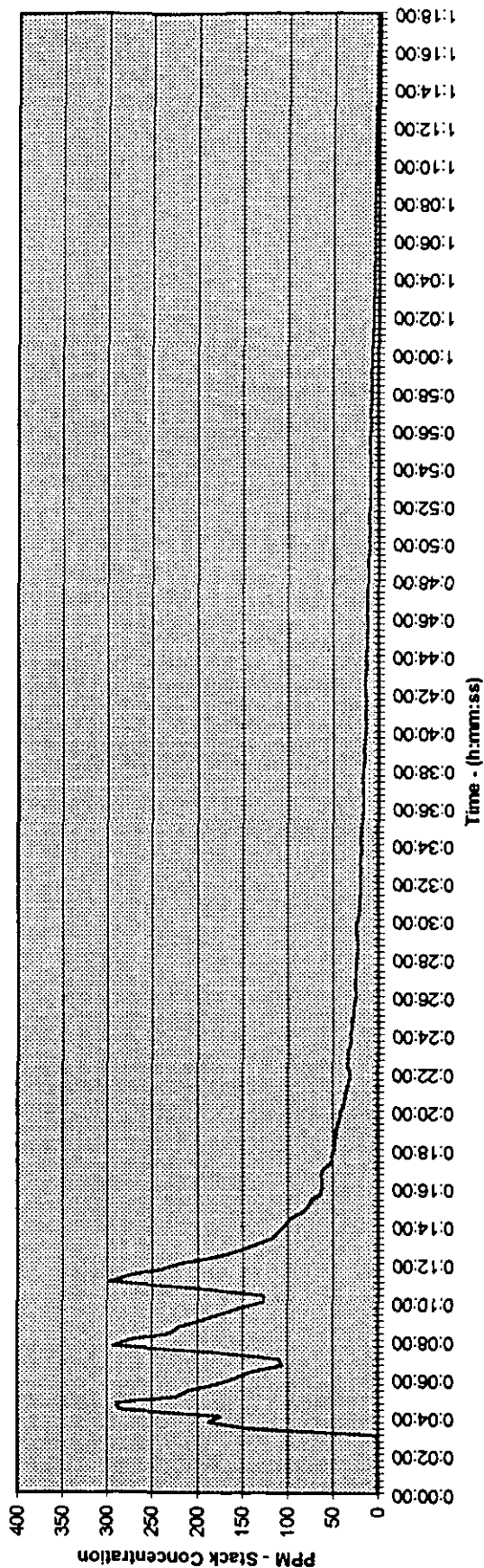
Gel Coat - Run 6



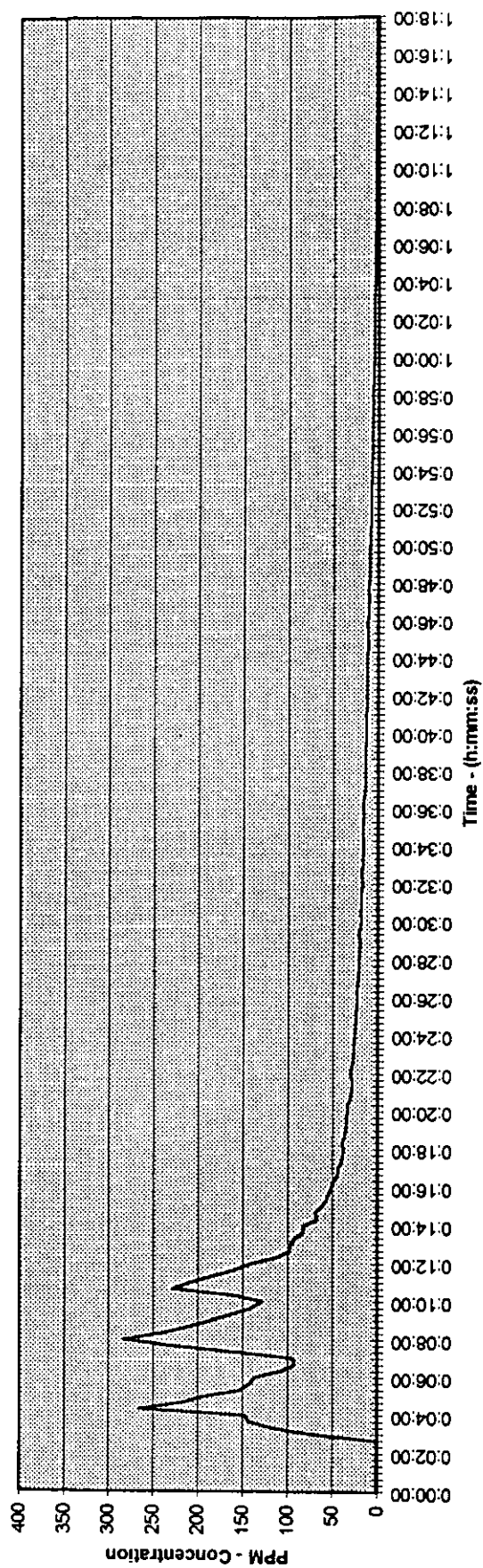
Gel Coat - Run 7



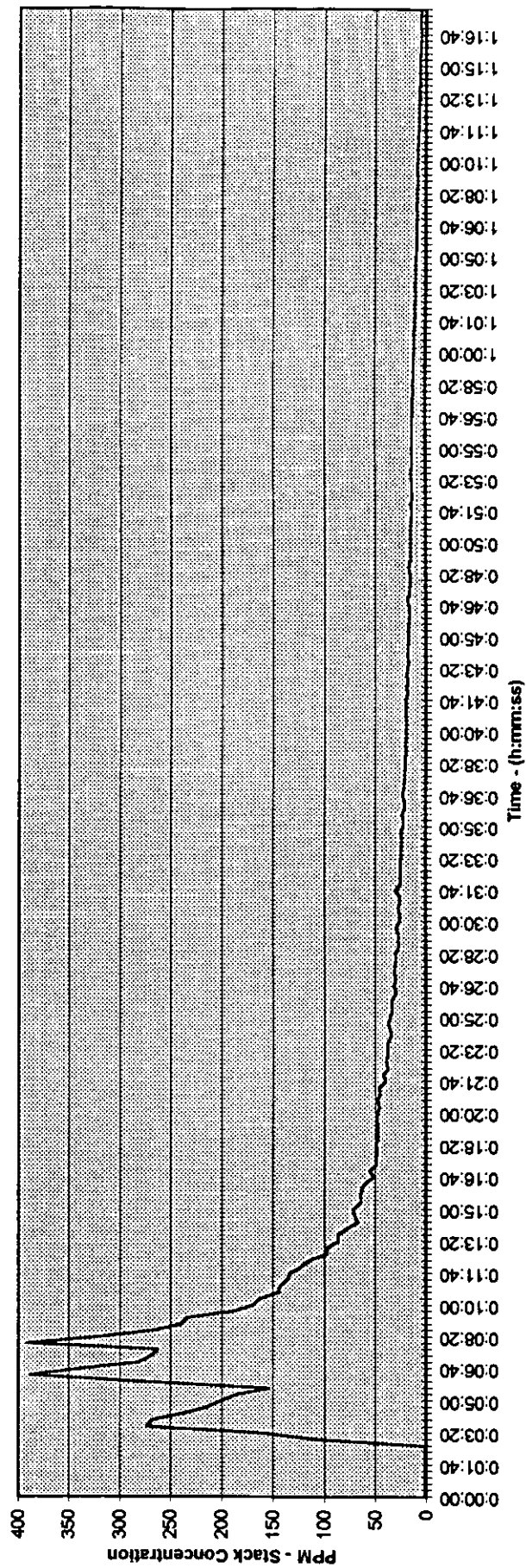
Gel Coat - Run 8



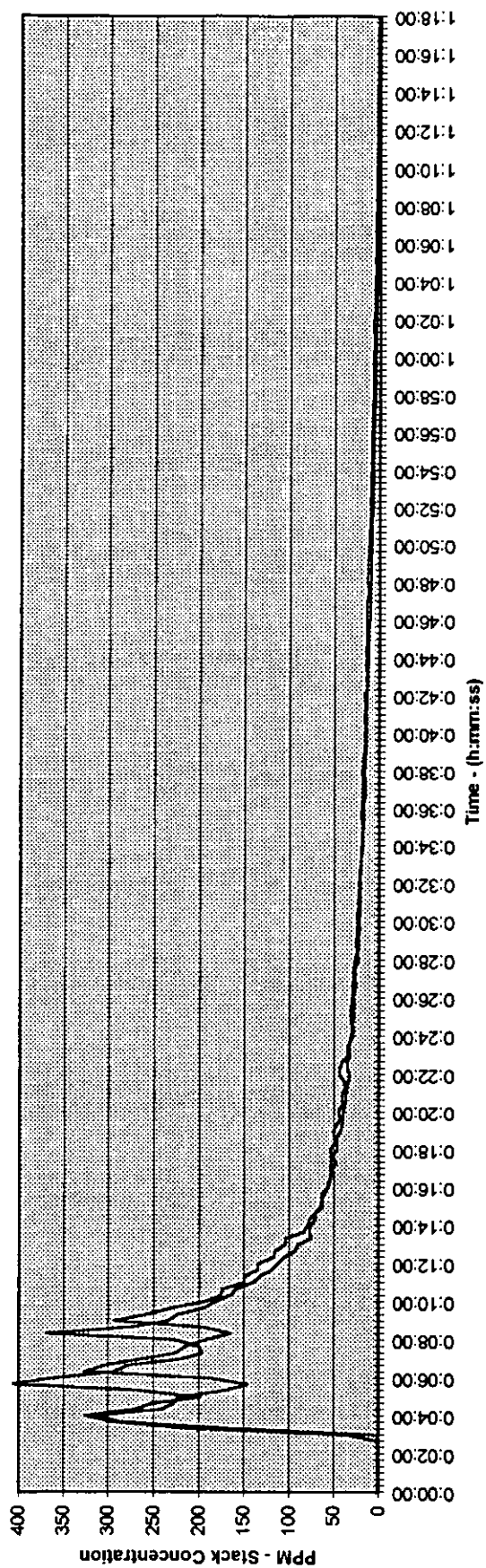
Gel Coat - Run 9



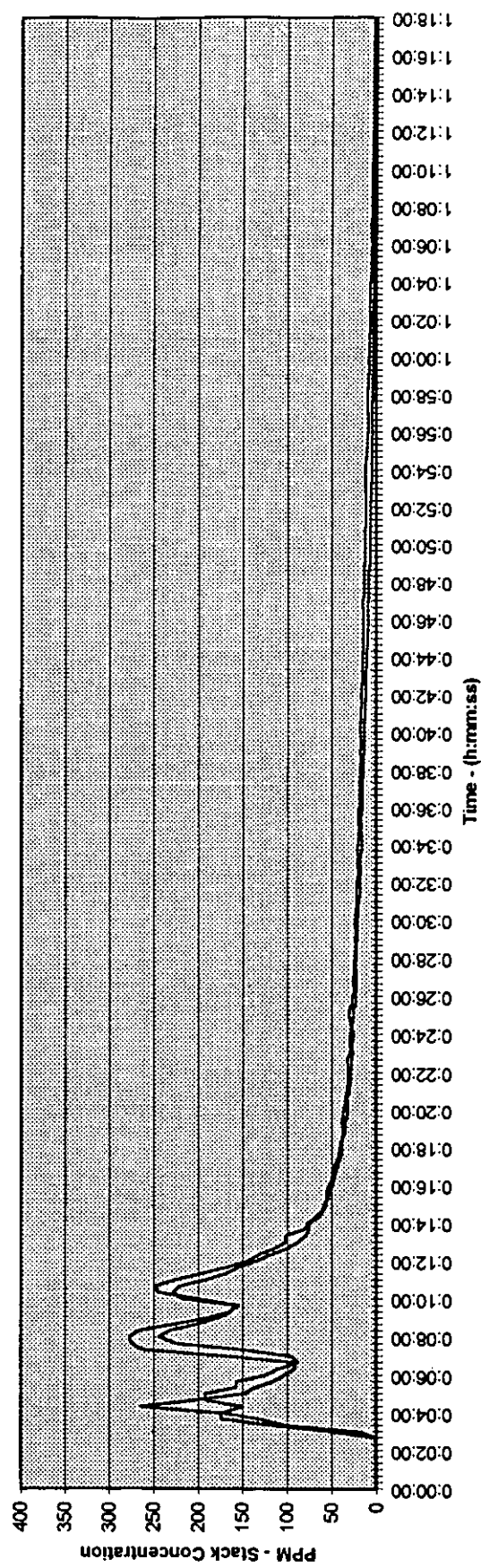
Gel Coat - Run 10



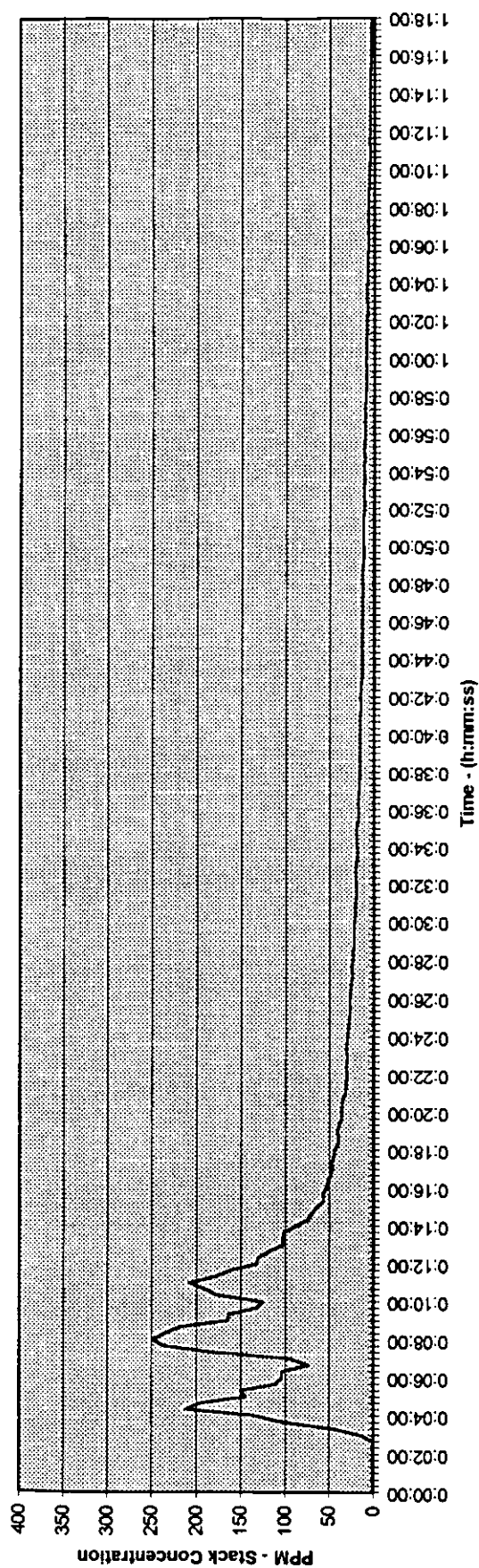
Gel Coat - Runs 11A & 11B



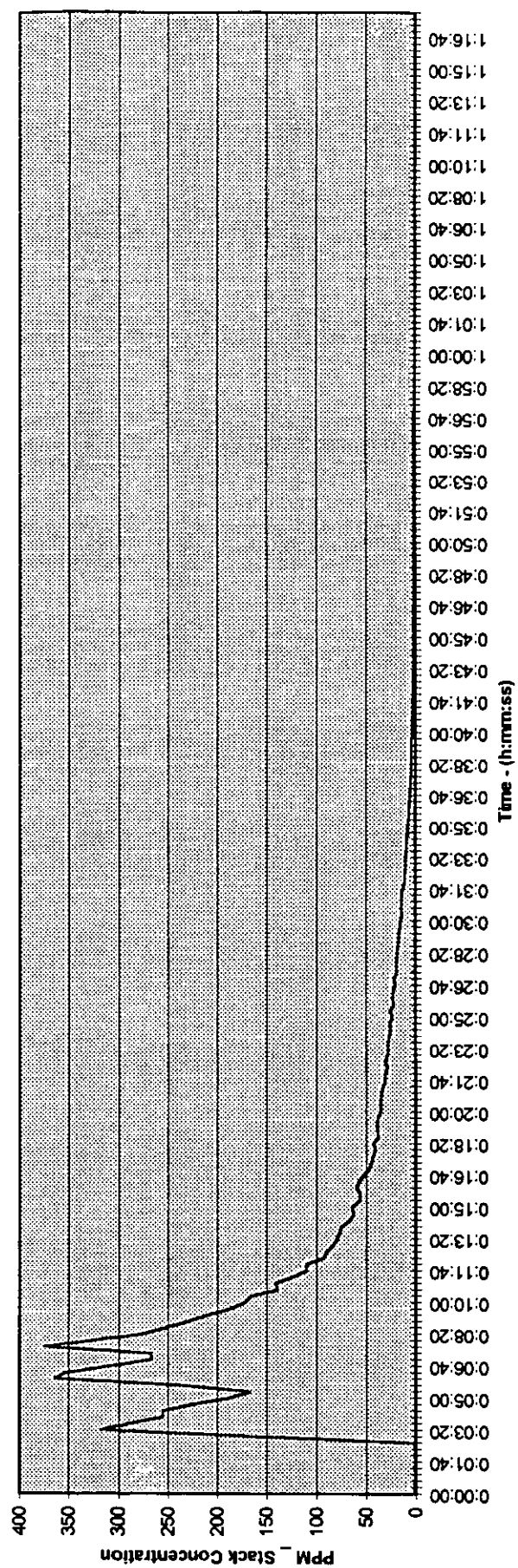
Gel Coat - Runs 12A & 12B



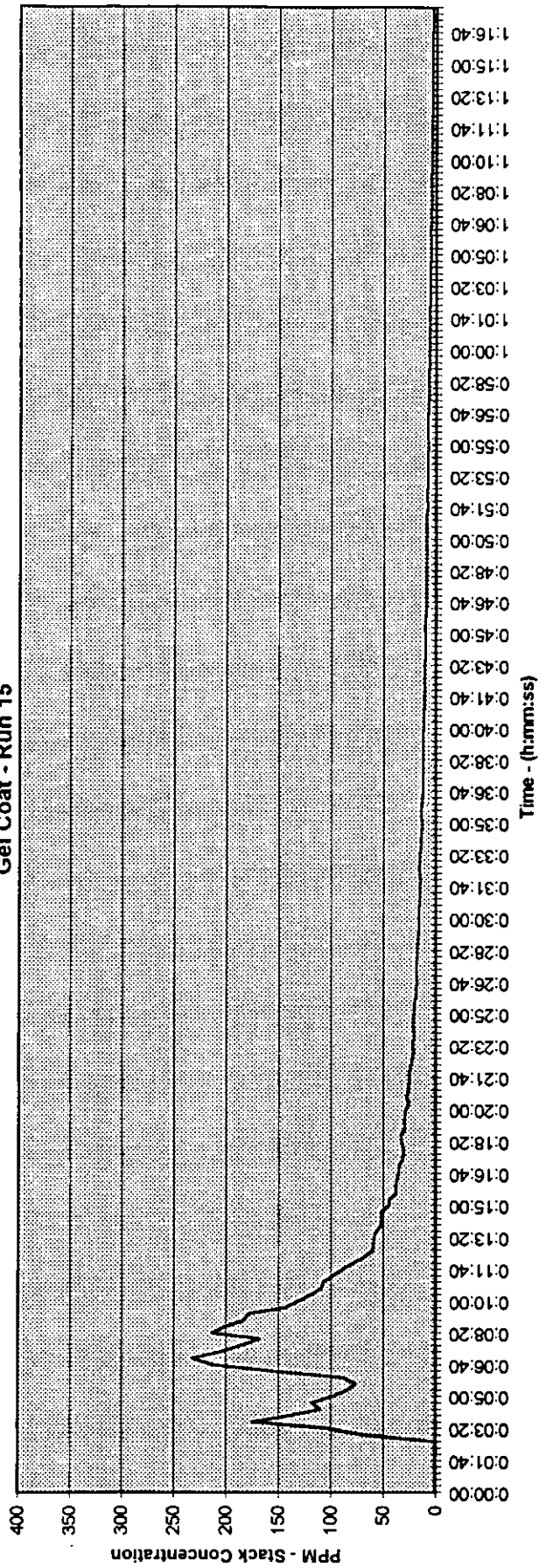
Gel Coat - Run 13



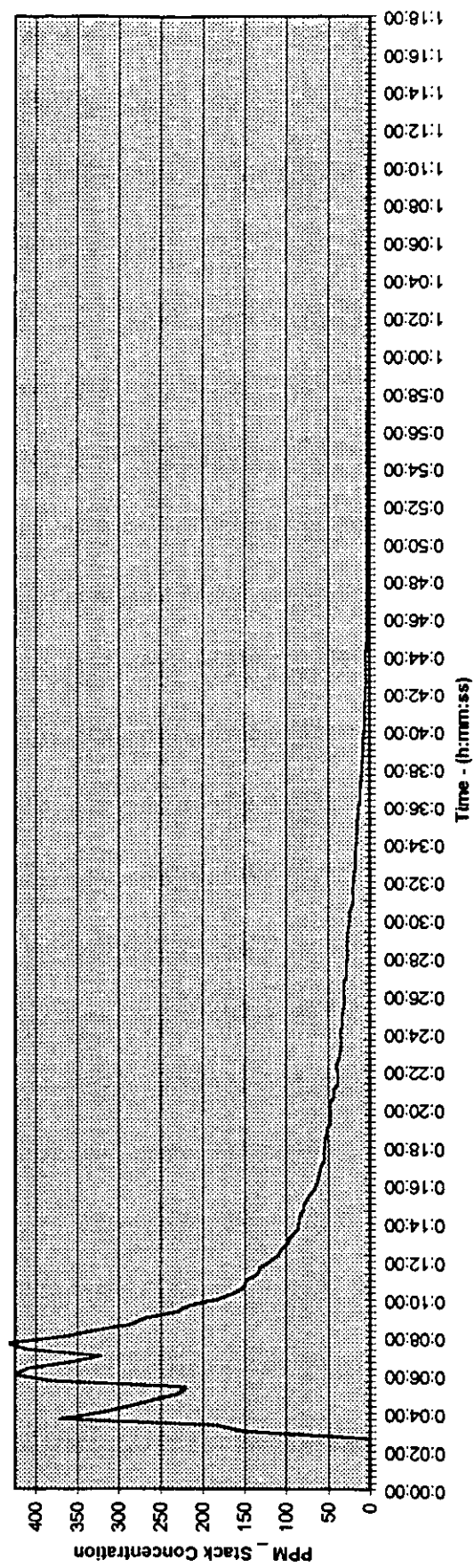
Gel Coat - Run 14



Gel Coat - Run 15



Gel Coat - Run 16



CFA Open Molding Styrene Emissions Test Project

Spray-Up Emissions Baseline Study

Table 8.22

Spray-Up Experiment Data Table

Run Parameters																
Run No.	Data ID	Laminate Thickness (in.)	Resin Styrene %	Gel Time (min.)	Resin Flow (lb/min)	Air Flow (fpm)	Data					Normalized		Emission % of Resin (RW)	Emission Lbs/Ton Resin Consumed	
							Resin Consumed (g)	Available Styrene (g)	Emission Weight (g)	Emission % of AS	Surface Area Emiss. (g/ft2)	Surface Area Emiss. (g/m2)				
1	111595B	0.040	35	30	4	100	3589.00	1256.15	235.80	18.8%	6.45	69.41	1.80	6.6%		131.40
2	111695A	0.080	42	15	2	50	8062.00	3458.60	1144.50	33.1%	31.30	336.91	3.88	14.2%		283.92
3A	111695B	0.040	42	15	2	50	4080.00	1750.30	542.20	31.0%	14.83	159.61	3.63	13.3%		265.78
4A	112895A	0.080	35	30	4	100	8032.00	2803.20	532.60	19.0%	14.56	156.79	1.81	6.6%		132.62
5	112895B	0.040	42	30	2	100	4031.00	1701.10	609.70	35.8%	16.67	179.48	4.14	15.1%		302.51
6	112995A	0.080	35	15	4	50	8025.00	2864.90	521.80	18.2%	14.27	153.61	1.78	6.5%		130.04
4B	112995B	0.080	35	30	4	100	8040.00	2806.00	550.40	19.6%	15.05	162.03	1.87	6.8%		136.92
3B	113095A	0.040	42	15	2	50	4077.00	1687.90	572.20	33.9%	15.65	168.44	3.84	14.0%		280.70
7	120495A	0.040	35	15	4	50	4104.00	1463.90	341.00	23.3%	9.32	100.38	2.27	8.3%		166.18
8	120595B	0.080	42	30	2	100	8071.00	3406.00	1295.20	38.0%	35.42	381.28	4.39	16.0%		320.95
9	120695A	0.040	35	15	2	100	4044.00	1442.50	330.80	22.9%	9.05	97.38	2.24	8.2%		163.60
10	120695B	0.080	42	30	4	50	8070.00	3405.50	763.00	22.4%	20.86	224.61	2.59	9.5%		189.10
11A	120795A	0.040	42	30	4	50	4042.00	1705.70	489.50	28.7%	13.39	144.10	3.31	12.1%		242.21
12A	120895A	0.080	35	15	2	100	8090.00	2885.70	521.70	18.1%	14.27	153.58	1.76	6.4%		128.97
13	120895B	0.080	35	30	2	50	8088.00	2822.70	524.50	18.6%	14.34	154.40	1.77	6.5%		129.70
14	121495B	0.040	42	15	4	100	4065.00	1745.50	432.70	24.8%	11.83	127.38	2.91	10.6%		212.89
11B	121195B	0.040	42	30	4	50	4045.00	1707.00	519.70	30.4%	14.21	152.99	3.51	12.8%		256.96
12B	121295A	0.080	35	15	2	100	8061.00	2875.40	462.60	16.1%	12.65	136.18	1.57	5.7%		114.77
15	121295B	0.040	35	30	2	50	4059.00	1416.60	292.20	20.6%	7.99	86.02	1.97	7.2%		143.98
16	121495A	0.080	42	15	4	100	8099.00	3477.70	882.90	25.4%	24.14	259.91	2.98	10.9%		218.03

CFA Open Molding Styrene Emissions Test Project
Spray-Up Emissions Baseline Study

Table 8.23

Spray-Up Experiment Master Table- Replicate Averages

Run Parameters												
Run No.	Data ID	Laminate Thick-ness (in.)	Resin Styrene %	Gel Time (min.)	Resin Flow (lb/min)	Air Flow (fpm)	Data			Normalized Surf. Area Emission (g/ft2/kg R)	Emission % of Resin (RW)	Emission Lbs/Ton Resin Consumed
							Emission % of AS	Surface Area Emiss. (g/ft2)	Surface Area Emiss. (g/m2)			
1	111595B	0.040	35	30	4	100	18.8%	6.45	69.41	1.80	6.6%	131.40
2	111695A	0.080	42	15	2	50	33.1%	31.30	336.91	3.88	14.2%	283.92
3	Replicate Avg.	0.040	42	15	2	50	32.4%	15.24	164.03	3.74	13.7%	273.24
4	Replicate Avg.	0.080	35	30	4	100	19.3%	14.81	159.41	1.84	6.7%	66.31
5	112895B	0.040	42	30	2	100	35.8%	16.67	179.48	4.14	15.1%	302.51
6	112995A	0.080	35	15	4	50	18.2%	14.27	153.61	1.78	6.5%	130.04
7	120495A	0.040	35	15	4	50	23.3%	9.32	100.38	2.27	8.3%	166.18
8	120595B	0.080	42	30	2	100	38.0%	35.42	381.28	4.39	16.0%	320.95
9	120695A	0.040	35	15	2	100	22.9%	9.05	97.38	2.24	8.2%	163.60
10	120695B	0.080	42	30	4	50	22.4%	20.86	224.61	2.59	9.5%	189.10
11	Replicate Avg.	0.040	42	30	4	50	29.6%	13.80	148.54	3.41	12.5%	249.58
12	Replicate Avg.	0.080	35	15	2	100	17.1%	13.46	144.88	1.67	6.1%	121.87
13	120895B	0.080	35	30	2	50	18.6%	14.34	154.40	1.77	6.5%	129.70
14	121495B	0.040	42	15	4	100	24.8%	11.83	127.38	2.91	10.6%	212.89
15	121295B	0.040	35	30	2	50	20.6%	7.99	86.02	1.97	7.2%	143.98
16	121495A	0.080	42	15	4	100	25.4%	24.14	259.91	2.98	10.9%	218.03

CFA Open Molding Styrene Emissions Test Project
Spray-Up Emissions Baseline Study

Table 8.24

Emissions % Of Available Styrene

Emissions % of Available Styrene												
Run Parameters												
Run No.	Data ID	Laminate Thick-ness (in.)	Resin Styrene %	Gel Time (min.)	Resin Flow (lb/min)	Air Flow (fpm)	Data			Normalized Surf. Area Emission (g/ft2/kg R)	Emission % of Resin (RW)	Emission Lbs/Ton Resin Consumed
							Emission % of AS	Surface Area Emiss. (g/ft2)	Surface Area Emiss. (g/m2)			
12	Replicate Avg.	0.080	35	15	2	100	17.1%	13.46	144.88	1.67	6.1%	121.87
6	112995A	0.080	35	15	4	50	18.2%	14.27	153.61	1.78	6.5%	130.04
13	120895B	0.080	35	30	2	50	18.6%	14.34	154.40	1.77	6.5%	129.70
1	111595B	0.040	35	30	4	100	18.8%	6.45	69.41	1.80	6.6%	131.40
4	Replicate Avg.	0.080	35	30	4	100	19.3%	14.81	159.41	1.84	6.7%	66.31
15	121295B	0.040	35	30	2	50	20.6%	7.99	86.02	1.97	7.2%	143.98
10	120695B	0.080	42	30	4	50	22.4%	20.86	224.61	2.59	9.5%	189.10
9	120695A	0.040	35	15	2	100	22.9%	9.05	97.38	2.24	8.2%	163.60
7	120495A	0.040	35	15	4	50	23.3%	9.32	100.38	2.27	8.3%	166.18
14	121495B	0.040	42	15	4	100	24.8%	11.83	127.38	2.91	10.6%	212.89
16	121495A	0.080	42	15	4	100	25.4%	24.14	259.91	2.98	10.9%	218.03
11	Replicate Avg.	0.040	42	30	4	50	29.6%	13.80	148.54	3.41	12.5%	249.58
3	Replicate Avg.	0.040	42	15	2	50	32.4%	15.24	164.03	3.74	13.7%	273.24
2	111695A	0.080	42	15	2	50	33.1%	31.30	336.91	3.88	14.2%	283.92
5	112895B	0.040	42	30	2	100	35.8%	16.67	179.48	4.14	15.1%	302.51
8	120595B	0.080	42	30	2	100	38.0%	35.42	381.28	4.39	16.0%	320.95

CFA Open Molding Styrene Emissions Test Project
Spray-Up Emissions Baseline Study

Table 8.25

Emissions By Normalized Surface Area

Run Parameters												
Run No.	Data ID	Laminate Thickness (in.)	Resin Styrene %	Gel Time (min.)	Resin Flow (lb/min)	Air Flow (fpm)	Data			Normalized Surf. Area Emission (g/ft2/kg R)	Emission % of Resin (RW)	Emission Lbs/Ton Resin Consumed
							Emission % of AS	Surface Area Emiss. (g/ft2)	Surface Area Emiss. (g/m2)			
12	Replicate Avg.	0.080	35	15	2	100						
13	120895B	0.080	35	30	2	50	17.1%	13.46	144.88	1.67	6.1%	121.87
6	112995A	0.080	35	15	4	50	18.6%	14.34	154.40	1.77	6.5%	129.70
1	111595B	0.040	35	30	4	100	18.2%	14.27	153.61	1.78	6.5%	130.04
4	Replicate Avg.	0.080	35	30	4	100	18.8%	6.45	69.41	1.80	6.6%	131.40
15	121295B	0.040	35	30	2	50	19.3%	14.81	159.41	1.84	6.7%	66.31
9	120695A	0.040	35	15	2	100	20.6%	7.99	86.02	1.97	7.2%	143.98
7	120495A	0.040	35	15	4	50	22.9%	9.05	97.38	2.24	8.2%	163.60
10	120695B	0.080	42	30	4	50	23.3%	9.32	100.38	2.27	8.3%	166.18
14	121495B	0.040	42	15	4	100	22.4%	20.86	224.61	2.59	9.5%	189.10
16	121495A	0.080	42	15	4	100	24.8%	11.83	127.38	2.91	10.6%	212.89
11	Replicate Avg.	0.040	42	30	4	50	25.4%	24.14	259.91	2.98	10.9%	218.03
3	Replicate Avg.	0.040	42	15	2	50	29.6%	13.80	148.54	3.41	12.5%	249.58
2	111695A	0.080	42	15	2	50	32.4%	15.24	164.03	3.74	13.7%	273.24
5	112895B	0.040	42	30	2	100	33.1%	31.30	336.91	3.88	14.2%	283.92
8	120595B	0.080	42	30	2	100	35.8%	16.67	179.48	4.14	15.1%	302.51
							38.0%	35.42	381.28	4.39	16.0%	320.95

Emissions By % Resin Weight

Run Parameters													
Run No.	Data ID	Laminate Thick-ness (in.)	Resin Styrene %	Gel Time (min.)	Resin Flow (lb/min)	Air Flow (fpm)	Data			Normalized Surf. Area Emission (g/ft2/kg R)	Emission % of Resin (RW)	Emission Lbs/Ton Resin Consumed	
							Emission % of AS	Surface Area Emiss. (g/ft2)	Surface Area Emiss. (g/m2)				
12	Replicate Avg.	0.080	35	15	2	100		13.46		144.88	1.67	6.1%	121.87
13	120895B	0.080	35	30	2	50		14.34		154.40	1.77	6.5%	129.70
6	112995A	0.080	35	15	4	50		14.27		153.61	1.78	6.5%	130.04
1	111595B	0.040	35	30	4	100		6.45		69.41	1.80	6.6%	131.40
4	Replicate Avg.	0.080	35	30	4	100		14.81		159.41	1.84	6.7%	66.31
15	121295B	0.040	35	30	2	50		7.99		86.02	1.97	7.2%	143.98
9	120695A	0.040	35	15	2	100		9.05		97.38	2.24	8.2%	163.60
7	120495A	0.040	35	15	4	50		9.32		100.38	2.27	8.3%	166.18
10	120695B	0.080	42	30	4	50		20.86		224.61	2.59	9.5%	189.10
14	121495B	0.040	42	15	4	100		11.83		127.38	2.91	10.6%	212.89
16	121495A	0.080	42	15	4	100		24.14		259.91	2.98	10.9%	218.03
11	Replicate Avg.	0.040	42	30	4	50		13.80		148.54	3.41	12.5%	249.58
3	Replicate Avg.	0.040	42	15	2	50		15.24		164.03	3.74	13.7%	273.24
2	111695A	0.080	42	15	2	50		31.30		336.91	3.88	14.2%	283.92
5	112895B	0.040	42	30	2	100		16.67		179.48	4.14	15.1%	302.51
8	120595B	0.080	42	30	2	100		35.42		381.28	4.39	16.0%	320.95

CFA Open Molding Styrene Emissions Test Project
Spray-Up Emissions Baseline Study

Table 8.27

Emissions -Pounds (lbs) Per Ton Resin Consumed

Run Parameters												
Run No.	Data ID	Laminate Thick-ness (in.)	Resin Styrene %	Gel Time (min.)	Resin Flow (lb/min)	Air Flow (fpm)	Data			Normalized Surf. Area Emission (g/ft2/kg R)	Emission % of Resin (RW)	Emission Lbs/Ton Resin Consumed
							Emission % of AS	Surface Area Emiss. (g/ft2)	Surface Area Emiss. (g/m2)			
4	Replicate Avg.	0.080	35	30	4	100	19.3%	14.81	159.41	1.84	6.7%	66.31
12	Replicate Avg.	0.080	35	15	2	100	17.1%	13.46	144.88	1.67	6.1%	121.87
13	120895B	0.080	35	30	2	50	18.6%	14.34	154.40	1.77	6.5%	129.70
6	112995A	0.080	35	15	4	50	18.2%	14.27	153.61	1.78	6.5%	130.04
1	111595B	0.040	35	30	4	100	18.8%	6.45	69.41	1.80	6.6%	131.40
15	121295B	0.040	35	30	2	50	20.6%	7.99	86.02	1.97	7.2%	143.98
9	120695A	0.040	35	15	2	100	22.9%	9.05	97.38	2.24	8.2%	163.60
7	120495A	0.040	35	15	4	50	23.3%	9.32	100.38	2.27	8.3%	166.18
10	120695B	0.080	42	30	4	50	22.4%	20.86	224.61	2.59	9.5%	189.10
14	121495B	0.040	42	15	4	100	24.8%	11.83	127.38	2.91	10.6%	212.89
16	121495A	0.080	42	15	4	100	25.4%	24.14	259.91	2.98	10.9%	218.03
11	Replicate Avg.	0.040	42	30	4	50	29.6%	13.80	148.54	3.41	12.5%	249.58
3	Replicate Avg.	0.040	42	15	2	50	32.4%	15.24	164.03	3.74	13.7%	273.24
2	111695A	0.080	42	15	2	50	33.1%	31.30	336.91	3.88	14.2%	283.92
5	112895B	0.040	42	30	2	100	35.8%	16.67	179.48	4.14	15.1%	302.51
8	120595B	0.080	42	30	2	100	38.0%	35.42	381.28	4.39	16.0%	320.95

Spray-Up Emissions Baseline Study

Table 8.28

Laminate Thickness Effects

Run Parameters												
Run No.	Data ID	Laminate Thick-ness (in.)	Resin Styrene %	Gel Time (min.)	Resin Flow (lb/min)	Air Flow (fpm)	Data			Normalized Surf. Area Emission (g/ft2/kg R)	Emission % of Resin (RW)	Emission Lbs/Ton Resin Consumed
							Emission % of AS	Surface Area Emiss. (g/ft2)	Surface Area Emiss. (g/m2)			
Thin laminate												
7	120495A	0.040	35	15	4	50			9.32	100.38		
9	120695A	0.040	35	15	2	100			9.05	97.38		
1	111595B	0.040	35	30	4	100			6.45	69.41		
15	121295B	0.040	35	30	2	50			7.99	86.02		
3	Replicate Avg.	0.040	42	15	2	50			15.24	164.03		
14	121495B	0.040	42	15	4	100			11.83	127.38		
5	112895B	0.040	42	30	2	100			16.67	179.48		
11	Replicate Avg.	0.040	42	30	4	50			13.80	148.54		
Thick laminate												
6	112995A	0.080	35	15	4	50			14.27	153.61		
12	Replicate Avg.	0.080	35	15	2	100			13.46	144.88		
4	Replicate Avg.	0.080	35	30	4	100			14.81	159.41		
13	120895B	0.080	35	30	2	50			14.34	154.40		
2	111695A	0.080	42	15	2	50			31.30	336.91		
16	121495A	0.080	42	15	4	100			24.14	259.91		
8	120595B	0.080	42	30	2	100			35.42	381.28		
10	120695B	0.080	42	30	4	50			20.86	224.61		

	% Available Styrene	Norm. Surface Area	% Resin Weight	Lbs/Ton Resin
Avg. Emissions - Thin Laminate	26.0%	2.81	10.3%	205.42
Avg. Emissions - Thick Laminate	24.0%	2.61	9.6%	182.49

Avg. Emissions - Thin/High Styrene	30.7%	3.55	13.0%	259.55
Avg. Emissions - Thin/Low Styrene	21.4%	2.07	7.6%	151.29

Avg. Emissions - Thick/High Styrene	29.7%	3.46	12.6%	253.00
Avg. Emissions - Thick/Low Styrene	18.3%	1.77	6.5%	111.98

Spray-Up Emissions Baseline Study

Table 8.29

Available Styrene Effects

Run Parameters												
Run No.	Data ID	Laminate Thick-ness (in.)	Resin Styrene %	Gel Time (min.)	Resin Flow (lb/min)	Air Flow (fpm)	Data			Normalized Surf. Area Emission (g/ft2/kg R)	Emission % of Resin (RW)	Emission Lbs/Ton Resin Consumed
							Emission % of AS	Surface Area Emiss. (g/ft2)	Surface Area Emiss. (g/m2)			
Low Styrene												
7	120495A	0.040	35	15	4	50	23.3%	9.32	100.38	2.27	8.3%	166.18
9	120695A	0.040	35	15	2	100	22.9%	9.05	97.38	2.24	8.2%	163.60
1	111595B	0.040	35	30	4	100	18.8%	6.45	69.41	1.80	6.6%	131.40
15	121295B	0.040	35	30	2	50	20.6%	7.99	86.02	1.97	7.2%	143.98
6	112995A	0.080	35	15	4	50	18.2%	14.27	153.61	1.78	6.5%	130.04
12	Replicate Avg	0.080	35	15	2	100	17.1%	13.46	144.88	1.67	6.1%	121.87
4	Replicate Avg	0.080	35	30	4	100	19.3%	14.81	159.41	1.84	6.7%	66.31
13	120895B	0.080	35	30	2	50	18.6%	14.34	154.40	1.77	6.5%	129.70
High Styrene												
3	Replicate Avg	0.040	42	15	2	50	32.4%	15.24	164.03	3.74	13.7%	273.24
14	121495B	0.040	42	15	4	100	24.8%	11.83	127.38	2.91	10.6%	212.89
5	112895B	0.040	42	30	2	100	35.8%	16.67	179.48	4.14	15.1%	302.51
11	Replicate Avg	0.040	42	30	4	50	29.6%	13.80	148.54	3.41	12.5%	249.58
2	111695A	0.080	42	15	2	50	33.1%	31.30	336.91	3.88	14.2%	283.92
16	121495A	0.080	42	15	4	100	25.4%	24.14	259.91	2.98	10.9%	218.03
8	120595B	0.080	42	30	2	100	38.0%	35.42	381.28	4.39	16.0%	320.95
10	120695B	0.080	42	30	4	50	22.4%	20.86	224.61	2.59	9.5%	189.10

	% Available Styrene	Norm. Surface Area	% Resin Weight	Lbs/Ton Resin
Avg. Emissions - Low Styrene	19.9%	1.92	7.0%	131.64
Avg. Emissions - High Styrene	30.2%	3.50	12.8%	256.28

Avg. Emissions - Low Styrene/Thick	18.3%	1.77	6.5%	111.98
Avg. Emissions - Low Styrene/Thin	21.4%	2.07	7.6%	151.29

Avg. Emissions - High Styrene/Thick	29.7%	3.46	12.6%	253.00
Avg. Emissions - High Styrene/Thin	30.7%	3.55	13.0%	259.55

CFA Open Molding Styrene Emissions Test Project

Spray-Up Emissions Baseline Study

Table 8.30

Gel Time Effects

Run Parameters												
Run No.	Data ID	Laminate Thick-ness (in.)	Resin Styrene %	Gel Time (min.)	Resin Flow (lb/min)	Air Flow (fpm)	Data			Normalized Surf. Area Emission (g/ft2/kg R)	Emission % of Resin (RW)	Emission Lbs/Ton Resin Consumed
							Emission % of AS	Surface Area Emiss. (g/ft2)	Surface Area Emiss. (g/m2)			
Fast Gel Time												
7	120495A	0.040	35	15	4	50	23.3%	9.32	100.38	2.27	8.3%	166.18
9	120695A	0.040	35	15	2	100	22.9%	9.05	97.38	2.24	8.2%	163.60
3	Replicate Avg.	0.040	42	15	2	50	32.4%	15.24	164.03	3.74	13.7%	273.24
14	121495B	0.040	42	15	4	100	24.8%	11.83	127.38	2.91	10.6%	212.89
6	112995A	0.080	35	15	4	50	18.2%	14.27	153.61	1.78	6.5%	130.04
12	Replicate Avg.	0.080	35	15	2	100	17.1%	13.46	144.88	1.67	6.1%	121.87
2	111695A	0.080	42	15	2	50	33.1%	31.30	336.91	3.88	14.2%	283.92
16	121495A	0.080	42	15	4	100	25.4%	24.14	259.91	2.98	10.9%	218.03
Slow Gel Time												
1	111595B	0.040	35	30	4	100	18.8%	6.45	69.41	1.80	6.6%	131.40
15	121295B	0.040	35	30	2	50	20.6%	7.99	86.02	1.97	7.2%	143.98
5	112895B	0.040	42	30	2	100	35.8%	16.67	179.48	4.14	15.1%	302.51
11	Replicate Avg.	0.040	42	30	4	50	29.6%	13.80	148.54	3.41	12.5%	249.58
4	Replicate Avg.	0.080	35	30	4	100	19.3%	14.81	159.41	1.84	6.7%	66.31
13	120895B	0.080	35	30	2	50	18.6%	14.34	154.40	1.77	6.5%	129.70
8	120595B	0.080	42	30	2	100	38.0%	35.42	381.28	4.39	16.0%	320.95
10	120695B	0.080	42	30	4	50	22.4%	20.86	224.61	2.59	9.5%	189.10

	% Available Styrene	Norm. Surface Area	% Resin Weight	Lbs/Ton Resin
Avg. Emissions - Fast Gel Time	24.7%	2.68	9.8%	196.22
Avg. Emissions - Slow Gel Time	25.4%	2.74	10.0%	191.69

Avg. Emissions -Fast Gel Time/Thick	23.4%	2.58	9.4%	188.47
Avg. Emissions - Fast Gel Time/Thin	25.9%	2.79	10.2%	203.98

Avg. Emissions - Slow Gel Time/Thick	24.6%	2.65	9.7%	176.51
Avg. Emissions - Slow Gel Time/Thin	26.2%	2.83	10.3%	206.87

Spray-Up Emissions Baseline Study

Table 8.31

Resin Flow Rate Effects

Run Parameters												
Run No.	Data ID	Laminate Thick-ness (in.)	Resin Styrene %	Gel Time (min.)	Resin Flow (lb/min)	Air Flow (fpm)	Data			Normalized Surf. Area Emission (g/ft2/kg R)	Emission % of Resin (RW)	Emission Lbs/Ton Resin Consumed
							Emission % of AS	Surface Area Emiss. (g/ft2)	Surface Area Emiss. (g/m2)			
Low Flow												
9	120695A	0.040	35	15	2	100	22.9%	9.05	97.38	2.24	8.2%	163.60
15	121295B	0.040	35	30	2	50	20.6%	7.99	86.02	1.97	7.2%	143.98
3	Replicate Avg.	0.040	42	15	2	50	32.4%	15.24	164.03	3.74	13.7%	273.24
5	112895B	0.040	42	30	2	100	35.8%	16.67	179.48	4.14	15.1%	302.51
12	Replicate Avg.	0.080	35	15	2	100	17.1%	13.46	144.88	1.67	6.1%	121.87
13	120895B	0.080	35	30	2	50	18.6%	14.34	154.40	1.77	6.5%	129.70
2	111695A	0.080	42	15	2	50	33.1%	31.30	336.91	3.88	14.2%	283.92
8	120595B	0.080	42	30	2	100	38.0%	35.42	381.28	4.39	16.0%	320.95
High Flow												
1	111595B	0.040	35	30	4	100	18.8%	6.45	69.41	1.80	6.6%	131.40
7	120495A	0.040	35	15	4	50	23.3%	9.32	100.38	2.27	8.3%	166.18
11	Replicate Avg.	0.040	42	30	4	50	29.6%	13.80	148.54	3.41	12.5%	249.58
14	121495B	0.040	42	15	4	100	24.8%	11.83	127.38	2.91	10.6%	212.89
4	Replicate Avg.	0.080	35	30	4	100	19.3%	14.81	159.41	1.84	6.7%	66.31
6	112995A	0.080	35	15	4	50	18.2%	14.27	153.61	1.78	6.5%	130.04
10	120695B	0.080	42	30	4	50	22.4%	20.86	224.61	2.59	9.5%	189.10
16	121495A	0.080	42	15	4	100	25.4%	24.14	259.91	2.98	10.9%	218.03

	% Available Styrene	Norm. Surface Area	% Resin Weight	Lbs/Ton Resin
Avg. Emissions - Low Resin Flow	27.3%	2.97	10.9%	217.47
Avg. Emissions - High Flow Rate	22.7%	2.45	8.9%	170.44

Avg. Emissions - Low Flow/Thick	26.7%	2.93	10.7%	214.11
Avg. Emissions - Low Flow/Thin	28.0%	3.02	11.0%	220.83

Avg. Emissions - High Flow/Thick	21.3%	2.30	8.4%	150.87
Avg. Emissions - High Flow/Thin	24.1%	2.60	9.5%	190.01

CFA Open Molding Styrene Emissions Test Project
Spray-Up Emissions Baseline Study

Table 8.32

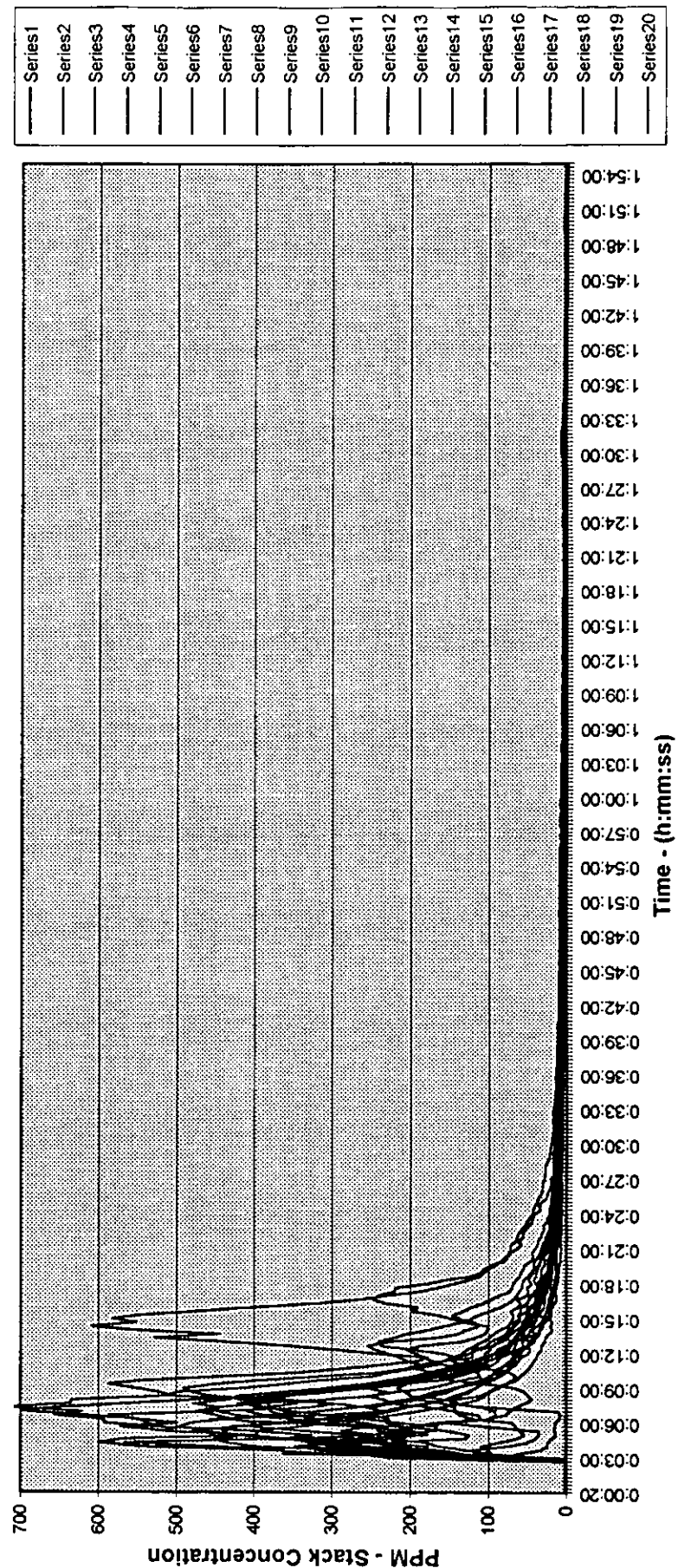
Air Flow Effects

Run Parameters												
Run No.	Data ID	Laminate Thickness (in.)	Resin Styrene %	Gel Time (min.)	Resin Flow (lb/min)	Air Flow (fpm)	Data			Normalized Surf. Area Emission (g/ft2/kg R)	Emission % of Resin (RW)	Emission Lbs/Ton Resin Consumed
							Emission % of AS	Surface Area Emiss. (g/ft2)	Surface Area Emiss. (g/m2)			
Low Air Flow												
7	120495A	0.040	35	15	4	50	23.3%	9.32	100.38	2.27	8.3%	166.18
15	121295B	0.040	35	30	2	50	20.6%	7.99	86.02	1.97	7.2%	143.98
3	Replicate Avg.	0.040	42	15	2	50	32.4%	15.24	164.03	3.74	13.7%	273.24
11	Replicate Avg.	0.040	42	30	4	50	29.6%	13.80	148.54	3.41	12.5%	249.58
6	112995A	0.080	35	15	4	50	18.2%	14.27	153.61	1.78	6.5%	130.04
13	120895B	0.080	35	30	2	50	18.6%	14.34	154.40	1.77	6.5%	129.70
2	111695A	0.080	42	15	2	50	33.1%	31.30	336.91	3.88	14.2%	283.92
10	120695B	0.080	42	30	4	50	22.4%	20.86	224.61	2.59	9.5%	189.10
High Air Flow												
1	111595B	0.040	35	30	4	100	18.8%	6.45	69.41	1.80	6.6%	131.40
9	120695A	0.040	35	15	2	100	22.9%	9.05	97.38	2.24	8.2%	163.60
5	112895B	0.040	42	30	2	100	35.8%	16.67	179.48	4.14	15.1%	302.51
14	121495B	0.040	42	15	4	100	24.8%	11.83	127.38	2.91	10.6%	212.89
4	Replicate Avg.	0.080	35	30	4	100	19.3%	14.81	159.41	1.84	6.7%	66.31
12	Replicate Avg.	0.080	35	15	2	100	17.1%	13.46	144.88	1.67	6.1%	121.87
8	120595B	0.080	42	30	2	100	38.0%	35.42	381.28	4.39	16.0%	320.95
16	121495A	0.080	42	15	4	100	25.4%	24.14	259.91	2.98	10.9%	218.03

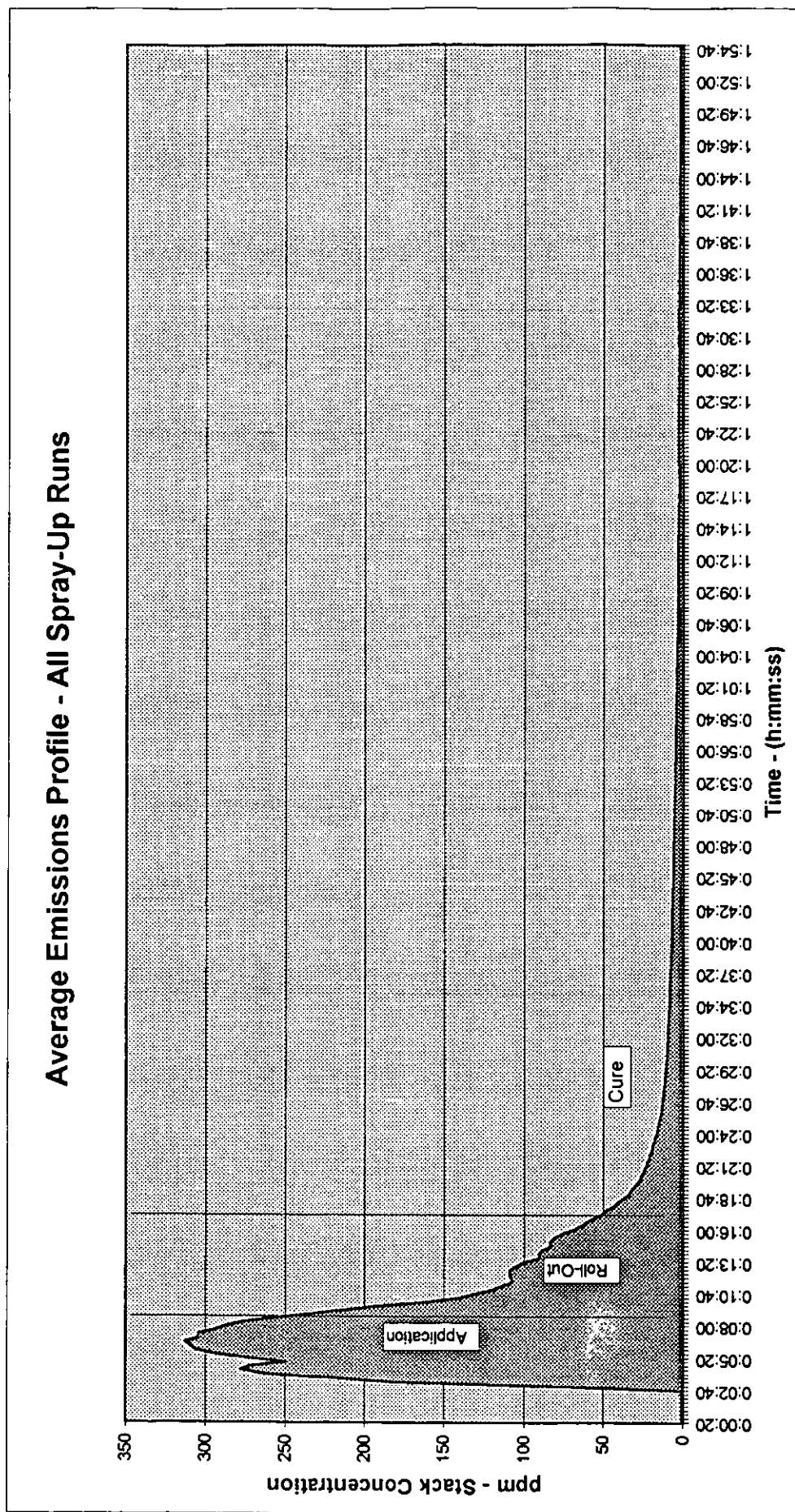
	% Available Styrene			% Resin Weight		Lbs/Ton Resin
	Norm.	Surface Area				
Avg. Emissions - Low Air Flow Rate	24.8%	2.68	9.8%			195.72
Avg. Emissions - High Air Flow Rate	25.3%	2.74	10.0%			192.20

Spray-Up Baseline Study

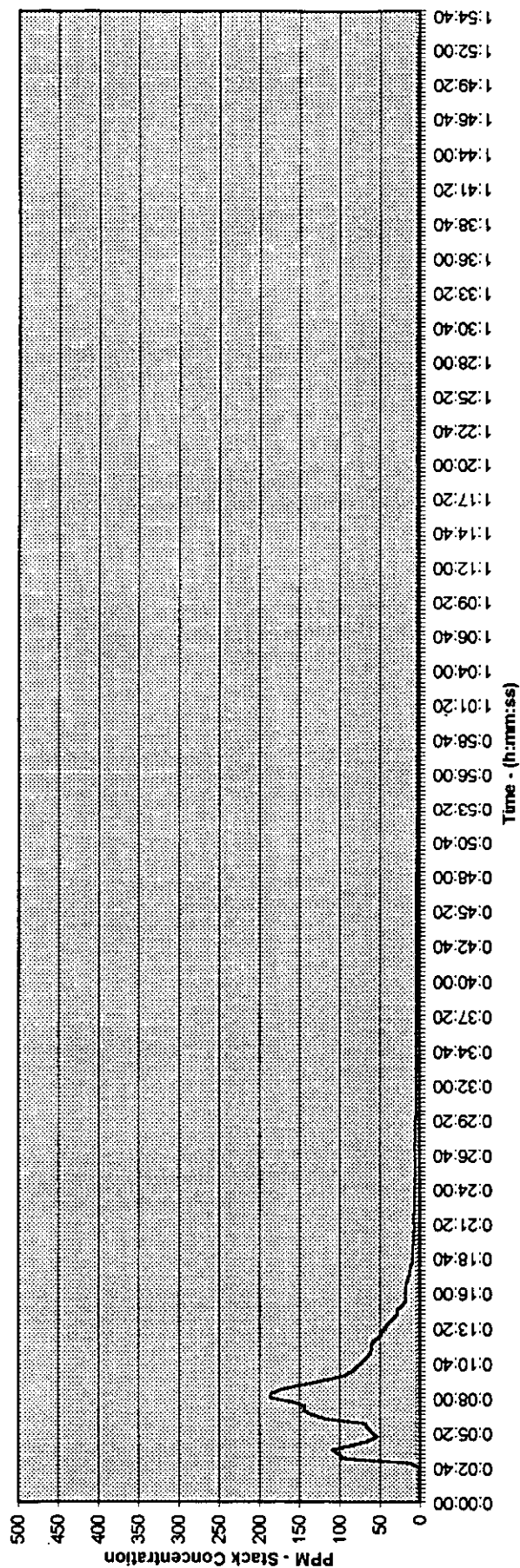
Composite Graph - All Spray-Up Runs



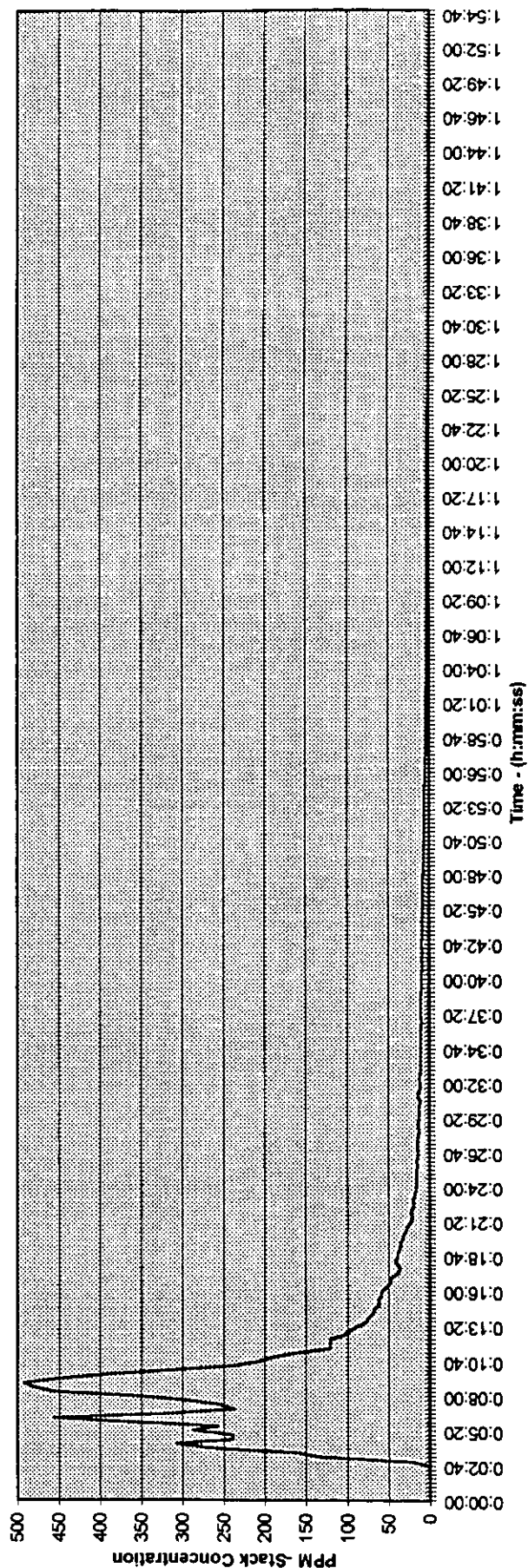
Spray-Up Baseline Study



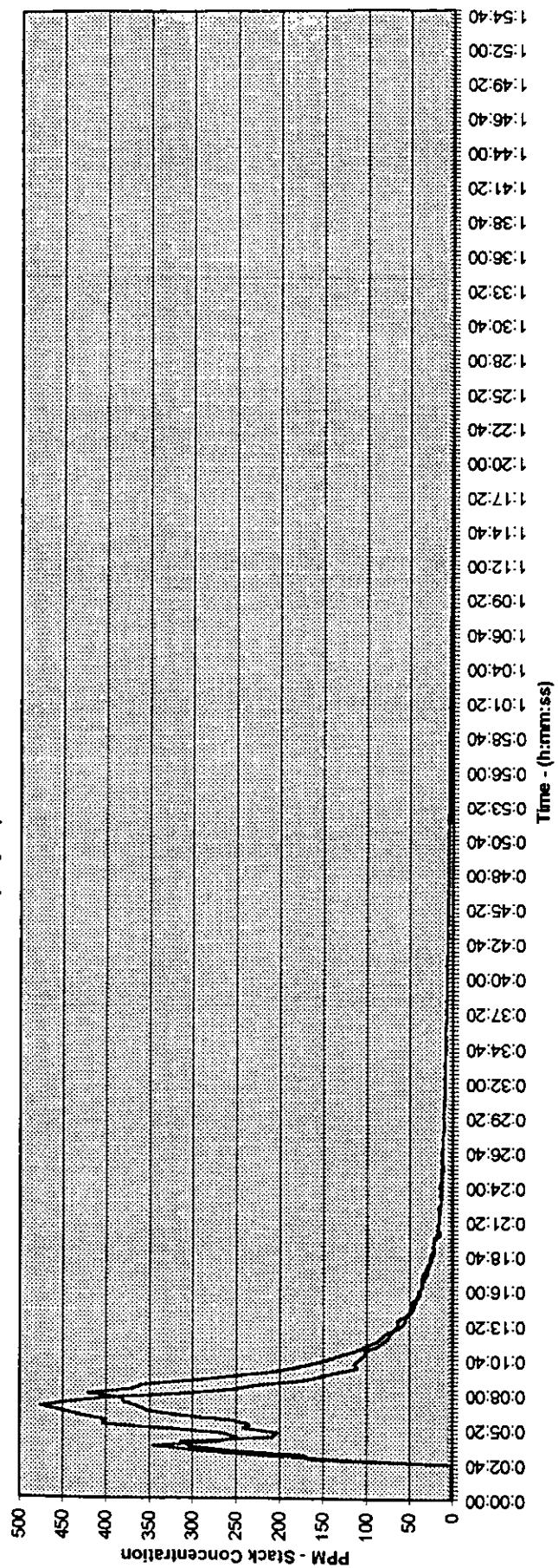
Spray-Up - Run 1



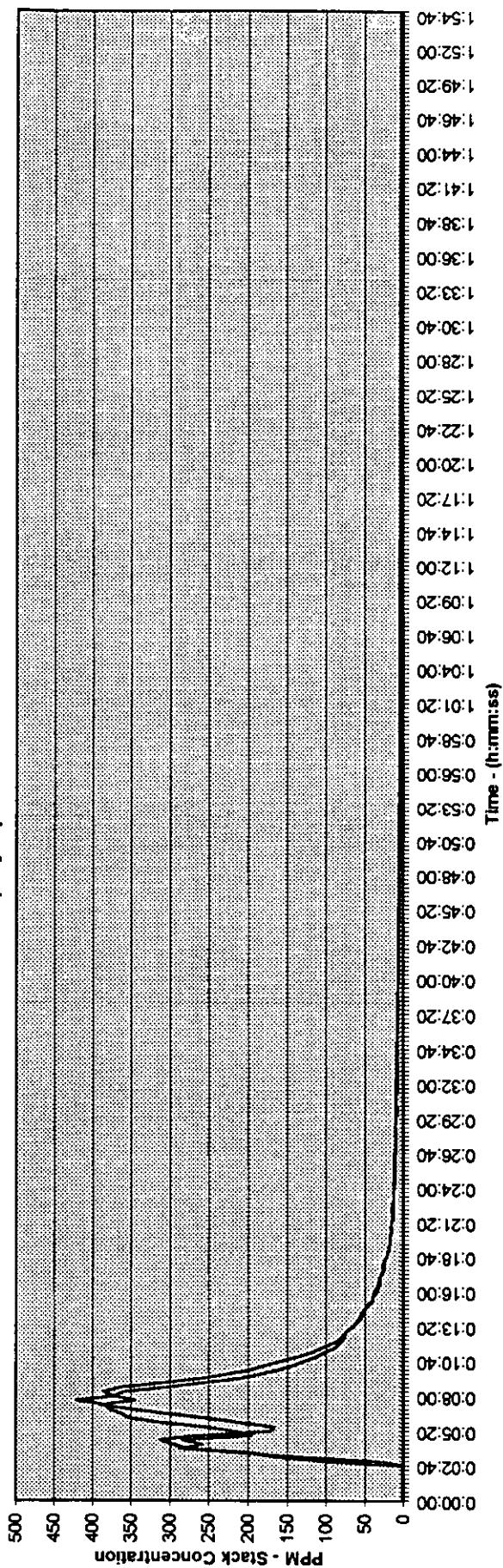
Spray-Up - Run 2



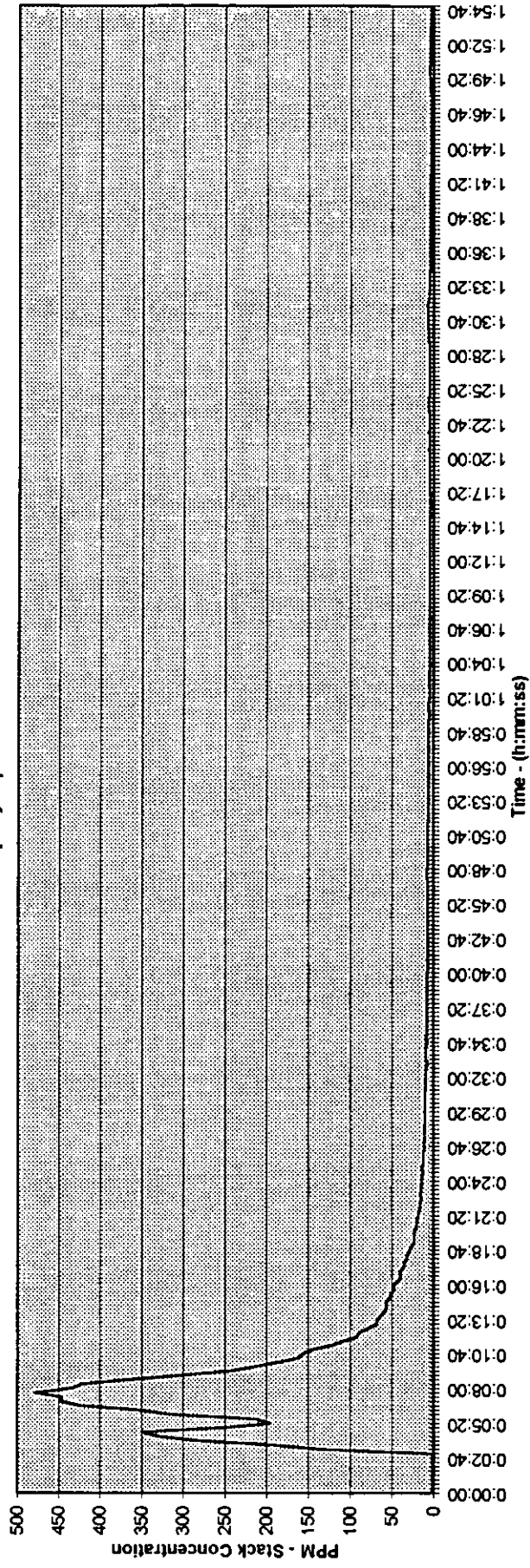
Spray-Up - Runs 3A & 3B



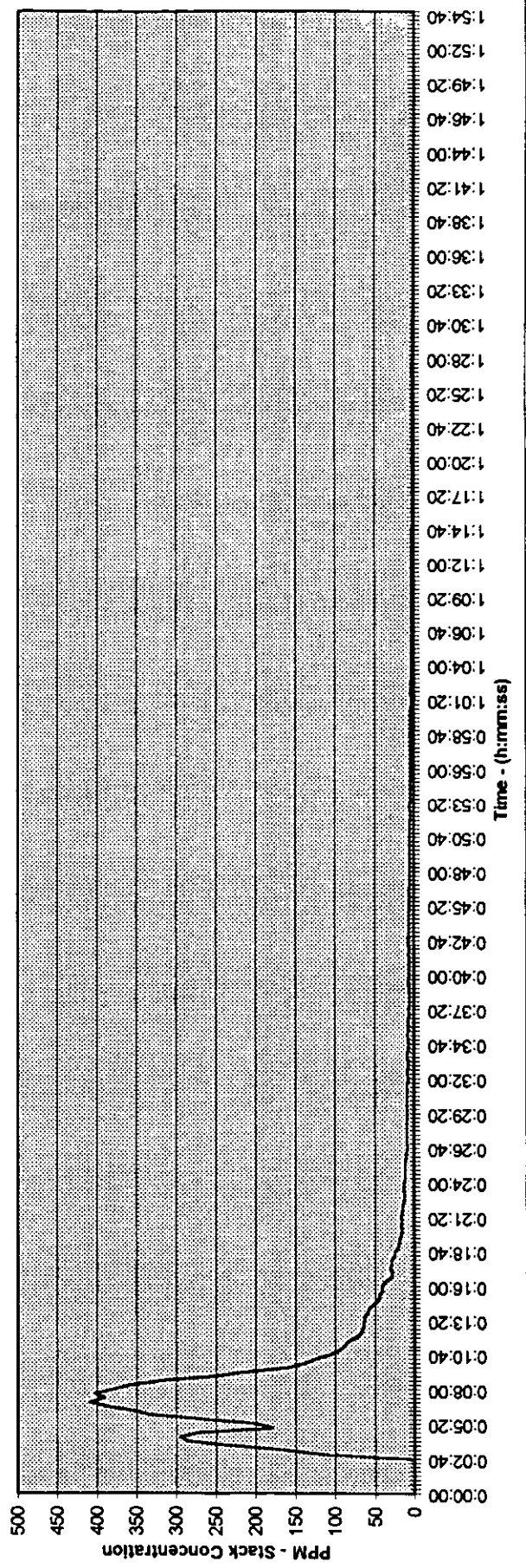
Spray-Up - Runs 4A & 4B



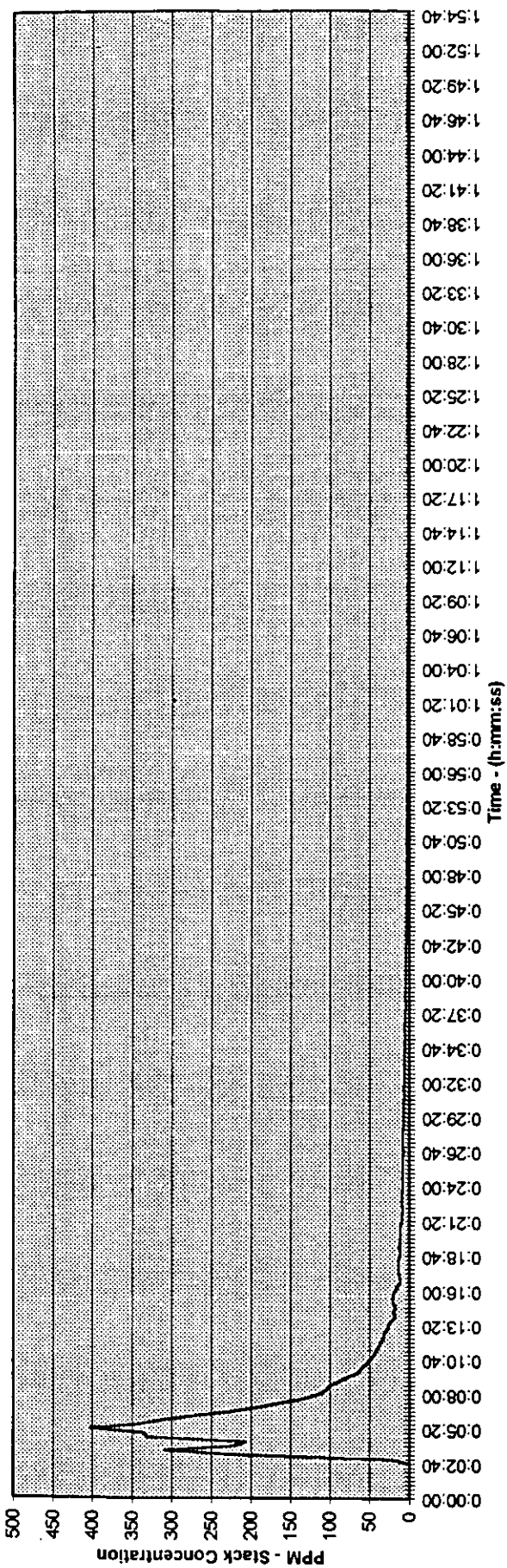
Spray-Up - Run 5



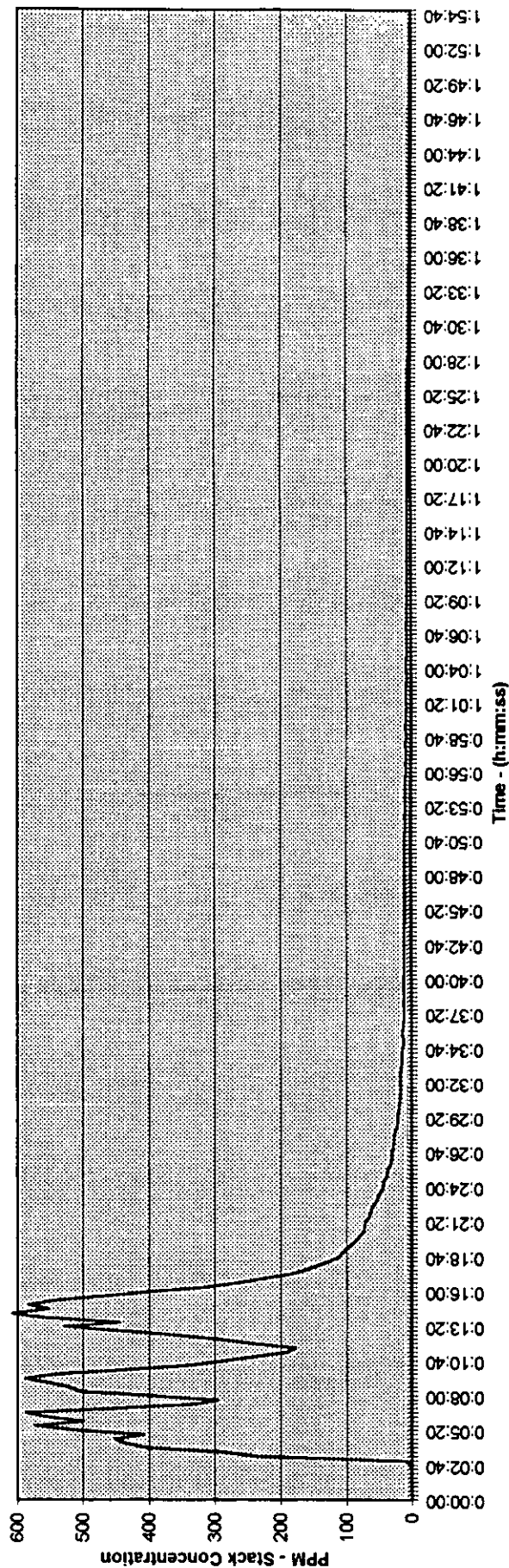
Spray-Up - Run 6



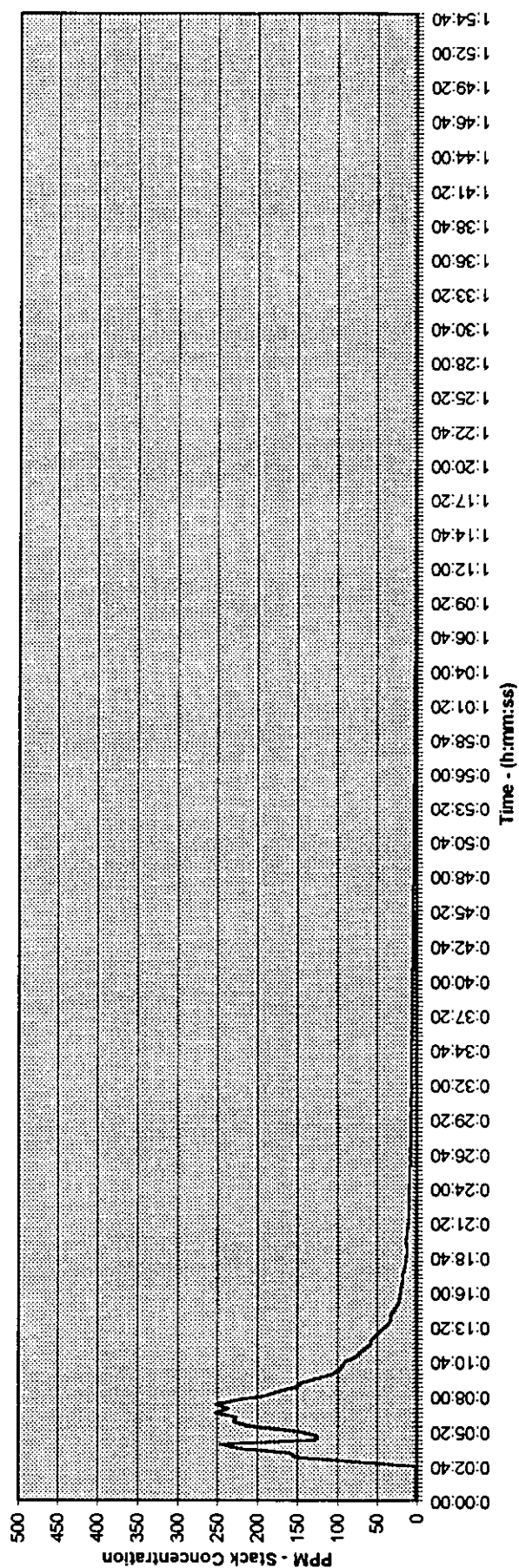
Spray-Up - Run 7



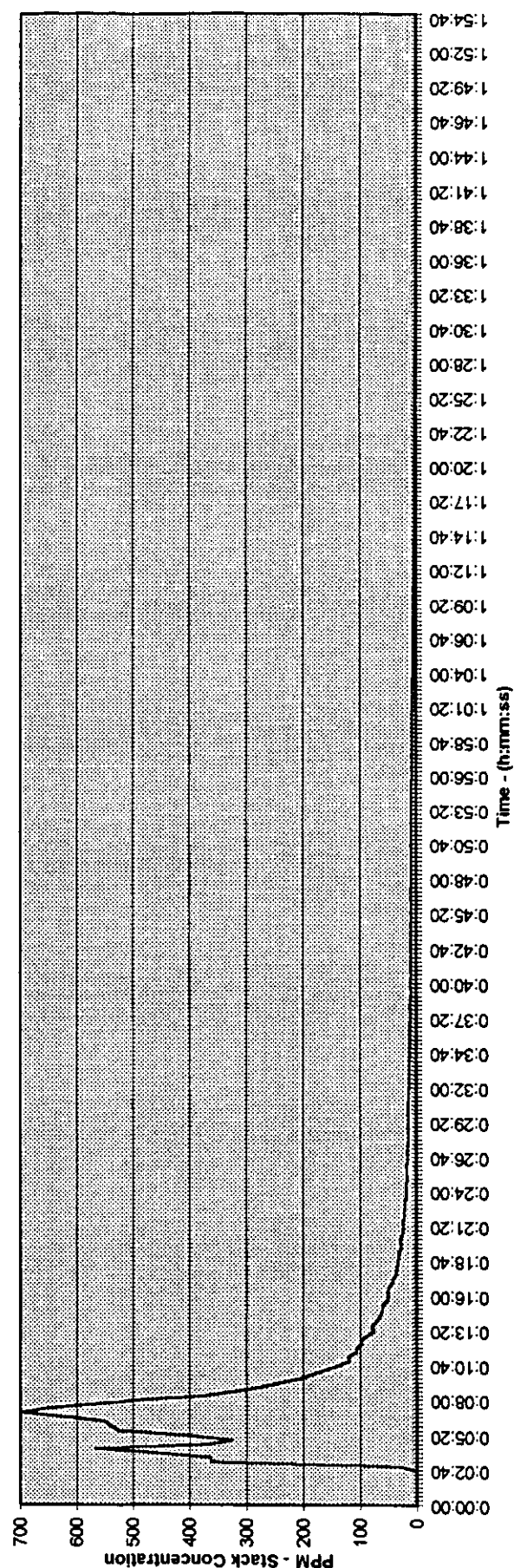
Spray-Up - Run 8



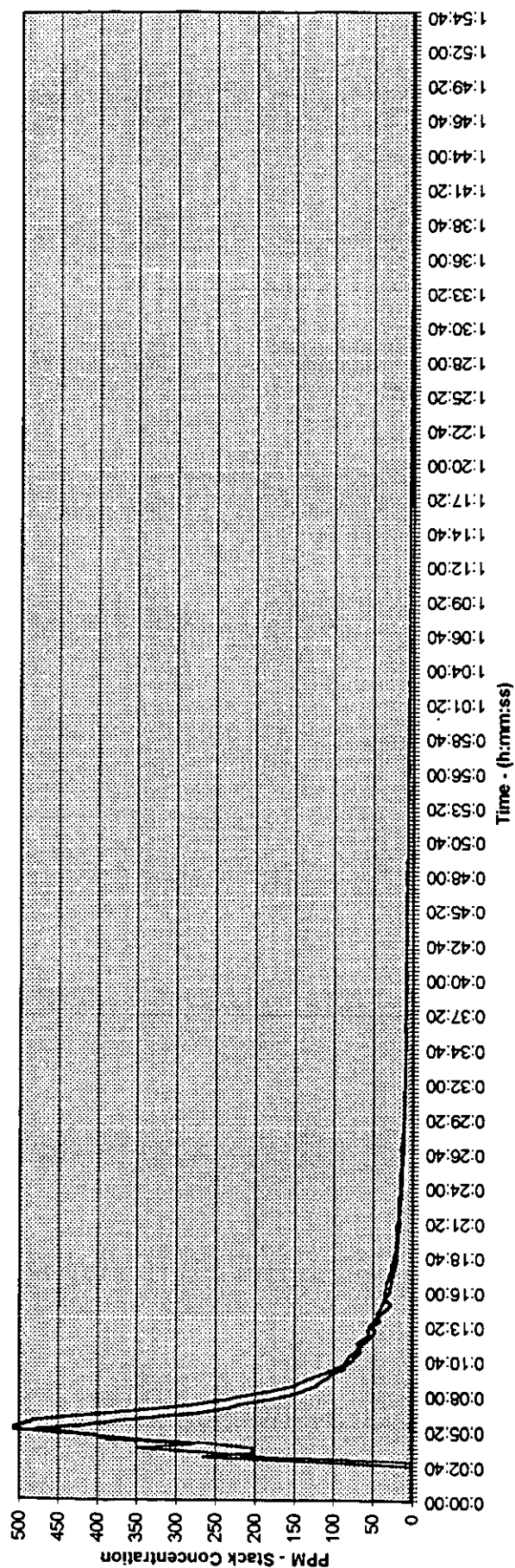
Spray-Up - Run 9



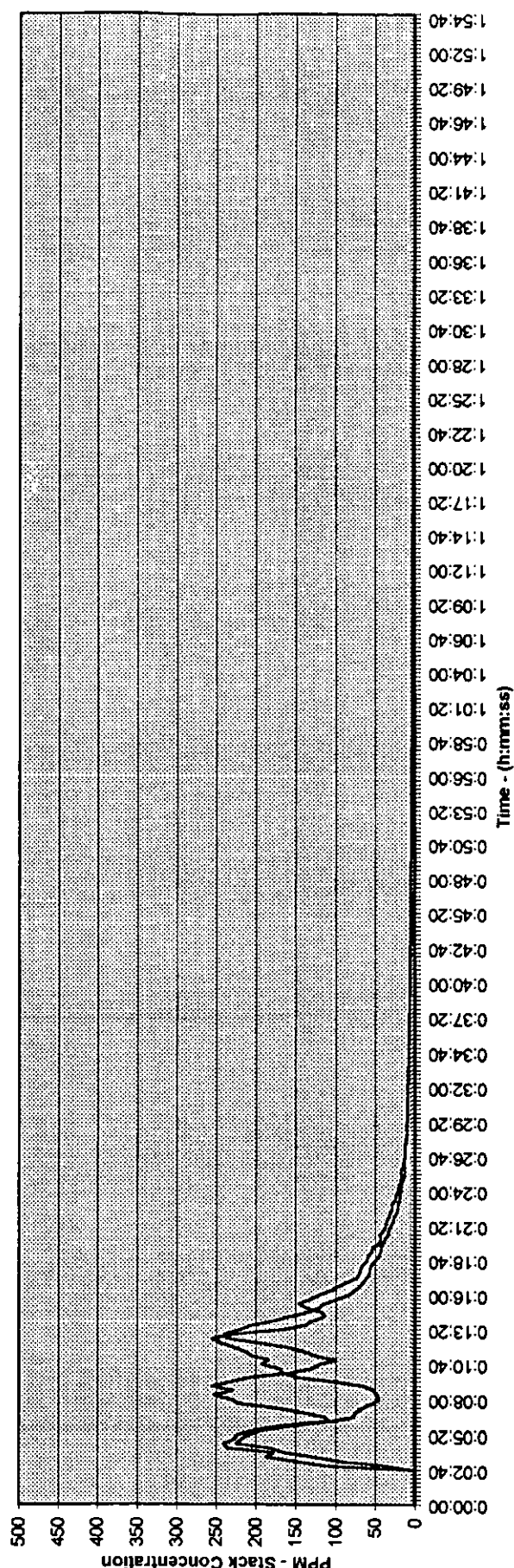
Spray-Up - Run 10



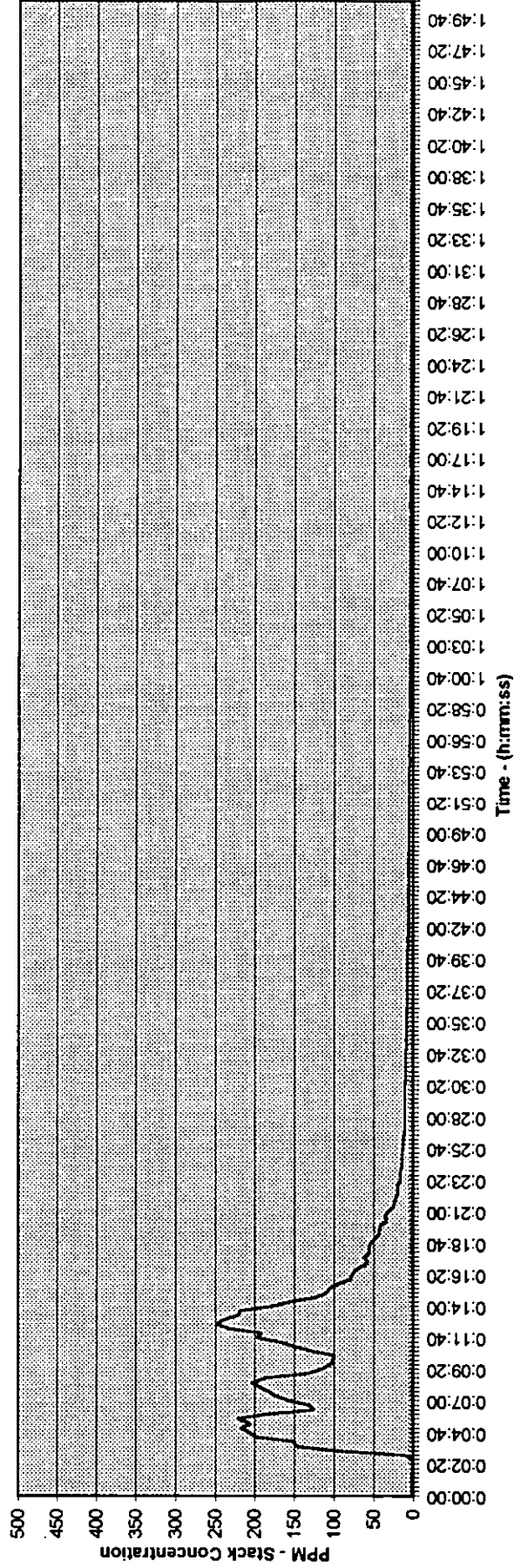
Spray - Up - Runs 11A & 11B



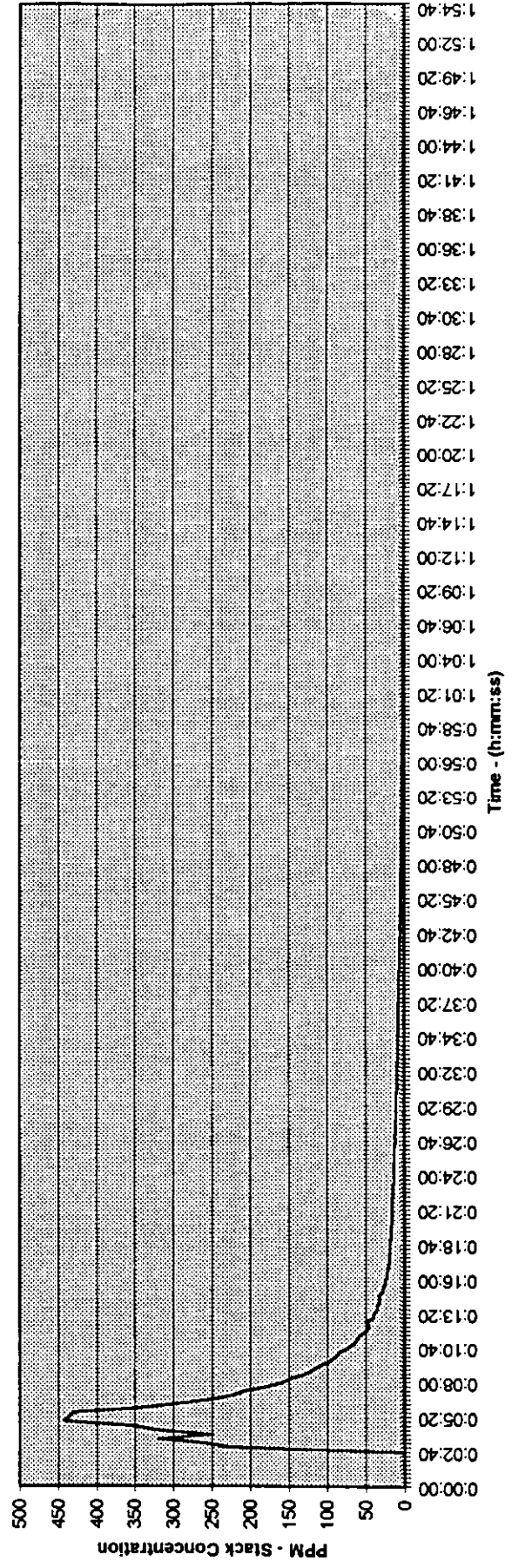
Spray-Up - Runs 12A & 12B



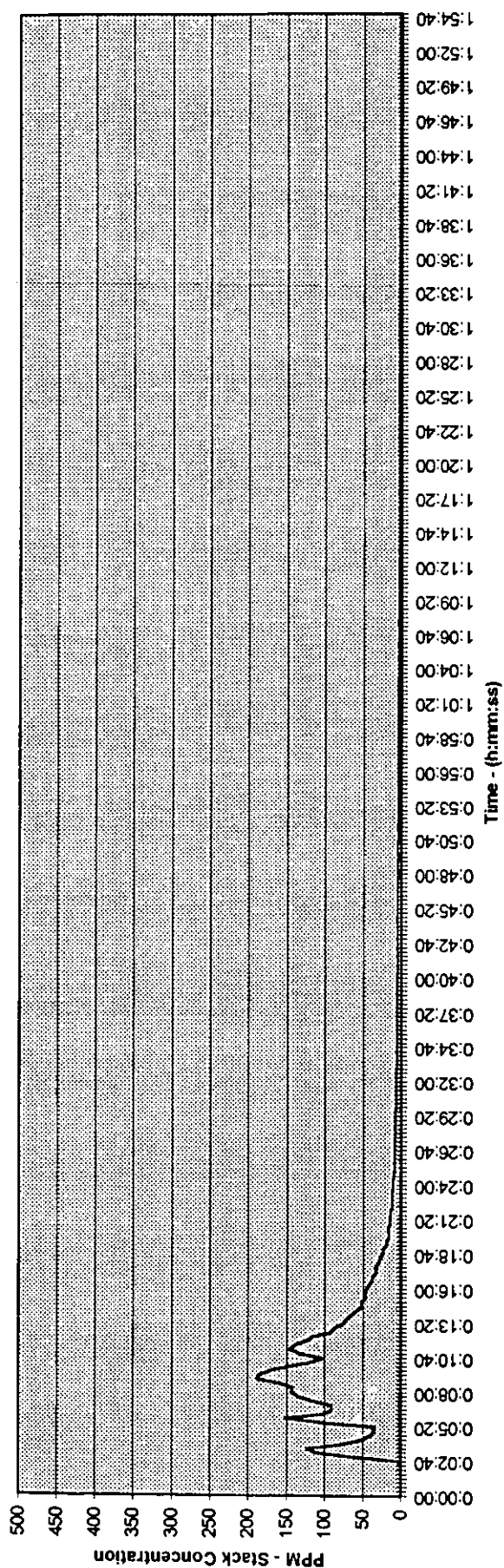
Spray-Up - Run 13



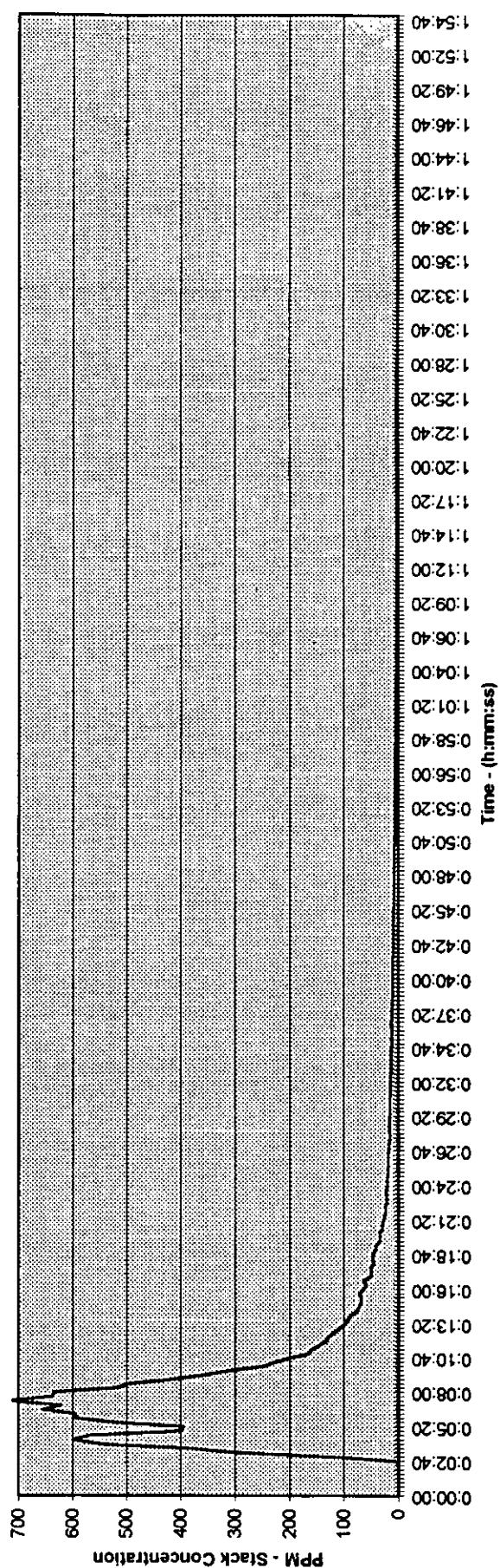
Spray-Up - Run 14



Spray - Up - Run 15

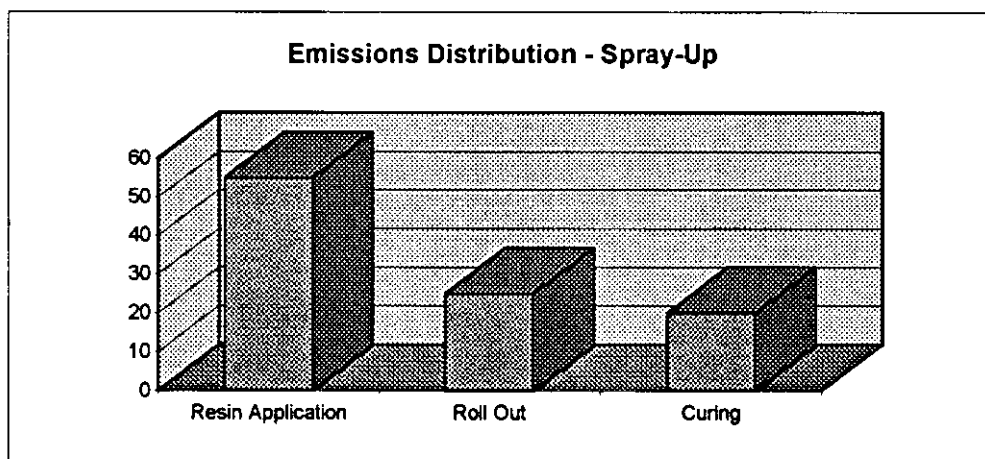
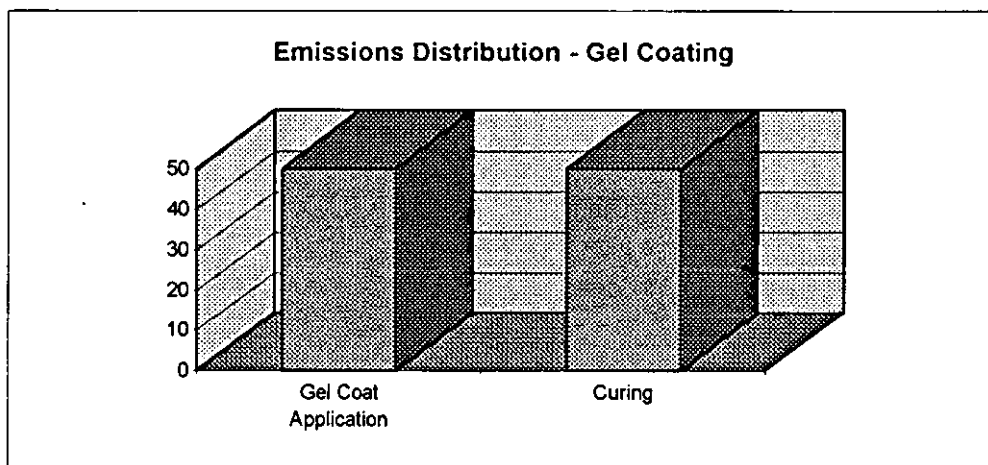
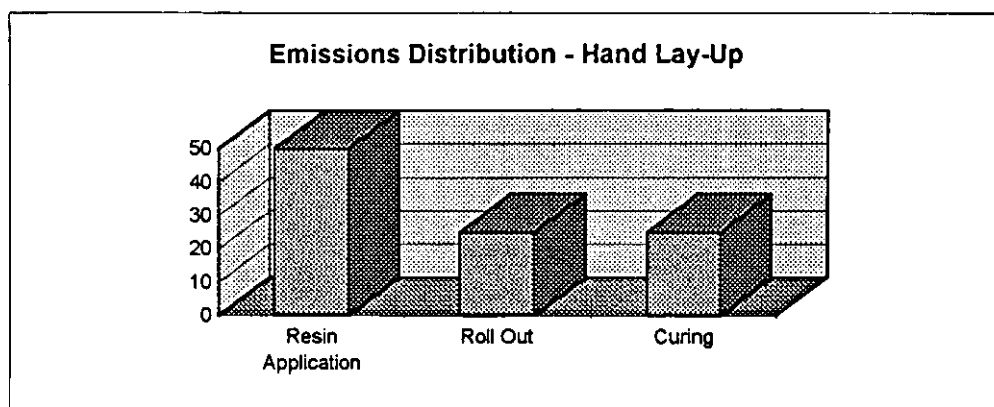


Spray-Up - Run 16



GENERAL DISTRIBUTION OF EMISSIONS

Figure 8.33



Section 9.0

Data Analysis

9.1 Data Reduction

The data reduction for these experiments have been done with the program JMP, version 3.1.5 (SAS Institute Inc., SAS Campus Drive, Cary, NC 27513).

9.2 Evaluation of Results from the Hand Lay-up Study

The results of the study from the hand lay-up study indicate that an average of 14.1% of the available styrene is lost during the process. Working under conditions of a fast gel time, higher laminate thickness, low styrene content, and low air flow minimizes the available styrene loss to about 9.6%. Further examination of the factors showed that the major factors were those of laminate thickness, gel time, and styrene content. Air flow, two-factor interactions, and a three-factor interaction were found to be less important in the reduction of styrene emission however their inclusion enabled the construction of a refined model explaining over 98% of the variation.

9.2.1 Evaluation of the Model: Effects Test

Table 9.1 is a summary of the results from the hand lay-up study. The table contains the source factors being studied, the abbreviated terms used for each of the factors, the numbers of parameter (terms in the model equation) that the factors are contributing to the model, the degrees of freedom each factor represents, the sum of squares from each effect, the F-ratio indicating statistical significance, and the final column Prob>F is the parameter which indicates the probability that the value of the F-ratio is due to random chance. Further explanations of each of the terms may be found in the proposal.

The results of the hand lay-up study show that three factors are significant at the 95% confidence level ($[\text{Prob}>F] < 0.0500$), laminate thickness, styrene content, and gel time of the resin. Neither air flow nor any two-factor interactions were found contribute any significant effects to the model.

The effect of blocking from running the experiments on different days was not found to be significant. Because the experiments could not be run as planned on given days, the blocking pattern was modified in the analysis to account for the experiments as they were executed. The dates of the experimental runs are given in Table 9.3. Although the experiments were not all run on the planned days, the confounding of the factors was not significantly changed. The term "Data ID" is the effect due to the blocking on the different days, and as shown in the table, is not a significant effect. Therefore, another analysis was done to treat the experiment as a fully resolved 4-factor experimental design.

Table 9.2 is the summary analysis of the 4-factor full factorial design. This type of design resolves each of the factors to determine their contribution to the emission response because the blocking is now omitted. This model further verifies that the same three main effects are the significant terms in the model. A further analysis of the data was done with

the "stepwise" screening function. This stepwise approach optimizes the model to provide the best fit of the model to the data. The results of this analysis are given in Table 9.4.

The effects test for stepwise optimization of the model now includes as significant terms, air flow, two, two-factor interactions (thickness*styrene content, thickness*gel time), and a three-factor interaction (styrene content*gel time*air flow). As terms are removed from the model, the sum-of-squares and thereby the F-ratio will change for individual factors. The levels of significance for the terms are changed and those factors may become statistically significant at the 95% confidence level.

Choice of the parameters used in the model appears to be complicated by this apparent change of statistical significance. However, additional criteria and an additional inspection of Tables 9.2 and 9.4 serve to further elucidate the model. The factors are sorted by F-ratio in each of the fore-mentioned tables. The factors are ranked in the same order and verify each other in the relative importance of the factors. The question then becomes to what point should the cut-off point occur for use the terms in the model? This question will be addressed in the following sections.

9.2.2 Evaluation of the Model: Effects Table

Table 8.5 shows the effects terms of the model and their probability that the effects are not equal to zero. The effects term can be described as the coefficient in the linear equation as described in the proposal.

The prediction equation for the model using the coded terms is:

$$\text{Emission} = 14.624 - 2.707*TH - 1.352*GT + 1.078*SC + 0.248*AF + 0.227*TH*GT + 0.225*TH*SC - 0.214*SC*GT*AF \quad (\text{Eqn. 9.1})$$

The model may also be expressed in terms of the actual measurements used for the factors. The model was built from the software function. The converted model for calculating the emission from the actual factor values is:

$$\text{Emission} = -0.676 - 0.0251*TH' - 0.189*GT' + 0.463*SC' - 0.0124*AF' + 1.28 \times 10^{-3}*TH'*GT' - 2.93 \times 10^{-3}*TH'*SC' - 2.6 \times 10^{-5}*SC'*GT'*AF' \quad (\text{Eqn. 9.2})$$

The magnitude of the coefficients in equation 9.2 spans approximately 4 orders of magnitude. Using scaled variables as done with the model shown in equation 9.1 helps to better resolve the significant factors.

The model from the coded terms show that laminate thickness, gel time, and styrene content are the largest contributors to the emission model. A relative comparison of the contribution to the emissions is illustrated in Figure 9.1. Increasing thickness from its low to high value will result in lowering emissions by 5.4% (of measured styrene emission). Increasing styrene content from its low to high value contribute 2.16% to the total emission. Gel time was coded in an inverse manner ("slow" ~ 30 min. = -1, "fast" ~ 15 min. = +1) denoting that increasing the reaction rate (faster gel times) contributes a 2.6% reduction in emissions.

min. = +1) denoting that increasing the reaction rate (faster gel times) contributes a 2.6% reduction in emissions.

The second set of factors, air flow, TH*GT, TH*SC, and SC*GT*AF are approximately 20% of the styrene content effect. Each individual effect contributes approximately 0.5% to total emissions. In the refined model, their effects may be measurable and provide a best fit model. However, the ability to resolve these factors will depend on the control of the experiments and measurement precision. If the three major effects are not well controlled or if the measurement precision is degraded, then these smaller effects will not be seen as significant effects above the noise levels of the experiment.

The ability to control the three highest effects will dictate the choice of the initial screening or refined model. Control of the laminate thickness, gel time, and styrene content must be the priority in obtaining the maximum styrene reduction. With their proper control, then the model may be further refined and used to look into further experiments.

9.2.3 Evaluation of the Model: Prediction and Interaction Profiles

Effects of the factors on the response may be graphically illustrated with the use of prediction and interaction profiles. The prediction profile compares the mean response of the effect at the respective low and high values. The effect value is the slope of the line. These plots illustrate the negative effects of the gel time and laminate thickness and the positive effect from the styrene content. The comparative effect of the air flow is shown by the shallow slope.

The interaction plots as shown in Figure 9.3 present a visual concept of significant interactions. The family of lines shown are arranged by calculating the effects listed in each row against each factor-level on the x-axis for each level of the chosen factor listed. The first row of the interaction plots gives the effects of thickness at different factor levels of styrene content, gel time and air flow. Interactions are indicated as the slopes of the two comparison lines deviate from each other and therefore diverge from being parallel. The interactions of thickness with styrene content and gel time show some differentiation between the slopes. In contrast, those interactions with air flow appear parallel and in some cases identical. However, the main criteria for determination of an interaction should be based on the effects and F-test information.

9.2.4 Evaluation of the Model: Lack-of-Fit Testing

The summary-of-fit (R^2), analysis-of-variance (ANOVA), and lack-of-fit (LOF) provide indicators on how well the proposed model fits the data. Table 9.7a provides the comparison of model fits between the full-factorial model (Table 9.2) and the 7-term refined model (Table 9.6). The regression coefficient (R^2) indicates the fraction of the variance explained by the refined model. In this case, 0.998 (98.8%) of the variation is explained by the refined model where a value of 1 is a perfect fit of the model. An R^2 of 0 means that the model is no different than the mean value given in the table. The R^2_{adj} term takes into account the experimental error of the data and degrees of freedom better compare models with differing numbers of terms. The R^2 improves as more terms are added to the model. However, non-significant terms may be added and noise is introduced

into the model. The R^2_{adj} will improve as the significant terms of the model are retained and the less-significant terms are removed as is shown in Table 8.7a. As a model is refined, the difference between R^2 and R^2_{adj} become smaller. The model is considered at its optimum when the difference is at a minimum.

The one-way ANOVA provides the data by which to calculate the regression coefficients and indicates if the model is significant as indicated by the F-ratio and the Prob>F. This information helps determine if the model is related to the response although the model may not fully explain the data. The F-ratio is the mean square model divided by the mean square error. A F-ratio greater than the critical value (2.91) indicates that the model is significant at the 5% confidence level.

In contrast to the ANOVA table, a lack-of-fit test with a statistically insignificant F-ratio indicates that the model is a good fit of the data. If the response is non-linear or if the experimental variation prevents the data points from correlating to the model, then this test would show-up as a significant test. A significant result does not mean that the effects are not significant but that the chosen model is not a good explanation of the data. As this value in Table 9.7c is not significant, it further indicates that the model as given in equation 9.1 should be a good predictor of the emission response within the chosen experimental conditions.

9.2.5 Evaluation of the Model: Cube Plots

The predicted emission values from the refined model may be plotted against the experimental factors to give a visual presentation of the response relative to the experimental conditions. This plot, called a Cube Plot, is given in Figure 9.4. In this case, two cube plots are shown side-by-side at two levels of air flow. The edge of each cube represents the remaining main effect levels. This plot illustrates the emission response and indicate the area in which the emission is nearest the optimum. These values are shown in bold for each plot. The area for most likely optimization should exist under the conditions of fast gel time, high thickness, low styrene content, and low air flow.

Table 9.1
Effect Test of Hand Lay-up Study With Blocking

Source (1)	Abbr.	No. of Parameters	Degrees of Freedom	Sum of Squares	F Ratio	Prob>F
Thickness	TH	1	1	77.256088	684.8061	0.0015
Gel Time	GT	1	1	21.722987	192.5548	0.0052
Styrene Content	SC	1	1	10.506512	93.1308	0.0106
Air Flow (2)	AF	<i>1</i>	<i>1</i>	<i>0.901604</i>	<i>7.9919</i>	<i>0.1057</i>
TH*AF = -(TH*SC)		<i>1</i>	<i>1</i>	<i>0.561909</i>	<i>4.9808</i>	<i>0.1553</i>
GT*AF = -(SC*GT)		<i>1</i>	<i>1</i>	<i>0.152980</i>	<i>1.3560</i>	<i>0.3643</i>
SC*AF = -(TH*GT)		<i>1</i>	<i>1</i>	<i>0.049400</i>	<i>0.4379</i>	<i>0.5762</i>
Data ID (Blocking)		10	10	4.732521	4.1950	0.2077

(1) Terms refer to coded factors, -1, 1.

(2) Non-significant terms are in italics.

Table 9.2
Effect Test of Hand Lay-up Study as a Full Factorial Design

Source (1)	Abbr.	No. of Parameters	Degrees of Freedom	Sum of Squares	F Ratio	Prob>F
Thickness	TH	1	1	133.98258	318.3807	0.0001
Gel Time	GT	1	1	33.41835	79.4115	0.0009
Styrene Content	SC	1	1	21.25446	50.5067	0.0021
Air Flow	AF	<i>1</i>	<i>1</i>	<i>1.12573</i>	<i>2.6752</i>	<i>0.1773</i>
TH*GT		<i>1</i>	<i>1</i>	<i>0.93603</i>	<i>2.2243</i>	<i>0.2101</i>
TH*SC		<i>1</i>	<i>1</i>	<i>0.92571</i>	<i>2.1998</i>	<i>0.2122</i>
SC*GT*AF		<i>1</i>	<i>1</i>	<i>0.84035</i>	<i>1.9969</i>	<i>0.2305</i>
GT*AF		<i>1</i>	<i>1</i>	<i>0.52846</i>	<i>1.2558</i>	<i>0.3252</i>
TH*SC*GT*AF		<i>1</i>	<i>1</i>	<i>0.23660</i>	<i>0.5622</i>	<i>0.4951</i>
TH*SC*AF		<i>1</i>	<i>1</i>	<i>0.12258</i>	<i>0.2913</i>	<i>0.6180</i>
TH*AF		<i>1</i>	<i>1</i>	<i>0.10286</i>	<i>0.2444</i>	<i>0.6470</i>
SC*AF		<i>1</i>	<i>1</i>	<i>0.04367</i>	<i>0.1033</i>	<i>0.7640</i>
TH*SC*GT		<i>1</i>	<i>1</i>	<i>0.03206</i>	<i>0.0762</i>	<i>0.7962</i>
SC*GT		<i>1</i>	<i>1</i>	<i>0.00560</i>	<i>0.0133</i>	<i>0.9137</i>
TH*GT*AF		<i>1</i>	<i>1</i>	<i>0.00206</i>	<i>0.0049</i>	<i>0.9475</i>

(1) Terms refer to coded factors, -1, 1.

(2) Non-significant terms are in italics.

Table 9.3
Dates of Runs for Evaluation of Blocking Effects

Run No.	Date
1	100295
2	100295
3A	092095
4A	100395
5	092595
6	092695
4B	092695
3B	092695
7	092795
8	092795
9	092795
10	092895
11A	092895
12A	092895
13	092995
14	092995
11B	092995
12B	100295
15	091995
16	091995

Table 9.4
Effects Test of Model Using Stepwise Analysis

Source (1)	Abbrev.	No. of Parameters	Degrees of Freedom	Sum of Squares	F Ratio	Prob>F
Thickness	TH	1	1	136.92731	570.9026	<.0001
Gel Time	GT	1	1	35.43620	147.7471	<.0001
Styrene Content	SC	1	1	21.75840	90.7191	<.0001
TH*SC		1	1	1.42354	5.9353	0.0314
AF	AF	1	1	1.24644	5.1969	0.0417
TH*GT		1	1	1.22513	5.1080	0.0432
SC*GT*AF		1	1	0.87005	3.6276	0.0811

(1) Terms refer to coded factors, -1, 1.

(2) Non-significant terms are in italics.

Table 9.5
Effects Table of Full Factorial Model

Source (1)	Abbr.	Estimate	Std Error	t Ratio	Prob> t
Intercept		14.624	0.151703	96.40	<.0001
Thickness	TH	-2.707	0.151703	-17.84	<.0001
Gel Time	GT	-1.352	0.151703	-8.91	0.0009
Styrene Content	SC	1.078	0.151703	7.11	0.0021
Air Flow	AF	0.248	0.151703	1.64	0.1773
TH*GT		0.2265	0.151703	1.49	0.2101
TH*SC		-0.225	0.151703	-1.48	0.2122
SC*GT*AF		-0.214	0.151703	-1.41	0.2305
GT*AF		-0.170	0.151703	-1.12	0.3252
TH*SC*GT*AF		0.114	0.151703	0.75	0.4951
TH*SC*AF		-0.082	0.151703	-0.54	0.6180
TH*AF		-0.075	0.151703	-0.49	0.6470
SC*AF		0.049	0.151703	0.32	0.7640
TH*SC*GT		-0.042	0.151703	-0.28	0.7962
SC*GT		0.018	0.151703	0.12	0.9137
TH*GT*AF		0.011	0.151703	0.07	0.9475

Table 9.6
Effects Table for Optimized Hand Lay-up Model

Term	Abbr.	Estimate	Std Error	t Ratio	Prob> t
Intercept		14.671042	0.111767	131.26	<.0001
Thickness	TH	-2.708393	0.113352	-23.89	<.0001
Gel Time	GT	-1.358542	0.111767	-12.16	<.0001
Styrene Content	SC	1.0796429	0.113352	9.52	<.0001
TH*SC		-0.272292	0.111767	-2.44	0.0314
Air Flow	AF	0.2547917	0.111767	2.28	0.0417
TH*GT		0.2475	0.109509	2.26	0.0432
SC*GT*AF		-0.215893	0.113352	-1.90	0.0811

Figure 9.2
Main Effects Plots

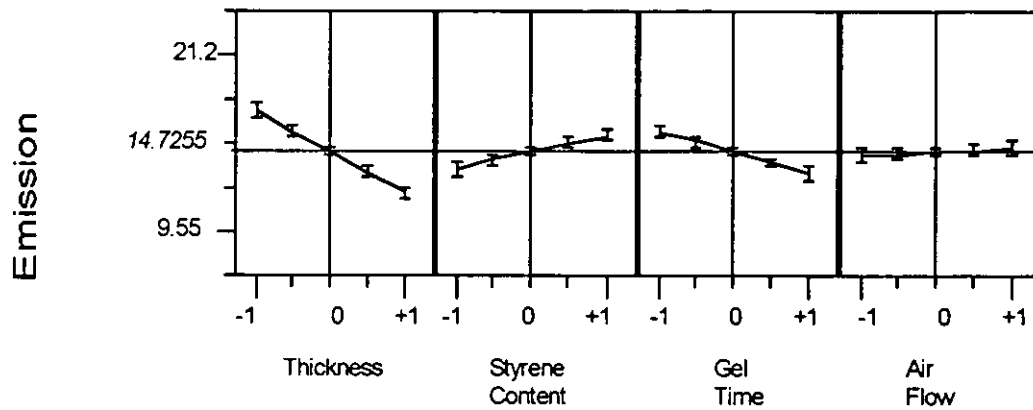


Figure 9.3
Interaction Plots

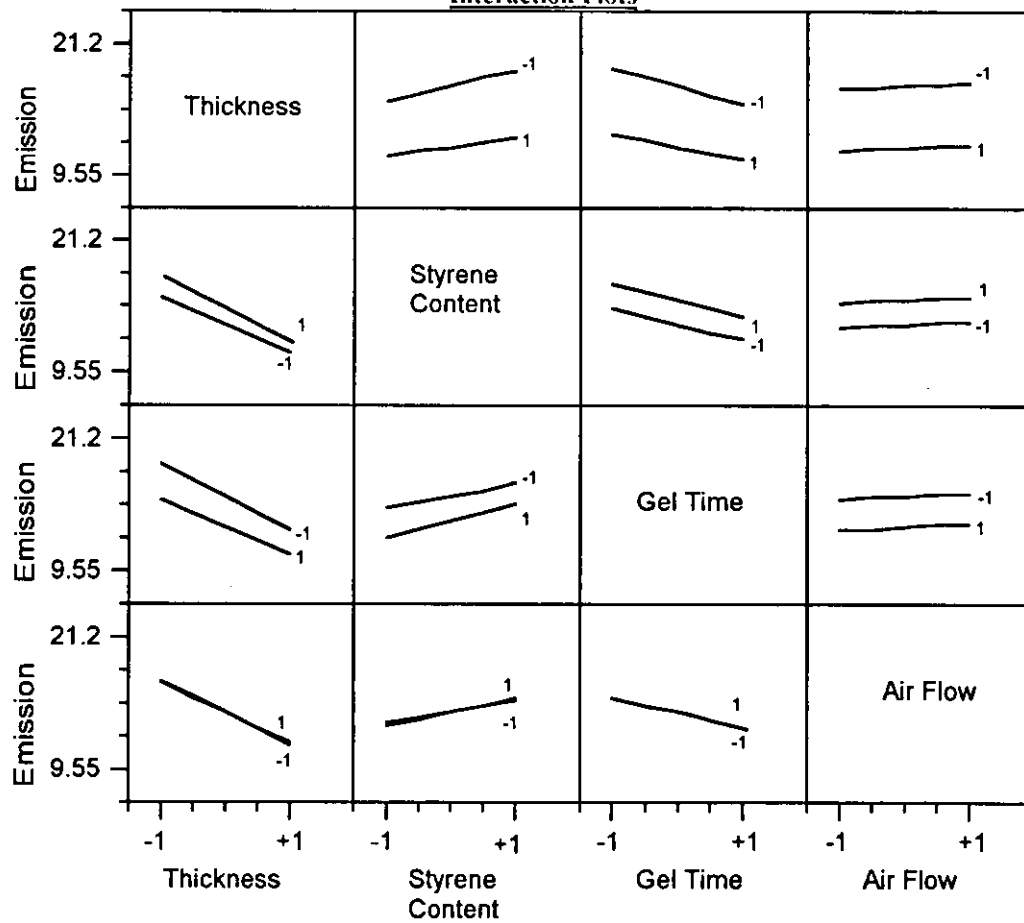


Table 9.7a
Summary of Fit

	<u>Full factorial</u>	<u>Refined Model</u>
R^2	0.993196	0.988366
R^2_{adj}	0.967681	0.98158
Root Mean Square Error	0.648710	0.489738
Mean of Response	14.7255	14.7255
Observations (or Sum Wgts)	20	20

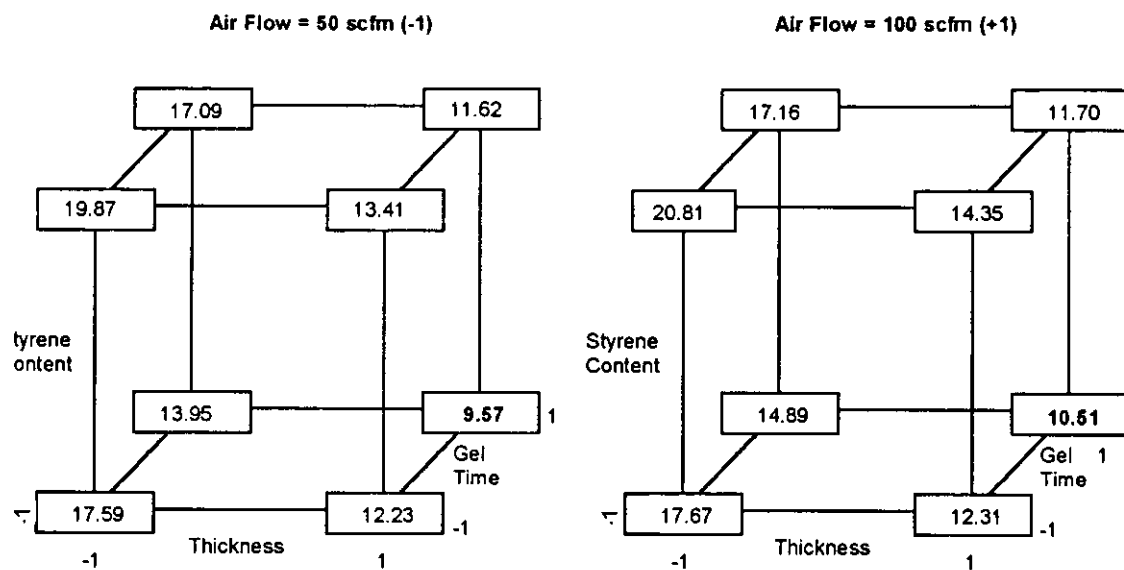
Table 9.7b
One-way Analysis of Variance Table

<u>Source</u>	<u>DF</u>	<u>Sum of Squares</u>	<u>Mean Square</u>	<u>F Ratio</u>
Model	7	244.51677	34.9310	145.6406
Error	12	2.87812	0.2398	<u>Prob>F</u>
Total	19	247.39490		<.0001

Table 9.7c
Lack-of-Fit Table

<u>Source</u>	<u>DF</u>	<u>Sum of Squares</u>	<u>Mean Square</u>	<u>F Ratio</u>
Lack of Fit	8	1.1948226	0.149353	0.3549
Pure Error	4	1.6833000	0.420825	<u>Prob>F</u>
Total Error	12	2.8781226		0.9008
				<u>Max RSq</u>
				0.9932

Figure 9.4
Cube Plot of the Predicted Emission Response



9.3 Evaluation of Results from the Gel Coat Study

The expected emission from the gel coat study resulted in an average of 51.5% of the available styrene being lost. The styrene emission could be reduced to 43.7% of available styrene under the conditions of slow gel time, lower styrene content and increased film thickness. A model was developed which could account for 82.4% of the variation in the study. Also, this study did not have the same precision as the case of the hand lay-up study and most likely contributed to the reduced regression coefficients. The reduced precision in this study was likely due to the difficulty in maintaining precise hand control of the spray gun in applying the thin layers of gel coat.

The model developed from this study may not have the high correlation and confidence for making predictions as from the hand lay-up study. However, the basic objective of isolating the most important effects, thickness and styrene content, was accomplished.

9.3.1 Evaluation of the model: Effects Test

Table 9.8 contains the summary of data for the significance of the five factors compared against the effect of blocking. Evaluation as a main effects plot indicate that the blocking was not a significant factor and therefore the design was treated as a half-fractional factorial study. The results indicate that thickness and styrene content will be the most significant and major factors affecting styrene emissions. The blocking effect was labeled as "Data ID" representing the actual date when the individual experiment was run and are given in Table 9.9.

The half-fractional factorial results given in Table 9.10 further verify that again gel coat thickness and styrene content are the two most significant effects. All five of the main effects are not confounded with any two-factor interactions. Inspection of Prob>F for gel time, air flow, and resin flow shows that these experimental parameters are not significant in affecting the amount of styrene emission.

The stepwise function was then applied to determine if a refined model may be obtained from the design. Reduction of the model terms indicated that thickness and styrene content were the foremost effect and a potential contribution from a two-factor interaction was included. The two-factor interaction was just beyond the 95% confidence criteria originally set, yet close enough to this boundary to merit consideration as a possible contributor to the model and further study. This interaction term was then included to provide a refined prediction model. However, this term is not a clearly resolved factor but represents two confounded two-factor interactions. The interaction terms styrene content*gel time and resin flow*air flow are two sets of interactions correlated with each other. Greater weight is given to the SC*GT interaction as this interaction contains main effects more significant than the other two in this and the previous study. In the hand lay-up, gel coat, and the following laminate spray-up study, air flow is a minor or insignificant effect. Only a further test could verify which of the two interactions is truly significant to eliminate the possibility that air flow, although minor, somehow interacts with another factor in an important manner.

9.3.2 Evaluation of the Model: Effects Table

Based on the effects terms from Tables 9.12 and 9.13, the prediction equation for this model is:

$$\text{Emission} = 51.65 - 4.23*TH + 2.51*SC - 1.26*SC*GT \quad (\text{Eqn. 9.3})$$

The model was evaluated based on the measured (non-scaled) experimental variables (X') to determine to provide the following equation:

$$\text{Emission} = 43.52 - 1.41*TH' + 0.927*SC' - 5.28 \times 10^{-3}*SC'*GT' \quad (\text{Eqn. 9.4})$$

Alternatively, the RF*AF interaction was substituted for the SC*GT term in the equation to provide the following equation for the model:

$$\text{Emission} = 41.66 - 1.43*TH' + 1.03*SC' - 5.28 \times 10^{-3}*RF*AF \quad (\text{Eqn. 9.5})$$

Table 9.14 compares the models from each of the equations based on the non-scaled factors. The model described by eqn. 9.4 has a slightly higher correlation coefficient, a smaller difference between the two regression coefficients, and the SC*GT interaction exhibits more significance than the RF*AF interaction. The first model should be the most probable, but should not be considered as the conclusive depiction.

9.3.3 Evaluation of the Model: Prediction and Interaction Profiles

Figure 9.5 gives the comparative illustration of the main effect terms and their relative magnitudes. The thickness and styrene content show the largest slopes deviating from the average value. The error bars depict the 95% confidence limits for the predicted value. The 95% confidence limit for the intercept is $\pm 1.34\%$ styrene emission. If additional values are measured under the conditions of this study, then values obtained within those confidence limits further validate the model.

9.3.4 Evaluation of the Model: Lack-of-Fit Testing

A review of Tables 9.51a through 9.51c helps to demonstrate that the refined model explains 82.4% of the variation ($R^2 = 0.824102$), is significant ($\text{Prob} > F < 0.0001$), and there the lack-of-fit is not significant ($\text{Prob} > F < 0.4720$). The results of this study indicate that the model may be used for an estimated prediction, but that other factors may need to be evaluated to improve the model reliability.

9.3.5 Evaluation of the Model: Cube Plot

Figure 9.7 is an illustration that the region of interest for reduction of styrene emissions lies in the area of high thickness (0.024"), low styrene content (35% wt.), and "slow" gel time (~30 minutes).

Table 9.8
Effect Test of Gel Coat Spray-up Study of Main Effects With Blocking

Source (1)	Abbr.	No. of Parameters	Degrees of Freedom	Sum of Squares	F Ratio	Prob>F
Thickness	TH	1	1	116.45571	13.4229	0.0145
Styrene Content	SC	1	1	102.13626	11.7724	0.0186
<i>Gel Time</i>	<i>GT</i>	<i>1</i>	<i>1</i>	<i>16.50715</i>	<i>1.9026</i>	<i>0.2263</i>
<i>Air Flow</i>	<i>AF</i>	<i>1</i>	<i>1</i>	<i>10.00541</i>	<i>1.1532</i>	<i>0.3319</i>
<i>Resin Flow</i>	<i>RF</i>	<i>1</i>	<i>1</i>	<i>1.40644</i>	<i>0.1621</i>	<i>0.7039</i>
<i>Data ID (Blocking)</i>		<i>9</i>	<i>9</i>	<i>85.01345</i>	<i>1.0888</i>	<i>0.4892</i>

(1) Terms refer to coded factors, -1, 1.

(2) Non-significant terms (Prob>F>0.05) are in italics.

Table 9.9
Dates of Runs for Evaluation of Blocking Effects

Run No.	Date
1	101195
2	101195
3A	101295
4A	101295
5	110195
6	101395
4B	110195
3B	101695
7	101695
8	101795
9	101795
10	101895
11A	101895
12A	101995
13	101995
14	101995
11B	102395
12B	102395
15	102495
16	102495

Table 9.10
Effect Test of Gel Coat Spray-up Study as a Half Fractional Factorial Design

Source (1)	Abbr.	No. of Parameters	Degrees of Freedom	Sum of Squares	F Ratio	Prob>F
Thickness	TH	1	1	355.25292	40.7231	0.0004
Styrene Content	SC	1	1	131.08667	15.0266	0.0061
<i>SC*GT=RF*AF</i>		<i>1</i>	<i>1</i>	<i>24.57875</i>	<i>2.8175</i>	<i>0.1371</i>
<i>SC*RF=GT*AF</i>		<i>1</i>	<i>1</i>	<i>19.09446</i>	<i>2.1888</i>	<i>0.1826</i>
Gel Time	GT	1	1	13.40008	1.5361	0.2551
Air Flow	AF	1	1	12.32292	1.4126	0.2734
<i>GT*RF=SC*AF</i>		<i>1</i>	<i>1</i>	<i>10.37161</i>	<i>1.1889</i>	<i>0.3117</i>
<i>TH*RF</i>		<i>1</i>	<i>1</i>	<i>5.34446</i>	<i>0.6126</i>	<i>0.4595</i>
<i>TH*AF</i>		<i>1</i>	<i>1</i>	<i>3.06446</i>	<i>0.3513</i>	<i>0.5720</i>
Resin Flow	RF	1	1	2.67008	0.3061	0.5973
<i>TH*SC</i>		<i>1</i>	<i>1</i>	<i>0.75446</i>	<i>0.0865</i>	<i>0.7772</i>
<i>TH*GT</i>		<i>1</i>	<i>1</i>	<i>0.00875</i>	<i>0.0010</i>	<i>0.9756</i>

(1) Terms refer to coded factors, -1, 1.

(2) Non-significant terms (Prob>F>0.05) are in italics.

Table 9.11
Effects Test of Model Using Stepwise Analysis

Source (1)	Abbr.	No. of Parameters	Degrees of Freedom	Sum of Squares	F Ratio	Prob>F
Thickness	TH	1	1	343.07008	42.8182	<.0001
Styrene Content	SC	1	1	121.40408	15.1523	0.0013
<i>SC*GT=RF*AF</i>		<i>1</i>	<i>1</i>	<i>31.75200</i>	<i>3.9629</i>	<i>0.0639</i>

(1) Terms refer to coded factors, -1, 1.

(2) Non-significant terms (Prob>F>0.05) are in italics.

Table 9.12
Effects Table of Half-fractional Factorial Model

Source (t)	Abbr.	Estimate	Std Error	t Ratio	Prob> t
Intercept		51.540625	0.690705	74.62	<.0001
Thickness	TH	-4.3625	0.683621	-6.38	0.0004
Styrene Content	SC	2.65	0.683621	3.88	0.0061
SC*GT=RF*AF		-1.159375	0.690705	-1.68	0.1371
SC*RF=GT*AF		1.021875	0.690705	1.48	0.1826
Gel Time	GT	-0.835417	0.674059	-1.24	0.2551
Air Flow	AF	0.8125	0.683621	1.19	0.2734
GT*RF=SC*AF		-0.753125	0.690705	-1.09	0.3117
TH*RF		0.540625	0.690705	0.78	0.4595
TH*AF		-0.409375	0.690705	-0.59	0.5720
Resin Flow	RF	0.3729167	0.674059	0.55	0.5973
TH*SC		-0.203125	0.690705	-0.29	0.7772
TH*GT		0.021875	0.690705	0.03	0.9756

Table 9.13
Effects Table for Optimized Gel Coat Spray-up Model

Term	Abbr.	Estimate	Std Error	t Ratio	Prob> t
Intercept		51.65	0.632939	81.60	<.0001
Thickness	TH	-4.227083	0.645991	-6.54	<.0001
Styrene Content	SC	2.5145833	0.645991	3.89	0.0013
SC*GT=RF*AF		-1.26	0.632939	-1.99	0.0639

Table 9.14
Summary of Fit Comparison for Non-scaled Experimental Variables

	<u>Equation 8.5a</u>	<u>Equation 8.5b</u>
R ²	0.807529	0.790891
R ² _{adj}	0.771441	0.751683
R ² - R ² _{adj}	0.036088	0.039208
Mean of Response	51.65	51.65
No. of Observations	20	20
Prob>F for:		
Thickness	<0.0001	<0.0001
Styrene Content	0.0039	0.0022
SC*GT	0.1536	-----
RF*AF	-----	0.3866

Figure 9.5
Main Effects Plots

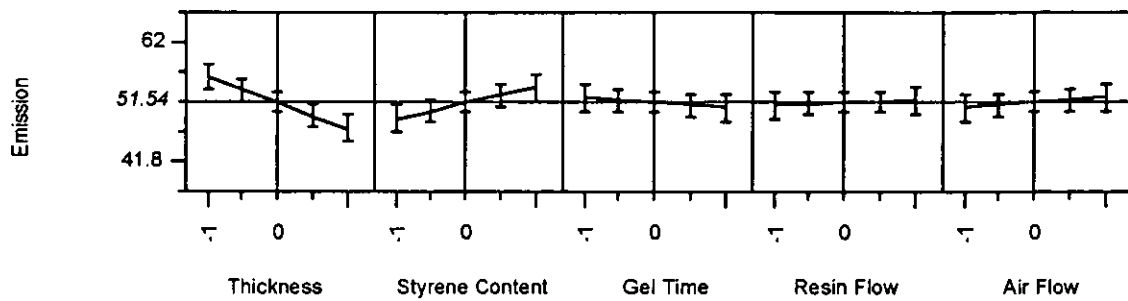


Figure 9.6
Interaction Plots

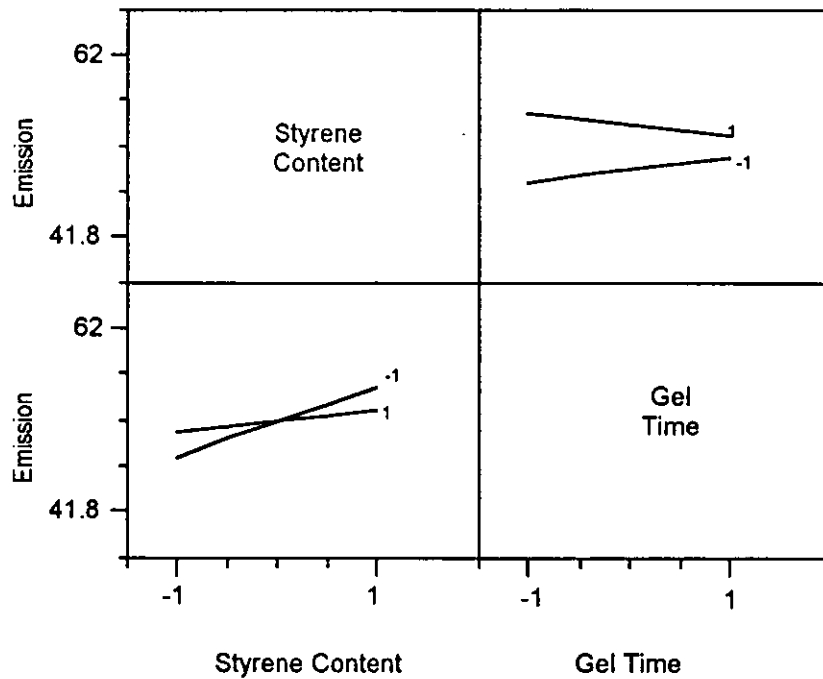


Table 9.15a
Summary of Fit

	Half-fractional	
	<u>Factorial</u>	<u>Refined Model</u>
R^2	0.916212	0.824102
R^2_{adj}	0.772576	0.791122
$R^2 - R^2_{adj}$	0.143642	0.032980
Root Mean Square Error	2.953579	2.830591
Mean of Response	51.65	51.65
Observations (or Sum Wgts)	20	20

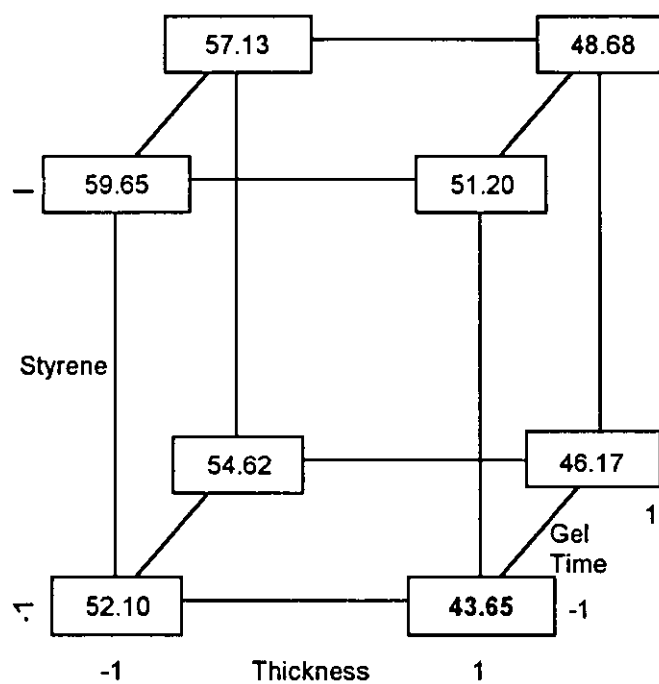
Table 9.15b
One-way Analysis of Variance Table

<u>Source</u>	<u>DF</u>	<u>Sum of Squares</u>	<u>Mean Square</u>	<u>F Ratio</u>
Model	3	600.61408	200.205	24.9873
Error	16	128.19592	8.012	<u>Prob>F</u>
Total	19	728.81000		<.0001

Table 9.15c
Lack-of-Fit Table

<u>Source</u>	<u>DF</u>	<u>Sum of Squares</u>	<u>Mean Square</u>	<u>F Ratio</u>
Lack of Fit	4	30.67425	7.66856	0.9436
Pure Error	12	97.52167	8.12681	<u>Prob>F</u>
Total Error	16	128.19592		0.4720
				<u>Max RSq</u>
				0.8662

Figure 9.7
Cube Plot of Predicted Emission Response



9.4 Evaluation of Results from the Laminate Spray-up Study

Use of the chopper-gun spray method results in about 25% of the available styrene being lost. The minimum emission was 16.1% which occurred under the conditions of thick laminate (0.080"), low resin flow (2 lb/min), and low styrene content (35%). The highest emission of 38.0% occurred with a thick laminate (0.080"), low resin flow (2 lb/min), and high styrene content (42%). Styrene content and resin flow were found to be the most significant factors and thickness was indicated to be a smaller contributor. The two-factor interaction, of styrene content*resin flow (confounded with gel time*air flow) was found to be significant in this analysis. The model equation derived from this evaluation explains about 89.3% of the variation.

The goal of running two experiments per day could not be met. The blocking scheme of ten blocks now became thirteen blocks with six of those blocks being single runs. An effective evaluation of blocking effects could not be done. The data was analyzed and the model was developed from evaluation of the half-fractional factorial design.

9.4.1 Evaluation of the Model: Effects Table

The initial evaluation of the main effects with blocking showed no clear-cut resolution of factors as shown in Table 9.16. The blocking scheme from the experimental runs are given in Table 9.17 and six of the experiments were run individually during a day. Due to the lack of organized blocks, the data was evaluated as a half-fractional factorial design.

Table 9.18 is the summary of effects data for a half-fractional factorial analysis. Using the criteria of 95% level then indicate that styrene content, resin flow, and either the SC*RF or AF*GT interactions are significant. Thickness, a significant factor in previous studies does not appear to have the same degree of contribution to emission in this study. However during the stepwise process of refining the model, the laminate thickness will play a role in optimization of the model as will be shown.

Refinement of the model from the stepwise analysis yielded a proposed model which include styrene content, resin flow, their interaction, and thickness as the significant terms. A summary of the effects test is presented in Table 9.19. The optimized model includes thickness although it was a less significant term. The two-factor interaction of SC*RF is thought to be the main interaction over its correlated term AF*GT, for the same reasons as mentioned in the previous section for the Gel Coat Study. A probable reason for the interaction is the spray aerosol could be a significant source of styrene emission. The emission from the spray droplet depends on such factors such as drop diameter, surface tension, liquid viscosity, liquid density, and volumetric flow rate². Each of these factors depends to some degree on either the styrene content or the resin flow.

9.4.4 Evaluation of the Model: Prediction and Interaction Profiles

The refined model equation using the scaled variables is defined as follows:

$$\text{Emission} = 25.02 + 5.22*SC - 2.02*RF - 1.09*TH - 2.35*SC*RF \text{ (Eqn. 9.6a).}$$

Converting the model to the use of unscaled terms yields the following equation:

$$\text{Emission} = -93.83 + 3.31 \cdot \text{SC}' + 21.60 \cdot \text{RF}' - 0.0528 \cdot \text{TH}' - 0.61 \cdot \text{SC}' \cdot \text{RF}' \quad (\text{Eqn. 9.6b}).$$

Both of the above models have regression coefficients of 0.892812 indicating that 89.2% of the variation may be explained by use of the above model equations as shown in the summary of fit in Table 9.22a. Substitution of the SC'*RF' interaction with the AF'*GT' interaction resulted in a model with a regression coefficient of 0.813226 and the interaction term itself was less significant (Prob>F was 0.1660). The SC'*RF' interaction is then assumed to be the two-factor interaction to interpret the model.

Figure 9.8 contains the Main Effects Plot illustrating the overall impact of the factors on the emission. The interaction plot in Figure 9.9 illustrates the degree of the interaction between the resin flow and styrene content.

9.4.6 Evaluation of the Model: Lack-of-Fit Testing

The ANOVA in Table 9.22b further verifies the significance of the that the factors have a significant effect on the variation. The data summarized in Table 9.22c indicates no significant lack of fit which gives additional support to the validity of the model.

9.4.7 Evaluation of the Model: Cube Plot

Figure 9.10 is the Cube Plot of the predicted data for the Spray-up study. The face of the cube at low thickness appears to be the region of minimum emission. The corners of the face of the cube at low resin flow show the extremes of the styrene emission.

Table 9.16
Effect Test of Spray-up Study of Main Effects With Blocking

Source (1)	Abbr.	No. of Parameters	Degrees of Freedom	Sum of Squares	F Ratio	Prob>F
<i>Thickness</i>	<i>TH</i>	<i>1</i>	<i>1</i>	<i>0.00083</i>	<i>0.0001</i>	<i>0.9927</i>
<i>Styrene Content</i>	<i>SC</i>	<i>1</i>	<i>1</i>	<i>34.85021</i>	<i>5.4397</i>	<i>0.2579</i>
<i>Gel Time</i>	<i>GT</i>	<i>1</i>	<i>1</i>	<i>4.72033</i>	<i>0.7368</i>	<i>0.5484</i>
<i>Resin Flow</i>	<i>RF</i>	<i>1</i>	<i>1</i>	<i>30.10008</i>	<i>4.6982</i>	<i>0.2752</i>
<i>Air Flow</i>	<i>AF</i>	<i>1</i>	<i>1</i>	<i>0.40833</i>	<i>0.0637</i>	<i>0.8426</i>
<i>Data ID</i>		<i>13</i>	<i>13</i>	<i>168.04836</i>	<i>2.0177</i>	<i>0.5061</i>

(1) Terms refer to coded factors, -1, 1.

(2) Non-significant terms (Prob>F>0.05) are in italics.

Table 9.18
Dates of Runs for Evaluation of Blocking Effects

Run No.	Date
1	111595
2	111695
3A	111695
4A	112895
5	112895
6	112995
4B	112995
3B	113095
7	120495
8	120595
9	120695
10	120695
11A	120795
12A	120895
13	120895
14	121495
11B	121195
12B	121295
15	121295
16	121495

Table 9.18
Effect Test of Spray-up Study as a Half Fractional Factorial Design

Source (1)	Abbr.	No. of Parameters	Degrees of Freedom	Sum of Squares	F Ratio	Prob>F
Styrene Content	SC	1	1	509.26339	78.0061	<.0001
SC*RF=GT*AF		1	1	100.98286	15.4680	0.0057
Resin Flow	RF	1	1	78.08533	11.9607	0.0106
<i>Thickness</i>	<i>TH</i>	<i>1</i>	<i>1</i>	<i>22.00381</i>	<i>3.3704</i>	<i>0.1090</i>
<i>SC*GT=RF*AF</i>		<i>1</i>	<i>1</i>	<i>14.00000</i>	<i>2.1444</i>	<i>0.1865</i>
<i>TH*AF</i>		<i>1</i>	<i>1</i>	<i>9.12071</i>	<i>1.3971</i>	<i>0.2758</i>
<i>Gel Time</i>	<i>GT</i>	<i>1</i>	<i>1</i>	<i>8.32133</i>	<i>1.2746</i>	<i>0.2961</i>
<i>GT*RF=SC*AF</i>		<i>1</i>	<i>1</i>	<i>6.17786</i>	<i>0.9463</i>	<i>0.3631</i>
<i>TH*SC</i>		<i>1</i>	<i>1</i>	<i>5.40643</i>	<i>0.8281</i>	<i>0.3931</i>
<i>TH*RF</i>		<i>1</i>	<i>1</i>	<i>2.74571</i>	<i>0.4206</i>	<i>0.5373</i>
<i>TH*GT</i>		<i>1</i>	<i>1</i>	<i>0.64286</i>	<i>0.0985</i>	<i>0.7628</i>
<i>Air Flow</i>	<i>AF</i>	<i>1</i>	<i>1</i>	<i>0.58339</i>	<i>0.0894</i>	<i>0.7737</i>

(1) Terms refer to coded factors, -1, 1.

(2) Non-significant terms (Prob>F>0.05) are in italics.

Table 9.19
Effects Test of Model Using Stepwise Analysis

Source (1)	Abbr.	No. of Parameters	Degrees of Freedom	Sum of Squares	F Ratio	Prob>F
Styrene Content	SC	1	1	517.92075	84.2648	<.0001
SC*RF=GT*AF		1	1	91.16450	14.8323	0.0016
Resin Flow	RF	1	1	71.06450	11.5621	0.0040
<i>Thickness</i>	<i>TH</i>	<i>1</i>	<i>1</i>	<i>21.42075</i>	<i>3.4851</i>	<i>0.0816</i>

(1) Terms refer to coded factors, -1, 1.

(2) Non-significant terms (Prob>F>0.05) are in italics.

Table 9.20
Effects Table of Half-fractional Factorial Model

Source (1)	Abbr.	Estimate	Std Error	t Ratio	Prob> t
Intercept		25.01875	0.597518	41.87	<.0001
Styrene Content	SC	5.2232143	0.591389	8.83	<.0001
SC*RF=GT*AF		-2.35	0.597518	-3.93	0.0057
Resin Flow	RF	-2.016667	0.583118	-3.46	0.0106
Thickness	TH	-1.085714	0.591389	-1.84	0.1090
SC*GT=RF*AF		-0.875	0.597518	-1.46	0.1865
TH*AF		0.70625	0.597518	1.18	0.2758
Gel Time	GT	-0.658333	0.583118	-1.13	0.2961
GT*RF=SC*AF		0.58125	0.597518	0.97	0.3631
TH*SC		0.54375	0.597518	0.91	0.3931
TH*RF		-0.3875	0.597518	-0.65	0.5373
TH*GT		-0.1875	0.597518	-0.31	0.7628
Air Flow	AF	0.1767857	0.591389	0.30	0.7737

Table 9.21
Effects Table for Optimized Laminate Spray-up Model

Term	Abbr.	Estimate	Std Error	t Ratio	Prob> t
Intercept		24.935	0.554362	44.98	<.0001
Styrene Content	SC	5.19375	0.565794	9.18	<.0001
SC*RF=GT*AF		-2.135	0.554362	-3.85	0.0016
Resin Flow	RF	-1.885	0.554362	-3.40	0.0040
Thickness	TH	-1.05625	0.565794	-1.87	0.0816

Figure 9.8
Main Effects Plots

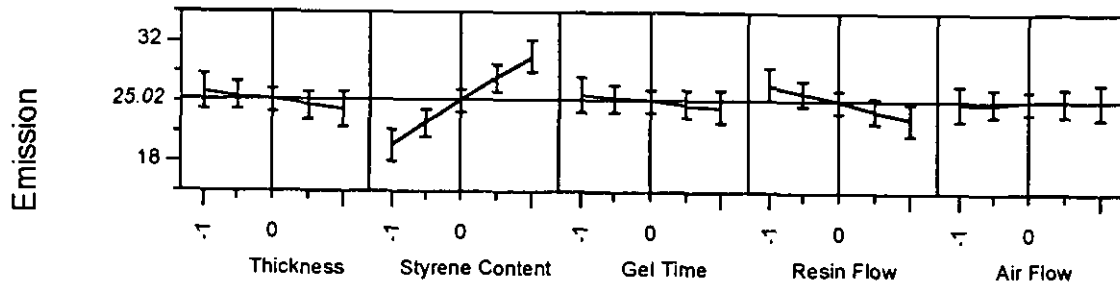


Figure 9.9
Interaction Plots

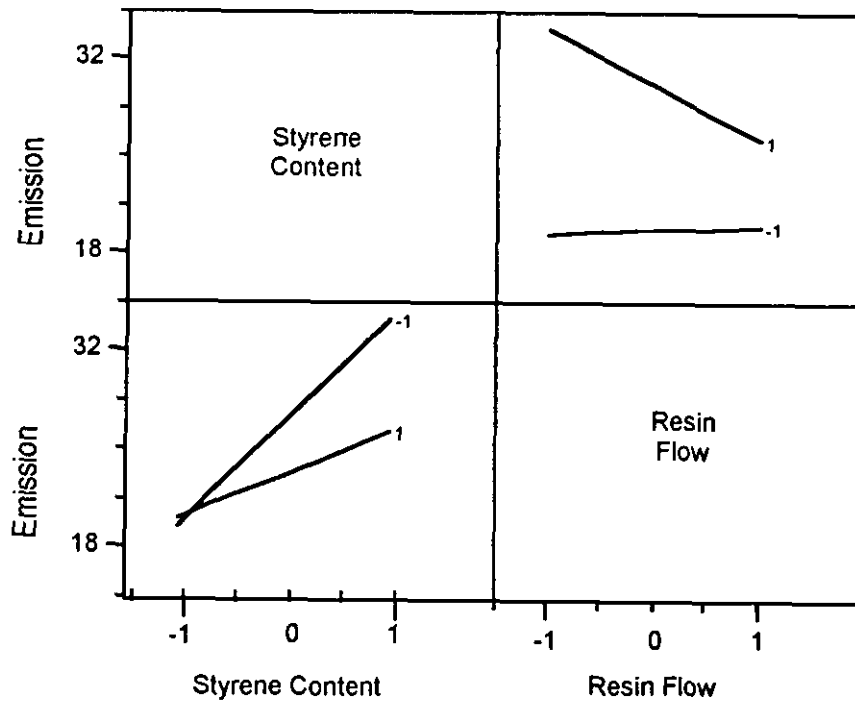


Table 9.22a
Summary of Fit

	Half-fractional	Scaled	Unscaled	Unscaled
	<u>Factorial</u>	<u>Refined Model</u>	<u>Refined Model</u>	<u>Model with</u>
				<u>AF*GT Term</u>
RSquare	0.946869	0.892812	0.892812	0.813226
RSquare Adj	0.855787	0.864228	0.864228	0.763419
Root Mean Square Error	2.555094	2.479183	2.479183	3.272608
Mean of Response	24.935	24.935	24.935	24.935
Observations				
(or Sum Wgts)	20	20	20	20

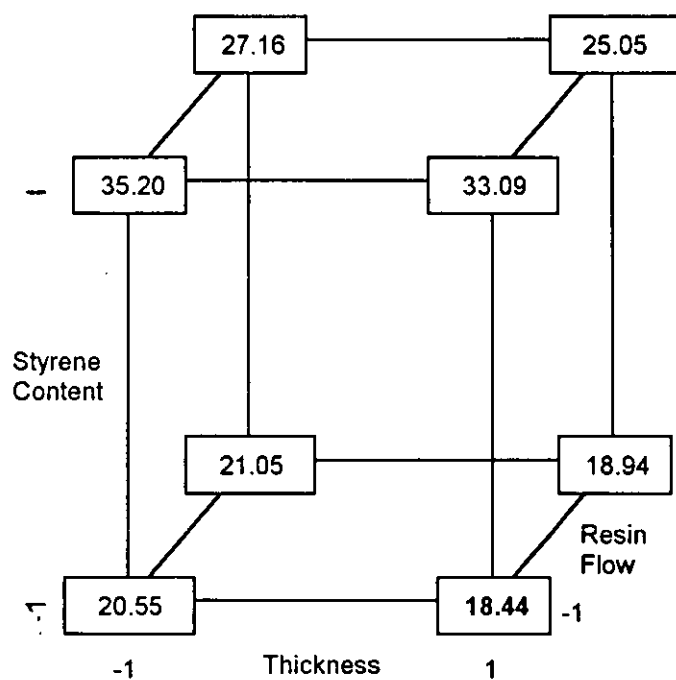
Table 9.22b
One-way Analysis of Variance Table

<u>Source</u>	<u>DF</u>	<u>Sum of Squares</u>	<u>Mean Square</u>	<u>F Ratio</u>
Model	4	767.93025	191.983	31.2352
Error	15	92.19525	6.146	<u>Prob>F</u>
Total	19	860.12550		<.0001

Table 9.22c
Lack-of-Fit Table

<u>Source</u>	<u>DF</u>	<u>Sum of Squares</u>	<u>Mean Square</u>	<u>F Ratio</u>
Lack of Fit	4	30.67425	7.66856	0.9436
Pure Error	12	97.52167	8.12681	<u>Prob>F</u>
Total Error	16	128.19592		0.4720
				<u>Max RSq</u>
				0.8662

Figure 9.10
Cube Plot of Predicted Emission Response



9.5 Data Analysis Conclusions

The analysis given in this section demonstrate that statistical design of experiments are a useful tool for the isolation and characterization of factors affecting styrene emission for open mold techniques. Each of the three open mold methods studied showed significant factors somewhat unique to the respective method.

Factors most significant in the hand lay-up study consisted of laminate thickness, styrene content, and gel time. The control of these factors are most important in defining methods to control the emission of the molding technique. Of the three molding methods studied, the hand lay-up method had the lowest emission of available styrene. Also because blocking was not found to be a significant factor, this study had the full-factorial design and all main effects and interactions could be resolved. A refined model using the terms of the interactions was developed to potentially predict the behavior of the system.

The gel coat spray method was found to lose as much as half of the available styrene. Thickness and styrene content were found to possess the most significant roles in the emission behavior. The results from this study did not have the same precision as the previous study possibly due to the variability of the spray technique and variation in the thin laminate may have a greater relative error. This study did not have the full resolution of the interactions, however, a predictive model was proposed for future testing.

The laminate spray-up study had styrene content and resin flow as the significant main effects. A two-factor interaction, most likely the one between these two main effects was also found to be significant. Thickness was found to have a role in the refined model but did not have the same significance as in the previous two studies. A model equation developed from this study should be a good prediction tool based on the lack-of-fit and regression analysis.

In all three studies, styrene content was consistently a major factor. Laminate thickness had exhibited some type of role to varying degrees in the model. Air flow was not found to make a significant contribution to the emission behavior in any of the studies. An argument may be made that the air flow rates did not span a wide enough range to be able to detect its effect. However, this range was chosen as what is typical and practical for current practice in the industrial shop. A wider range of air flow rates may however be considered for a future study. For expeditious results in the short-term, those factors already found to be significant should be the higher priority for study and control. When the styrene content, thickness and (where applicable) resin flow and gel time can be optimized and controlled, then a better possibility exists for more precisely characterizing the effect of the air flow rate.

9.6 Acknowledgments

The author wishes to acknowledge Jeffery Sweeney, Daniel Obermiller, Dr. Stanley Deming, Perry Regier, and John Skewes for their contributions and insights on the use of statistics and statistical experimental design in the project planning and data analysis.

9.7 References

- 1) "CFA Open Molding Styrene Emissions Test Project," Composite Fabricators Association/Dow Chemical, Freeport, Texas, Revision 4.0, August 18, 1995. Section 13.0
- 2) Porter, Harold F, G. A. Schurr, D. F. Wells, K. T. Semrau, "Solids Drying and Gas-Solids Systems," Perry's Chemical Engineers' Handbook, 6th ed., D. W. Green, editor, McGraw-Hill, New York, 1984. Chapt. 20, pg. 56ff.

Section 10.0

Determination of Styrene Emissions

10.1 Emission Measurement Methods

The objective of the experiments was to quantify styrene emissions from each of the three processes. Measurements were taken with a Varian 3700 gas chromatograph (GC), equipped with a flame ionization detector and a Thermo Environmental Instruments, Inc. Model 51 heated Total Hydrocarbon Analyzer (THA), using EPA Method 25A. The gas chromatograph was configured to cycle samples every 120 seconds, whereas the Total Hydrocarbon Analyzer provided continuous measurement capability. Both analytical units used sample probes in the form of pitot tubes in the enclosure exhaust duct. The THA sample probe is a "rake" type pitot tube having three (3) sample points. The sample points are a hole located in the center of the duct and two holes located 10% of the duct diameter from the edge of the duct. The GC sample point is a "S" type pitot tube located in the center of the duct.

The GC signal output is linked to a Hewlett-Packard Integrator, which provides a printed copy of data during the 120 second sample cycle. The continuous THA measurements are linked to a Dow Camille® Data Acquisition System. The Camille® system records data points at 1 second intervals (2 second interval data was stored to a floppy disk). In addition the Camille® system allows real time viewing of the incoming data.

10.1.1 THA Sampling Procedure

The THA sampling procedure was consistent with EPA Method 25A - Determination of Total Gaseous Organic Concentrations Using a Flame Ionization Analyzer. The following changes were made to Method 25A:

1. The acceptable accuracy for checking calibration with the 80% span gas standard was $\pm 10\%$ from the predicted response.
2. There were no checks on the THA accuracy during actual data collection.
3. The calibration of the THA was verified using the low span, mid-span and the 80% span gas before the first run of the day. The calibration was checked before the second run of the day using the mid-span calibration gas. The THA was recalibrated, if necessary for the second run; however, the previous test may not have been invalidated, depending on the values obtained by secondary measurements.
4. Only one detection range was used during each test study. The detection range was spanned to cover styrene emissions from 0-350 ppm for the resin batch application study, 0-500 ppm for the gel coat spray application study, and 0-1000 ppm for the resin spray application study.
5. 100% Hydrogen was used as a fuel gas.

10.1.2 Standardization of the THA

At the outset of the project, styrene-in-air gas standards were used to calibrate the THA and GC. These gas standards were found to be unstable, with resulting drifts in concentrations. At the recommendation of EPA and RTI, the styrene gas standards were replaced with propane standards, following the hand lay-up study. Prior to starting the gel coat study the propane-to-styrene correction factor was determined to be 0.453 for the THA. Two styrene mass balance checks yielded recoveries around 95% using the determined correction factor.

10.1.3 GC Sampling Procedure

A Varian 3700 gas chromatograph equipped with a flame ionization detector was used. The gas chromatograph sampling valves were controlled by a Camille® software system, and data was output to a Hewlett Packard 3392A integrator.

The GC conditions were as follows:

Gas Chromatograph Set-Up:

Oven Temperature = 90°C

Detector Temperature = 250°C

Sample Valve Injector = 90°C (located in gas chromatograph oven)

Gas Pressures:

Flame Ionization Detector:

Low pressure side of gas regulators

Air = 40 psig

Hydrogen = 40 psig

Column:

Helium = 40 psig

Column Identification:

10 m X 0.53 mm Bonded FSOT RSI-300

1.2 µm Polyphenyl Methysiloxane

(Megabore capillary column - 0.53 mm ID)

Column Gas Flow:

Helium = 4 ml/min. (no split)

10.1.4 Gas Chromatograph Standardization

- (1) An appropriate styrene gas standard was run until the area response for the styrene peak was consistent. A styrene gas standard for the THA was available to check data consistency between the GC and THA, if deemed necessary.
- (2) The Hewlett Packard Integrator was then re-calibrated to this response factor for styrene. Another standard analysis was run to assure consistent measurements.

10.1.5 Gas Chromatograph Sample Analysis

- (1) The GC was standardized at the beginning of each day with calibrated gas sample(s).
- (2) The analysis system was put into the sampling mode prior to resin being introduced into the test chamber. An ambient baseline of styrene concentration was established at this point. Typical baseline readings were <2.0 ppm.
- (3) The analysis system took a sample of air from the TTE exhaust stack ducting every two (2) minutes for gas chromatographic analysis. The gas sample was moved to the sample valve by a vacuum air aspirator.
- (4) The analysis system continued to take air samples throughout the experiment until styrene levels dropped to the original baseline level, at which time the sample sequence was stopped.
- (5) The analysis system is then standardized to determine if calibration was valid during sampling period.

10.2 Mass Balance Styrene Recovery Check

A mass balance calibration was conducted prior to each of the three experimental group runs. The THA and GC were calibrated according to previously described procedures. Styrene was evaporated from a shallow pan having an absorbent media hanging over the pan and extending down into the liquid styrene. An auxiliary fan was used to enhance evaporation. The input weight of the styrene was compared to the calculated weight based on the average ppm recorded by the THA and the GC. The percent styrene recovery was greater than 95%, eight out of ten checks. The two recovery checks below 95% were 81.6% (hand lay-up) and 94.7% (gel coat).

10.3 Leak Checks for Sample Lines

Leak checks were performed at the beginning of each week of testing. All fittings, valves and connections of the THA and GC were examined. A valve just down stream from each sample port was closed off while a sample was being drawn to a detector. The ball in a in-line flow meter would drop to zero if no leaks were in the sample line.

10.4 Air Flow Through the TTE Calibration

The method used to determine the air flow through the TTE is similar to that described in EPA 40 CFR Method 1, Ch. 1. An Airdata Multimeter Electric Micromanometer was used to determine the air flow through the TTE each Monday during test runs. The Airdata

Multimeter Electric Micromanometer was set to perform as a pitot tube. Traverse readings were taken one inch from each side of the duct wall and in the middle of the duct. At each position, three air flow measurements were taken and averaged. The resulting six averaged reading values were then averaged to determine the air flow through the TTE.

Early in the study a calibration error was found in the Vortek air flow sensor data output circuit. This resulted in an inaccurate stack air flow reading. The problem was remedied with the replacement of the sensor circuit board. All data collected prior to that time was re-calculated to the correct air flow values. The air flow through the TTE was determined to be 1470 cfm.

The Camille® data collection system was calibrated by Dow instrumentation technicians to output the air flow as 1470 cfm. A VorTek™ velocity sensing system automatically maintained that air velocity throughout the study. The air flow measurements obtained throughout the study were within ± 100 cfm of the initial air flow of 1470 cfm. No adjustments were made to the Camille® data collection system.

During the course of the testing the stack air flow was continuously monitored and re-calibrated as deemed necessary. A manometer reading was recorded at the beginning and end of each test run. If a change of ± 0.05 inches of water was noted from the initial reading (approximately 0.1 inches of water) at the time of initial air flow calibration, the air flow through the TTE was to be re-calibrated.

Section 11.0

Determination of Styrene Emission Quantities

11.1 Total Styrene Emissions Calculation

The total styrene emissions for each test run was determined as shown in the equation listed below.

Calculation for Total Styrene Emissions:

Total Styrene Emissions, lbs. =

$$\text{Average styrene emissions in cc/m}^3 \text{ (ppm)} \times \text{Air flow in m}^3/\text{min.} \times \text{Time (min.)} \times 104 \text{ g/mole} \\ 24.45 \text{ l/mole} \times 1000 \text{ cc/l} \times 454 \text{ g/lb}$$

- a.) The Average styrene emissions are determined from the total number of styrene emission readings obtained during the actual test run. The Average styrene emissions were determined in this manner for both the THA and GC.
- b.) Air flow is the value of 1470 cfm multiplied by a conversion factor (0.0283) to obtain air flow in m³/min.
- c.) 104 g/mole is the molecule weight of one mole of styrene.
- d.) 24.45 l/mole is the volume occupied by one mole of styrene in the gaseous phase at the test sites pressure and temperature.

11.2 Percent Styrene Emissions Based on Available Styrene

The percent styrene emissions based on available styrene for each test run was determined as shown in the equation listed below.

Calculation for percent styrene emissions based on available styrene:

$$\text{Percent styrene emissions} = \frac{\text{Total Styrene Emissions, lbs.} \times 100}{\text{Total Resin Used, lbs.} \times \text{Percent Styrene in Resin}}$$

11.3 Resin/Gel Coat Weight

Resin/gel coat weight was recorded immediately before resin/gel coat application and upon completion of application to the mold. The weight was measured with a calibrated balance with the calibration documentation available. The precision of the balance is ± 0.002 lbs. with a capacity greater than 100 pounds.

Section 12.0

Equipment Calibration

12.1 THA and GC Calibration

The calibration of the THA and GC are discussed in Section 10.0.

12.2 Spray Equipment Calibration

The spray equipment flow rate was calibrated to provide a specific resin and gel coat output as required by the experimental design. In the case of the spray-up application, the glass content was adjusted to the required resin flow rate. The flow rate calibration consisted of spraying resin into a pre-weighed container for 15 seconds and recording the material weight in lbs/min. The resin pump pressure was adjusted and spray tip sizes changed to achieve the specified flow rate.

For the spray-up experiments the calibration consisted of capturing both resin and chopped glass for 15 seconds, in separate containers, and weighing individually to determine the resin to glass ratio. Once the flow rate was established, the chopper speed was adjusted to provide the proper glass ratio.

Resin/gel coat to catalyst ratio was calibrated by means of catalyst volume measurement compared to flow rate. The catalyst ratio was adjusted by the slave pump setting.

The spray equipment calibration was checked before each test run.

12.2.1 Spray Gun's Flow Rate Calibration

- 1.) Spray tip was selected with specific orifice size and fan angle.
- 2.) Catalyst pump was disconnected.
- 3.) Atomizing air was shut off.
- 4.) Spray unit was charged with a specific resin or gel coat.
- 5.) Air was purged from the system and material flow was checked to verify that the cleaning solvent had been fully purged from fluid lines.
- 6.) Pump pressure was set to anticipated pressure.
- 7.) Analytical balance was tared.
- 8.) Container tare weight was recorded.
- 9.) Resin/gel coat was sprayed into container for a timed 15 seconds.
- 10.) Resin/gel coat weight and pressure setting were recorded.
- 11.) Pump pressure was adjusted to modify flow rate, if needed.
- 12.) Steps 8 -10 were repeated to produce the required flow rate within ± 0.3 lb/min.
- 13.) Two flow rate checks were made once final adjustments were made.

12.2.2 Catalyst Flow Rate Calibration

- 1.) Spray unit was charged and resin/gel coat flow rate calibration was completed as described in 6.4.1.

- 2.) The 250-ml graduated cylinder serving as the catalyst reservoir was filled with the catalyst to specified volume.
- 3.) The catalyst pump was positioned to the appropriate setting.
- 4.) The separator tip was mounted on the spray gun.
- 5.) The spray gun was activated for 15 seconds.
- 6.) The reduction in catalyst volume in the graduated cylinder was recorded.
- 7.) The catalyst pump setting was adjusted to modify flow rate.
- 8.) Steps 5-7 were repeated to produce the required flow rate yielding the specific gel time.
- 9.) The specific gravity of the catalyst was used to convert volume to mass. The specific gravity was obtained from the catalyst supplier specifications.

12.2.3 Chopper Gun Calibration - Resin:Glass Ratio

- 1.) Spray gun rate calibration and catalyst calibration are completed.
- 2.) Continuous strand roving was fed to the chopper and unit was initialized.
- 3.) Chopper unit air pressure was set to anticipated level.
- 4.) A pre-weighed plastic bag was placed over the chopper chute and another pre-weighed plastic bag was placed over the spray tip.
- 5.) The spray gun was activated for 15 seconds.
- 6.) The bag containing dry chopped glass and the bag containing sprayed resin were weighed and recorded separately.
- 7.) The chopper unit air pressure was adjusted to modify chopped glass output in relation to resin output.
- 8.) Steps 5 - 7 were repeated to produce the specified resin to glass ratio.

12.3 Balances Calibration Check

12.3.1 Lab Balance for Resin/Gel Coat % Solids

- 1.) The balance is calibrated semi-annually by an approved outside vendor utilizing NIST traceable standards and documented procedures.
- 2.) Internal adjustments are only made by a qualified repair technician.
- 3.) The vendor responsible for checking the balance's calibration is the Aldinger Company, Dallas, TX.

12.3.2 Balance for Resin Weight During Spray-Up and Hand Lay-Up

- 1.) A Sartorius balance model F61S was used.
- 2.) The balance upon arrival at the test site was calibrated by an approved outside vendor utilizing NIST traceable standards and documented procedures.
- 3.) Internal adjustments were only made by a qualified repair technician.
- 4.) The vendor responsible for checking the balance's calibration is the Aldinger Company, Dallas, TX.
- 5.) The balance is calibrated semi-annually by an approved outside vendor utilizing NIST traceable standards and documented procedures.

12.4 Gel Timer Calibration Check

Calibration check procedure for the Sunshine Gel Timer is as follows:

- 1.) Obtain a NIST traceable stopwatch.
- 2.) Press the "ON" button to the NIST stopwatch and Gel Timer simultaneously.
- 3.) Let the NIST traceable stopwatch and gel timer run for 15 minutes $\pm$ 5 seconds.
- 4.) When the time is up, simultaneously stop the NIST traceable stopwatch and the gel timer.
- 5.) Record the time displayed by the gel timer.
- 6.) The time displayed by the gel timer must be 15 minutes $\pm$ 15 seconds in order to meet acceptance criteria.
- 7.) The frequency of calibration check is "at the time of use or monthly, whichever is greater."

12.5 Thermometer for Constant Temperature Water Bath Calibration Check

- 1.) Immerse the probe of a NIST digital thermometer to the same depth as the probe of the thermometer for the constant temperature water bath.
- 2.) Wait one minute for temperature readings to stabilize.
- 3.) Compare the temperature readings of both thermometers.
- 4.) Acceptance criteria is a difference in temperature from the NIST thermometer of no greater than $\pm$ 5 °F.
- 5.) Frequency of calibration check is "At time of use or monthly, whichever is greater".

Section 13.0

Quality Assurance

13.1 QA Project Activities

A massive amount of data has been collected during the course of this project, and overall the data quality has met or exceeded the criteria in the Category II quality assurance project plan (QAPP). Refinements and adjustments were made to the operating system during the early stages of the project. These modifications were a result of an increasing proficiency and understanding of the testing system and of quality audits. Throughout this period data quality remained within quality standards. QA activities for this project are presented in the sections that follow. Additional information is provided in Appendixes.

The Category II quality assurance project plan, *Quality Assurance Project Plan for the Composites Fabricators Association Open Molding Styrene Emissions Testing Project*, was prepared by the Project Team and submitted to EPA in September, 1995, for approval prior to the start of the proposed testing. The QAPP is included in Appendix.

In September, 1995, Ms. Shirley Wasson (EPA) and Mr. Emery Kong (RTI) conducted both a technical systems and performance audits. Topics of examination included stack air flow rate and calibrations using styrene gas standards. The value for the volumetric air flow measured during the audit was not the value entered into the Camille system within the ± 100 cfm QA objective in the QA project plan. The styrene mid-range calibration checks did not meet the $\pm 10\%$ criteria by the QA plan. Corrections were made for the air flow rate and calibration of the total hydrocarbon analyzer.

Note: However, the performance audit in September showed that the response of the THC analyzer to the 31 ± 0.62 ppm audit standard met the data quality goal of $\pm 10\%$, despite calibration difficulties. The mid-range calibration check of the THC analyzer did not meet the criteria of the QAPP. Calibration was performed with zero air, and span was set with an IWECO styrene standard of 280 ± 5.6 ppm. A mid-range standard of 175 ± 1.8 ppm was analyzed and found to be 196 ppm, 12% greater than its true value. The QAPP criteria for accuracy of the midrange standard check is 10%. Despite the calibration difficulties, the audit styrene gas was accurately analyzed within 3.9% of its true value.

A second performance audit was conducted by Mr. Emery Kong, of RTI, on behalf of the EPA between November 13 and 14, 1995, at the Dow Chemical test site prior to the resin spray-up experiment. The audit included verification of the exhaust flow rate from the enclosure and the performance of the Thermal Environmental Instruments, Inc., Model 51 THC analyzer. The verification showed that the average exhaust flow rate was at 1474 cfm, which was in agreement with the Camille system readout, and the propane-to-styrene conversion was 0.4355, which is similar to 0.453 that Dow personnel determined earlier. The results of this audit indicate that the Dow and CFA personnel have made substantial improvement on their styrene emission measurement and exhaust flow rate measurement and these two critical measurements were within the accuracy specified in their Category II quality assurance project plan. See audit report in Appendix. Shirley Wasson, in a letter dated November 21, 1995, stated, "The slope ratio calculated by (Emery Kong) at 0.4355 is

about 96% of the slope ratio calculated by you, therefore either may be used as the conversion factor since they are not significantly different from one another." (See audit reports in Appendix).

13.2 Internal Audit

The audit found that the QAPP has been conducted by operating personnel as described by the plan with calibration and emission values being well documented. However, there have been some variations to the QAPP as originally described. For the most part, these variations are a result of experience with the operation system compared to the procedures described before actual operating experience. They are as follows:

13.2.1) Total Hydrocarbon Analyzer Calibration Procedure

Exception to the $\pm 10\%$ response from the predicted response.

During the calibration checks for hand lay-up emission tests the following styrene standards were used: 175 ppm, 99 ppm, and 49 ppm.

About 75% of the time, including calibration checks and drift checks, the THA value for the 49 ppm standard was outside the $\pm 10\%$ specified required accuracy from the predicted response. The values outside the $\pm 10\%$ specification averaged 5.5 ppm; the maximum allowable being 4.9 ppm.

The testing was continued for the following reasons:

- a.) the THA, calibrated by the standards listed previously, when used to check a styrene standard provided by the EPA, yielded a value within ± 2 ppm from the stated concentration of 31 ppm styrene,
- b.) the THA, calibrated by the standards listed previously, yielded an approximate 95% recovery for the styrene mass balance checks performed before the hand lay-up part of the study,
- c.) the same standards were used when EPA and RTI personnel were present during the initial phase of testing. The EPA personnel suggested that propane standards be used in place of styrene standards since propane standards are essentially stable throughout their life.

[Note: Calibration of the THA was a subject of comment during the audit in September, 1995. The issue dealt with a new mid-range standard that did not read within the $\pm 10\%$ limits. The true concentration of the new standard was in question because the subsequent analyses of the standard audit gases were well within the $\pm 10\%$ limit. See pages 2 and 3 of the audit.]

- d.) and finally, the total styrene emissions per run obtained by the gas chromatograph compared quite favorably with those obtained by the THA.

13.2.2) Air Flow Through the TTE Calibration

Exception to method used to verify the air flow through the TTE

An Airdata Multimeter Electric Micromanometer was used to determine air flow through the TTE each Monday during test runs. The Airdata Multimeter Electric Micromanometer is set to perform as a pitot tube. Traverse readings are taken one inch from each side of the duct wall and in the middle of the duct. At each position, three air flow measurements were taken and averaged. The resulting six

averaged reading values were then averaged to determine the air flow through the TTE.

Early in the study, this method for determining air flow was performed in conjunction with air flow measurements taken by the EPA using a pitot tube. The two methods were found to be comparable at that time.

13.2.3) Section 3.1.5 Air Flow

Exception to verifying air flow prior to the start of individual studies.

The air flows over the mold were not verified before the hand lay-up study as described in Table 3.3, Quality Assurance Objectives for Critical and Non-Critical Measurements. However, prior to any testing, the dampers were adjusted and settings marked to maintain the required air flows over the mold.

After the hand lay-up study was complete and prior to the start of the gel coat study, the air flows were verified as described in Table 3.3. That verification was used for both the hand lay-up and gel coat study.

13.2.4) Section 6.1 Total Hydrocarbon Analyzer Calibration Procedure

Exception to using styrene standards for determining total styrene emissions.

At EPA's personnel recommendation, the styrene standards were replaced with propane standards after the hand lay-up portion of the study. Prior to starting the gel coat study the propane-to-styrene correction factor was determined to be 0.453 for the Thermo Environmental Instruments, Inc. Model 51 Total Hydrocarbon Analyzer. Two styrene mass balance checks yielded recoveries greater than 99% using the determined correction factor.

13.2.5) Section 6.4.1 Spray Gun's Flow Rate Calibration

Exception to calibrating the spray gun's flow rate prior to each gel coat test run.

The spray gun's flow rate was not checked for calibration during the first five gel coat test runs. However, the pressures and tip sizes required to obtain the desired flow rates for each gel coat used were determined prior to the gel coat study. These settings were used during the first five gel coat test runs. Subsequent gel coat test runs have had the spray gun's flow rate checked for calibration. All of the flow rates have been correct for all the gel coats at both flow rates used with no adjustments to the prior determined pressures and tip sizes. This is a strong indication that the spray gun's flow rates for the first five gel coat test runs were within the required limits.

Section 14.0

Data Quality

14.1 Precision

Four sets of duplicate runs were during each set of test runs. The relative percent difference from the mean for each set of duplicate runs was calculated.

$$\text{Relative Percent Difference} = \frac{|C1 - C2|}{m} (100),$$

from the Mean

Where **C1** and **C2** are the measured styrene emission values from duplicate runs, and **m** is the mean of the two measured styrene emission values.

The average relative percent difference from the mean and standard deviation was then determined from all of the duplicate runs in the three sets of test runs. Table 14.1.1 below lists the mean percent emissions from duplicate runs and the relative percent difference from the mean. The average relative percent difference from the mean, and standard deviation of the relative percent differences are shown in bold print below the table.

Table 14.1.1
Percent Emissions and Relative Percent Difference

Duplicate Test Runs	Mean Percent Emissions	Relative Percent Difference
Hand Lay-Up		
3 A and B	17.2	3.0
4 A and B	12.4	11.7
11 A and B	21.1	0.4
12 A and B	9.8	2.7
Gel Coats		
3 A and B	55.5	4.2
4 A and B	45.3	7.7
11 A and B	61.9	0.2
12 A and B	45.6	1.7
Resin Spray		
3 A and B	32.4	4.5
4 A and B	19.3	1.5
11 A and B	29.5	2.9
12 A and B	17.1	5.8

Average Relative Percent Difference = 3.9%
from the Mean
Standard Deviation = 3.3

14.2 Completeness

Completeness is as follows for all measurements:

$$\%C = \frac{V}{N} (100)$$

Where: %C = percent completeness

V = number of measurements executed

N = total number of measurements planned

Calculation for percent completeness:

$$\%C = \frac{60}{60} (100)$$

$$\%C = 100$$

14.3 Accuracy

Accuracy is expressed as the percent relative error from a value from a known standard:

$$\%RE = \frac{\mu - S}{S} (100)$$

Where: %RE = percent relative error

μ = measured value

S = standard value

The accuracy of the measurements made by the THA can be found the in the recovery tests performed throughout the study.

The percent relative error can be also be defined as follows:

$$\%RE = 100\% - PR$$

where PR = percent styrene recovery.

Table 14.3.1 below lists the percent styrene recovery and the percent relative error.

Table 14.3.1
Percent Styrene Recovery and Relative Error

	% Styrene Recovery	% Relative Error
Hand Lay-Up		
Run 1	81.6*	18.4
Run 2	99.7	0.3
Gel Coats		
Run 1	94.7	5.3
Run 2	99.8	0.2
Resin Spray		
Run 1	97.3	2.7
Run 2	96.7	3.3
Run 3	97.1	2.9
Run 4	95.3	4.7
Run 5	98.0	2.0
Run 6	95.1	4.9
AVERAGE	95.5	4.5

* Corrective action taken before experimental run

(1) Additional recovery checks were made during Mr. Emory Kong's audit of November 1995.

Section 15.0

Laboratory Procedures

15.1 % Resin Solids Determination Procedure (Styrene Content)

Determination of Non-Volatile Content

- 1.) Bring oven to temperature of $125 \pm 2^{\circ}\text{C}$ with a calibrated thermocouple.
- 2.) Zero the analytical balance, place an aluminum dish on the scale and record the weight.
- 3.) Tare the scale, weight out 0.42 ± 0.02 grams of resin sample with a transfer pipet and immediately record the weight.
- 4.) Repeat steps 1 and 2 for a replicate sample as this procedure requires duplicates.
- 5.) Dispense 2 milliliters of acetone into each dish and carefully swirl the solution around to dissolve all of the resin.
- 6.) Place both dishes into the catch pan and place them into a forced air heated oven.
- 7.) Set a alarm timer to 45 minutes and remove dishes at 45 ± 2 minutes after placement in the oven.
- 8.) Remove the samples from the catch pan and place on a paper towel to cool for at least 5 minutes.
Note: It is extremely important that the sample be removed at 45 minutes, otherwise the accuracy of the test may be significantly altered.
- 9.) Zero the analytical balance, place dish on the scale and record this weight.
- 10.) Calculate the % solids content as follows:

$$\% \text{ Solids} = \frac{\text{MS}_2 - \text{M}_d}{\text{MS}_1 - \text{M}_d} \times 100$$

Where,

MS₁, is the combined mass of the sample and dish before heating,

MS₂, is the combined mass of the sample and dish after heating, and;

M_d, is the tare weight of the dish.

15.2 Gel Time Procedure

- 1.) The promoted resin should be brought to $77 \pm 2^{\circ}\text{F}$ by use of a constant temperature water bath.
- 2.) Weigh 100 ± 1.00 grams of the promoted resin into a tared 4 oz. wide mouth bottle.
- 3.) Catalyze the promoted resin with the prescribed amount of catalyst. Cap the bottle tightly, turn the Power switch "ON", and shake the bottle for 45 seconds.
- 4.) Immediately uncapped the bottle, place the bottle in a foam holder, and position the bottle under the gel timer. Attach the glass rod spindle to the gel timer, while centering the glass rod in the 4 oz. glass bottle. Gel times are performed at ambient

temperature.

- 5.) Turn the Test switch to the "ON" position to activate the gel time alarm.
- 6.) When the alarm sounds, immediately turn both the Power and Test switches "OFF". Record the gel time.

Acknowledgements

The Composites Fabricators Association would like to express its sincere appreciation to the management of Dow Chemical for providing exceptional facilities, equipment and personnel to make this project possible.

This industry project was supported by a number of suppliers who generously provided equipment, personnel, materials and expertise. CFA would like to acknowledge the participation of the following companies:

- Binks Manufacturing
- Reichhold Chemical
- Cook Composites & Polymers
- TFM Inc.
- GLS Corporation
- PPG Industries
- Owens Corning
- Vetrotex Certaineed

Additionally, CFA would like to acknowledge the support of the EPA and RTI. The contributions of Carlos Nunoz, Geddes Ramsey, Shirley Wasson, Emery Kong and Mark Bahner have made valuable enhancements to the project.

References

1. *Evaluation of Pollution Prevention Techniques To Reduce Styrene Emissions From Open Contact Molding Processes*, Kong, Bahner, , Wright, Clayton, September 1995, EPA Cooperative Agreement CR 818419-03, RTI Project No. 96U-5171-016, Research Triangle Institute, Research Triangle, NC
2. *Guides to Pollution Prevention, The Fiberglass-Reinforced and Composite Plastics Industry*, USEPA, ORD, EPA/625/7-91/014, October 1991
3. "Styrene Content of Gel Coat and Effects", Fax Memo - Richard Higgins, HK Research Corp. to Bob Lacovara, April 4, 1995
4. *Pultrusion Industry Council Phase II Emission Study*, February 1995, SPI Composites Institute, NY, NY
5. *Evaluation of Enclosures and Other Air Flow Management Techniques for Styrene Emissions From Open Molding*, Bahner, May, 1996, EPA Cooperative Agreement CR 82457, RTI Project No. 92U-6497-08, Research Triangle Institute, Research Triabgle, NC
6. *Measuring Volatile Organic Compounds From a New Low VOC Gel Coat Polyester Resin*, Acurex Environmental Corp., December 1993.

Appendix A

Composites Fabricators Association
OPEN MOLDING STYRENE
EMISSIONS TEST PROJECT

Gel Coat/Spray-Up
OPTIMIZATION
STUDY

Final Report

Prepared by:
Robert Lacovara, CFA
Larry Craigie, Dow Chemical
Terry Cowley, Dow Chemical
Paul Wykowski, Dow Chemical
Gary Webster, Dow Chemical

Composites Fabricators Association
McLean, VA
August 1996

Copyright CFA 1996

Optimization Study Summary

Conclusions and Recommendations

Background

This study was conducted to demonstrate and quantify effects of optimizing the spraying process for both gel coat and resin application. The baseline for these experiments is the Phase I Study - CFA Open Molding Styrene Emissions Test Project. In the Baseline Study, no attempt was made to reduce or control styrene emissions. Considerable data were collected from the original experiments, some of which is integrated into this study. The Optimization Study was conducted under the same rigorous Category II Quality Plan parameters as the Baseline Study. Elements of the original study were combined with the Optimization Study to provide replicate experiments. The replication between the original experiments and the Optimization experiments was good.

Conclusions

These experiments have determined that overspray (off-mold spray) is a major factor in styrene emissions from polyester resin and gel coat spray application. Overspray can dramatically increase the wet surface area of a mold and surrounding area, and has a corresponding effect on emissions, based on surface area evaporation. In addition, because the overspray film is very thin the rate of cure is slow, which also increases emissions per unit of surface area. The ratio of mold surface area to linear edge is an important determinant in the potential for overspray. As a mold becomes larger the surface area per mold perimeter increases, which decreases the potential for overspray.

The optimization of spray gun set-up and spraying technique can have a highly significant impact in reducing styrene emissions. These methods should be considered the primary form of pollution prevention and source reduction in all polyester/vinyl ester resin and gel coat spraying operations.

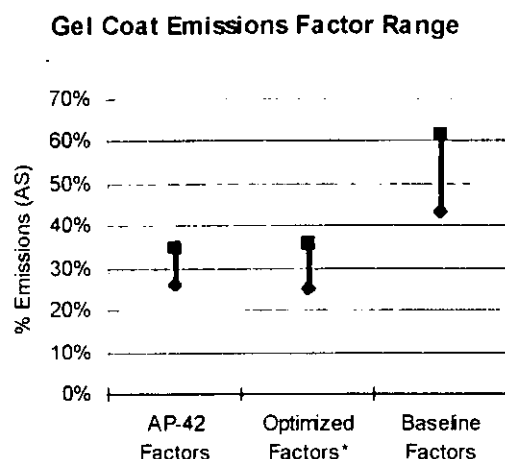
With gel coat application, an optimized spray gun set-up yielded a reduction of 21.1% from baseline emissions, while controlled spraying produced a 41.6% decrease in emissions.

The spray-up process gun optimization yielded a 9.1% decrease in emissions, while controlled spraying produced a 21.4% decrease in emissions.

These emissions reductions provide substantial pollution prevention opportunities at little or no cost to the manufacturer. In fact, the net reduction in overspray (increasing transfer efficiency), should actually produce a net savings in material cost. In addition, the reduction in peak emissions levels from spray gun optimization may reduce personnel exposure to styrene, and aid in compliance with the industries voluntary 50 ppm personal exposure limit.

In the Phase I Baseline Study the range for gel coat emissions was 43.5% AS to 61.8% AS. Extrapolating the Optimization reductions, this range might be reduced to between 25.4% AS to 36.0% AS, which is similar to the current AP-42¹ emissions factors. Baseline Spray-up emissions ranged from 17.1% AS to 38.0% AS. Extrapolating the Optimization results may yield an emissions range of 13.4% AS to 29.8% AS. In this case, the upper limit of AP-42 emission factors is attainable through optimization techniques.

These conclusions serve to point out, that although the Baseline emissions average higher than AP-42¹ factors, relatively minor changes in equipment and application methods can produce emissions more in line with the long used EPA factors. In actual practice, larger molds than used in this test project, with a greater surface area to linear edge ratio, may exhibit baseline emissions closer to the traditional AP-42 factors.



*Optimized Factors Extrapolated

Figure A

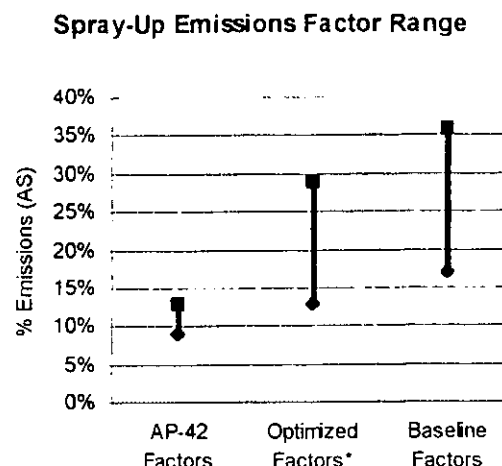


Figure B

Recommendations

Optimization of spray gun set-up and spraying technique should be the first line of pollution prevention and source reduction in polyester/vinyl ester resin spraying operations. These methods provide a "win-win" scenario for mitigating styrene emissions while providing cost savings. It is recommended that all spray application equipment be optimized, and spraying techniques aimed at reducing overspray be adopted to achieve these emissions reductions. Following are specific recommendations for spray application optimization:

1. **Spray Equipment Set-up:** Spray tips should be sized for a specific application, in order to spray from between 12" - 18", or as close as reasonably possible, from the surface. The primary method for adjusting material flow rate is varying the spray tip orifice size. The fan pattern width is adjusted by selecting the appropriate orifice angle.
2. **Tip Pressure:** The spray gun should be adjusted to the lowest possible pressure that produces an acceptable fan pattern. (The procedure is described in this document).
3. **Spray Operator Training:** Operator training is a critical part of the optimization plan. This training should include: The use of proper spraying techniques; An understanding of the function and proper set-up of spray equipment; And an understanding of the effects of overspray.
4. **Spraying Technique:** Handling of the spray gun is a critical element of optimizing the process. In simple terms, where the gun is "aimed" is very important. These techniques designed to minimize "off-spray" and reduce wet surface area surrounding the mold.
 - a. The spray gun should be held as close to the mold surface as possible, in consideration of the material output, fan pattern size, and size and configuration of the mold.
 - b. The fan pattern intercept angle should be maintained as close to perpendicular to the mold surface as possible.
 - c. The perimeter of the mold should be sprayed as accurately as possible, avoiding spraying off the edge to the greatest extent possible.
5. **Overspray Capture/Mold Edge Configuration:** It is a distinct advantage to capture "off-spray" as close to the mold edge as possible. When considering the geometry of spray off the edge of the mold, the total wet surface area increases considerably as the "footprint" of the overspray area increases. It is recommended that a wide flange be incorporated at the mold perimeter, or an arrangement of masking the mold edge be used. The objective is to spray to the useful edge of the part and contain as much overspray as possible with the masking around the mold perimeter.

Optimization Study Gel Coat & Spray-Up Application

1.0 Purpose

The purpose of the optimization study is to explore the effects of spray gun set-up and spraying technique on styrene emissions from the gel coating and spray-up processes. An "optimized" or fine tuned spray gun set-up will be compared to the standard gun set-up used in the Baseline studies. Additionally, the effects of overspray will be assessed through the use of controlled and uncontrolled spraying techniques.

1.1 Approach

These experiments are based on earlier test runs from the original Baseline Study. In both gel coat application and spray-up application, a run from the original experiments which produced emissions approximate to the mid-point range of emissions was selected. In the case of gel coating, Run 14 from the Baseline experiment was selected. This original run produced 56% AS emissions, where the average gel coat emissions from all runs was 51.5 % AS. In the case of spray-up, original Run 10 was selected, which yielded 22.3% AS emissions, where the overall average emissions were 25.0% AS.

1.2 Controlled vs. Uncontrolled Spraying

The original Baseline Study was conducted using an uncontrolled spraying technique. This involves producing overspray which would be considered typical or normal for application of this type and configuration mold. A study of video tapes was conducted to determine the distance and duration of overspray off the edge of various molds. It was determined that carrying the spray gun stroke approximately 6" off the edge of the mold, would produce conditions considered typical of uncontrolled spraying. In addition, fan pattern intercept angles were used which would represent a typical industry application. The controlled spraying technique used in the Optimization Studies contains the overspray to the greatest extent possible within the flange of the mold. In this case the fan pattern intercept angles are maintained as close to 90° to the surface as possible. The ramifications of surface area coverage become apparent when taking overspray into account. As illustrated, the effective surface area of the uncontrolled application is 53.94 ft², while the controlled technique has an effective area of 34.58 ft².

Spray Area Coverage - Spray-Up & Gel Coating

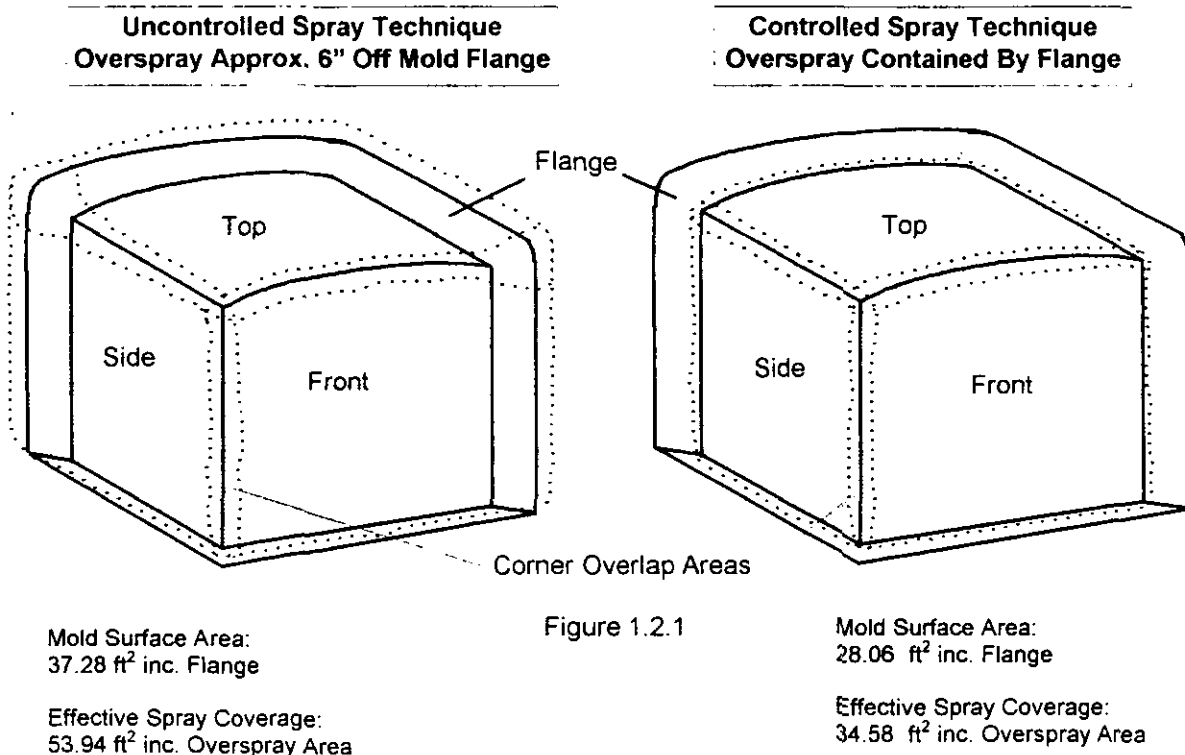
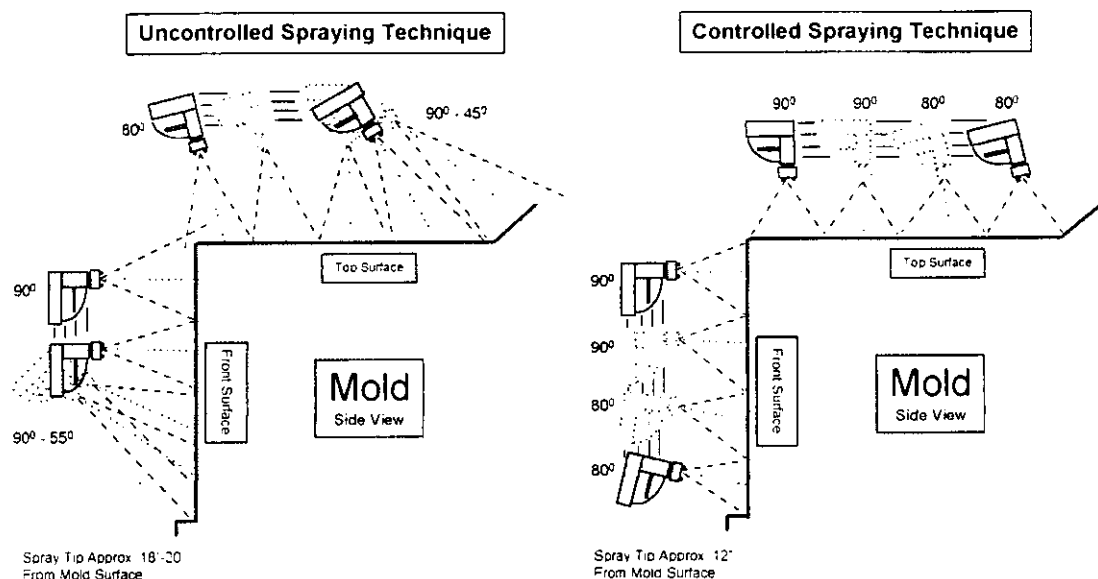


Figure 1.2.1

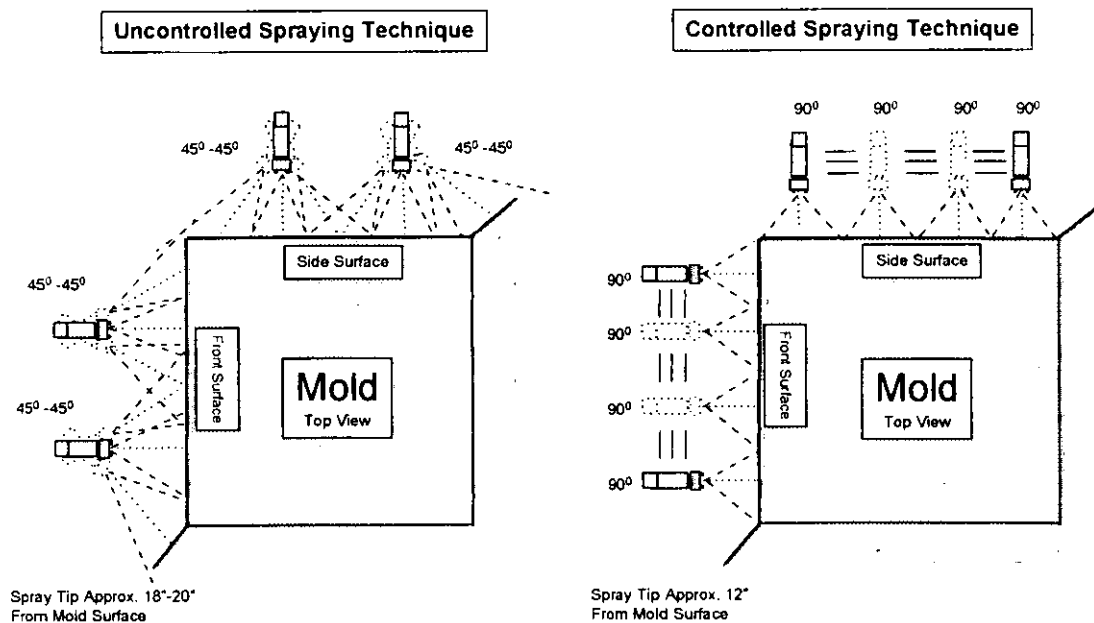
Fan Pattern Intercept Angles Side View

Figure 1.2.2



Fan Pattern Intercept Angles Top View

Figure 1.2.3



1.3 Experimental Design

This series of experiments is designed to compare controlled spray technique to uncontrolled technique, and to examine the effects of spray gun set-up on emissions. The design for these experiments is as follows.

1.3.1 Gel Coat Application Optimization

Table 1.3.1

Optimization Run No.	Pattern	Spray Gun Set-Up Optimized	Controlled or Uncontrolled Spraying Technique	Spray Mold Flange (Overspray)
1	--+	No	Uncontrolled	Yes
2	---	No	Controlled	No
3	+-+	Yes	Uncontrolled	Yes
4A	++-	Yes	Controlled	No
4B	++-	Yes	Controlled	No
14/Original	--+	No	Uncontrolled	Yes

1.3.2 Spray-Up Application Optimization

Table 1.3.2

Optimization Run No.	Pattern	Spray Gun Set-Up Optimized	Controlled or Uncontrolled Spraying Technique	Spray Mold Flange (Overspray)
1	--+	No	Uncontrolled	Yes
2	-+-	No	Controlled	No
3	+-+	Yes	Uncontrolled	Yes
4A	++-	Yes	Controlled	No
4B	++-	Yes	Controlled	No
10/Original	--+	No	Uncontrolled	Yes

1.4 Replicate Experiment Correlation

During the course of the project, replicate experiments conducted with a substantial time interval in between have been shown to produce a high level of correlation. For example, the original Spray-Up Experiment Run 10, conducted on 12/6/95 produced 22.3% AS emissions. The replicate run for the optimization experiment (Run 1), conducted on 2/22/96, produced 21.5% AS emissions, a difference of only 0.8%. The original Gel Coat Experiment Run 14, conducted on 10/19/95 produced 56.0% AS emissions. The optimization experiment replicate, conducted on 3/5/96, produced 52.1% AS emissions, for a difference of 3.9%. This indicates the reproducibility of experiments is high and correlated results from experiment to experiment are reliable, within the range of indicated error.

1.5 Spray Tip Pressure Emissions Study

In order to provide data on the optimization of the spray gun, an adjunct study was conducted, in order to better understand the relationship between spray tip pressure and styrene emissions. Measurements of emissions at various spray gun pressures were undertaken. In the first segment, a specific amount of gel coat or resin was sprayed to provide a specified thickness over the designated surface area. In the second segment, the gel coat or resin was sprayed for a specific period of time (60 seconds) at various tip pressures and the peak emissions were recorded.

1.5.1 Spray Gun and Experimental Set-up

The same airless air assist spray equipment used in previous experiments was documented in these studies. For the gel coat application a .021" tip with a 40° fan pattern was used. Gel coat viscosity was measured at 14,400 cps (RVF 4@4). A target thickness of .018" (18 mils) was used. For the Spray-Up resin application a .031"-60° spray tip was used. The resin viscosity was measured at 448 cps (LVF). The target thickness for the application was .080" of laminate.

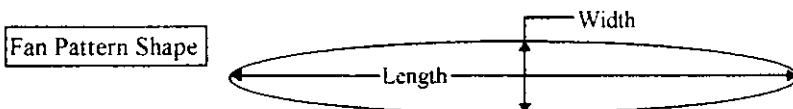
The fan patterns at each pressure setting are described as follows:

Gel Coat Fan Patterns - Table 1.5.2

Pump Pressure	Fan Pattern Length (in.)	Fan Pattern Width (in.)	Fan Pattern Quality
30	9.00	3.25	Poor
40	11.00	3.50	Adequate
50	13.00	3.75	Good
60	14.25	3.75	Good
70	15.25	3.75	Good

Spray-Up Fan Patterns - Table 1.5.3

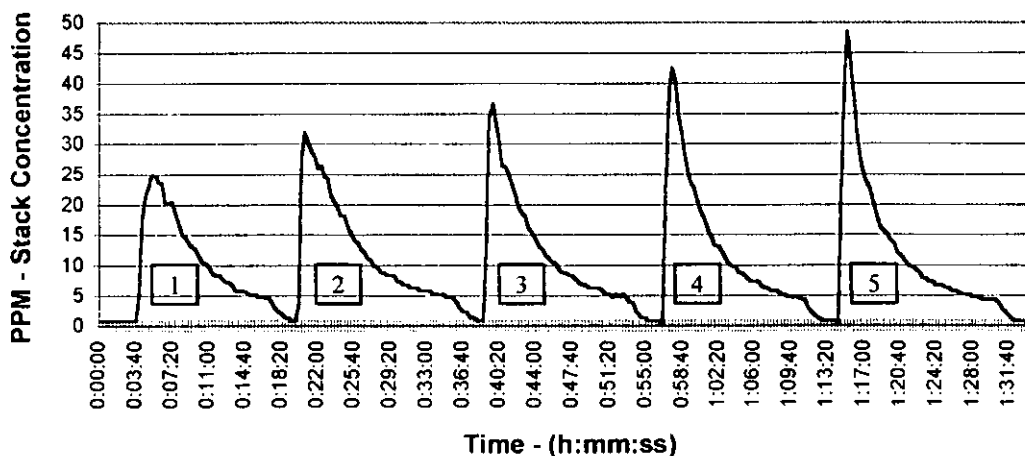
Pump Pressure	Fan Pattern Length (in.)	Fan Pattern Width (in.)	Fan Pattern Quality
30	12.00	2.25	Adequate
40	14.00	3.25	Good
50	15.00	3.00	Good
60	16.50	3.00	Good
70	17.50	3.50	Good



For the Gel Coat Optimization Study a pump pressure of 50 psi was selected to provide the best quality fan pattern at the lowest available tip pressure. For the Spray-up Optimization Study a pump pressure of 40 psi was used to provide the best fan pattern at the lowest available pressure.

SPRAY TIP PRESSURES vs. EMISSIONS PEAK GEL COAT

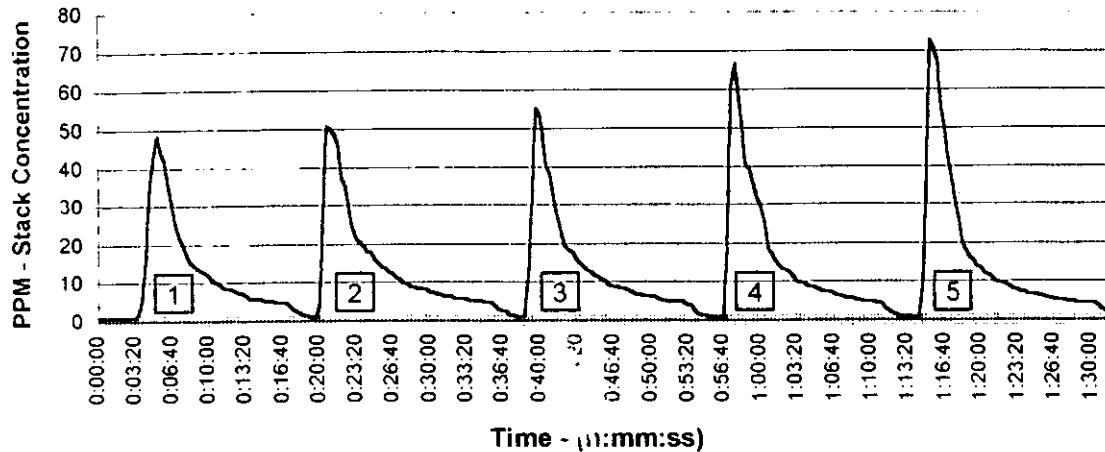
Table 1.5.4



Peak No.	Pump Pressure (psi)	Pump Ratio	Tip Pressure (psi)	Wt. Of Gel Coat Sprayed (g)	Gel Coat Thickness (mils)	Surface Area (ft ²)	Peak Styrene Emission (ppm)
1	30	14.5	435	189	18.0	6	25
2	40	14.5	580	196	18.0	6	32
3	50	14.5	725	170	17.5	6	36
4	60	14.5	870	197	18.0	6	42
5	70	14.5	1015	203	18.0	6	48

Table 1.5.5

SPRAY TIP PRESSURES vs. EMISSIONS PEAK SPRAY-UP



Peak No.	Pump Pressure (psi)	Pump Ratio	Tip Pressure (psi)	Wt. Of Resin Sprayed (g)	Laminate Thickness (in.)	Surface Area (ft ²)	Peak Styrene Emission (ppm)
1	30	14.5	435	468	.081	6	48
2	40	14.5	580	491	.085	6	51
3	50	14.5	725	454	.080	6	55
4	60	14.5	870	498	.085	6	67
5	70	14.5	1015	465	.080	6	72

1.6 Optimization Methodology

1.6.1 Spray Gun Set-up Optimization Method

The method for optimizing the spray gun set-up is universal, in that it will apply to all available gel coat or resin spray application equipment. The optimization process consists of: 1) Determining the appropriate spray tip size and fan pattern angle; 2) Setting fluid pump pressure and air assist pressure (if applicable) to produce the best fan pattern at the lowest pressure.

Spray tip size is determined by a number of factors, including: Required material flow rate; viscosity of material; spray gun distance from the mold; and required width of fan pattern. These interacting factors preclude the possibility of pre-determining a specific spray tip size for a given circumstance. A series of tip sizes and angles should be available to trial various combinations.

Once a spray tip is selected, pump pressure and air assist pressure (if an airless air assist unit) are used to produce a spray pattern acceptable for the application. The set-up procedure is as follows: Air assist pressure (if applicable) is set to the within the anticipated range. Fluid pump pressure is turned down to "0" on the pump air pressure regulator. While holding the spray gun at a specified distance away from a disposable surface (floor paper), the trigger is pulled. The air pressure to the fluid pump is then slowly increased while observing the fan pattern. When an adequate fan pattern is produced the pump pressure is fixed. The gun is then moved over a clean area of paper and held at 90° to the surface and at the specified distance. The trigger is then quickly pulled and released to provide a "snapshot" imprint of the fan pattern. At this point the air assist pressure may be adjusted to "fine tune" the shape of the fan pattern. This procedure is repeated until the best fan pattern at the lowest pressure is produced.

There are several points to note concerning spray gun optimization:

1. Based on test results, lower tip pressures produce lower peak emissions. Tip pressure should always be adjusted to the lowest possible pressure that produces an acceptable fan pattern.
2. Material flow rate adjustments should be accomplished by changing spray tip size and not by adjusting fluid pressure.
3. The distance between the spray gun and the mold surface, and the viscosity of the material sprayed will affect the fan pattern angle selected.

1.6.2 Spraying Technique Optimization

The primary factor in optimizing spraying technique is to reduce overspray (off-mold spray) to the greatest extent possible. Close capture of overspray with an extended mold flange is an effective method of restricting overspray surface area. From a practical standpoint the "extended flange" does not have to be an integral part of the mold, but can simply be a removable mask installed around the mold perimeter.

A second issue is to match the angle of the fan pattern to the distance of the spray gun to the mold. With the proper fan pattern angle, distances of 12" - 18" are achievable. On larger parts, distance from the mold is less critical, due to the surrounding mold surface capturing a large portion of the overspray. Fan pattern width should be adjusted for a particular configuration of mold, minimizing the required spray gun distance to the surface.

The orientation of the spray pattern and the distance from the mold are substantial contributing factors to the overspray equation. The optimum technique is to keep the fan pattern intercept angle as close to 90° (perpendicular) to the surface as possible and to keep the spray gun as close as reasonably possible to the surface. At acute fan pattern intercept angles (less than 90°), the tendency is to create horizontal transport of material across the mold surface. The more acute the spray angle the greater the horizontal velocity across the surface, thus carrying more material off the mold edge. In addition, acute spray angles create a wider overspray footprint due to the geometry of the material flow path.

In summary, the critical elements of spray technique optimization are:

1. Contain overspray as close to the perimeter of the mold as possible to reduce the overall overspray footprint.
2. Minimize spray gun distance to the mold.
3. Maintain fan pattern intercept angle as close to 90° (perpendicular) to the mold surface as possible.

1.7 GEL COAT OPTIMIZATION COMPARISONS and CONCLUSIONS

Table 1.7.1

Run No.	Emission % of Gel Coat (RW)	Emission % of AS	Surface Area Emiss. (g/ft ²)	Surface Area Emiss. (g/m ²)	Normalized Surf. Area Emission (g/ft ² / kg GC)
Replicate Avg. - Runs 1 & 14	21.9%	54.0%	13.36	146.58	5.87
Run 2	12.7%	31.5%	8.23	68.00	4.54
Run 3	17.2%	42.6%	10.76	118.10	4.62
Replicate Avg. - Runs 4A & 4B	12.6%	31.1%	8.09	66.84	4.49

RESULTS:

1. *Baseline Runs:* The average of runs 1 & 14 produced 54.0% emissions of available styrene (AS).
2. *Optimized Spray Gun Set-up:* Run 3 produced 42.6% emissions of available styrene (AS).
3. *Controlled Spraying:* Run 2 produced 31.5% emissions of available styrene (AS).
4. *Optimized Spray Gun Set-up - Controlled Spraying:* The average of Runs 4A & 4B produced 31.1% emissions of available styrene (AS).

CONCLUSIONS:

1. Spray gun set-up optimization resulted in a 21.1% decrease in AS emissions.
2. Controlled spraying resulted in a 41.6% decrease in AS emissions.
3. Optimized spray gun set-up + Controlled spraying resulted in a 42.4% decrease in AS emissions.
4. Controlled spraying provides a reduction of nearly two times that of an optimized spray gun set-up.
5. Overspray, which increases wet surface area, is a major factor in styrene emissions.
6. The results of emissions decreases for controlled spraying only runs vs. the controlled spraying + optimized spray gun set-up runs (41.6% vs. 42.4%) should be considered equivalent, being within the experimental error of the measurements.
7. The effects of spray gun set-up and controlled spraying are not cumulative. The effects of spray gun efficiency are enveloped by the effects of controlled spraying.
8. The emissions from either controlled spraying only, or controlled spraying + optimized spray gun set-up, are in the mid-range of AP-42 emission factors for gel coating (26%-35% emissions AS). The AP-42 maximum factor (35%) x .89 yields optimization emission factors.

1.8 SPRAY-UP OPTIMIZATION COMPARISONS and CONCLUSIONS

Table 1.8.1

Run No.	Emission % of Gel Coat (RW)	Emission % of AS	Surface Area Emiss. (g/ft ²)	Surface Area Emiss. (g/m ²)	Normalized Surf. Area Emission (g/ft ² / kg Resin)
Replicate Avg. - Runs 1 & 10	9.3%	21.9%	19.87	218.06	2.48
Run 2	7.3%	17.2%	14.45	119.40	2.59
Run 3	8.4%	19.9%	18.19	199.65	2.25
Replicate Avg. - Runs 4A & 4B	7.3%	17.4%	14.64	120.96	2.61

RESULTS:

1. *Baseline Runs*: The average of runs 1 & 10 produced 21.9% emissions of available styrene (AS).
2. *Optimized Spray Gun Set-up*: Run 3 produced 19.9% emissions of available styrene (AS).
3. *Controlled Spraying*: Run 2 produced 17.2% emissions of available styrene (AS).
4. *Optimized Spray Gun Set-up - Controlled Spraying*: The average of Runs 4A & 4B produced 17.4% emissions of available styrene (AS).

CONCLUSIONS:

1. Spray gun set-up optimization resulted in a 9.1% decrease in AS emissions.
2. Controlled spraying resulted in a 21.4% decrease in AS emissions.
3. Optimized spray gun set-up + Controlled spraying resulted in a 20.4% decrease in AS emissions.
4. The results of emissions decreases for controlled spraying only runs vs. the controlled spraying + optimized spray gun set-up runs (21.4% vs. 20.4%) should be considered equivalent, being within the experimental error of the measurements.
5. Controlled spraying provides a reduction of over two times that of an optimized spray gun set-up.
6. Overspray, which increases wet surface area, is a major factor in styrene emissions.
7. The effects of spray gun set-up and controlled spraying are not cumulative. The effects of spray gun efficiency are enveloped by the effects of controlled spraying.
8. The emissions from either controlled spraying only (17.2%), or controlled spraying + optimized spray gun set-up (17.4%), are approximately 1.33 times higher than AP-42¹ (9-13% AS for non-vapor suppressed (NVS) resins).

¹AP-42 - U.S. EPA, Office of Air Quality Planning and Standards. *Compilation of Air Pollutant Emission Factors (AP-42)*. Research Triangle Park, NC, September 1988

1.9 Data Tables - Optimization Study

Table 1.9.1

Gel Coat Optimization Experiment Data Table

Run Parameters														Data					Normalized	
Run No.	Data ID	GC Film Thick-ness (in.)	GC Styrene %	Gel Time (min.)	GC Flow (lb/min)	Air Flow (fpm)	Gel Coat Consumed (g)	Available Styrene (g)	Emission Weight (g)	Emission % of Coat (RW)	Emission % of AS	Surface Area Emiss. (g/m2)	Surface Area Emiss. (g/m2)	Surf. Area Emission (g/m2/ kg GC)						
1	030596A	0.018	40	10	4	100	2242.00	907.10	472.50	21.1%	52.1%	12.67	139.09	5.65						
2	030796A	0.018	40	10	4	100	1812.00	733.10	231.00	12.7%	31.5%	8.23	68.00	4.54						
3	030596B	0.018	40	10	4	100	2330.00	942.70	401.20	17.2%	42.5%	10.76	118.10	4.52						
4A	030796B	0.018	40	10	4	100	1801.00	728.70	228.50	12.7%	31.4%	8.14	67.27	4.52						
4B	030796D	0.018	40	10	4	100	1803.00	729.50	225.60	12.5%	30.9%	8.04	66.41	4.48						
14	101995C	0.018	40	10	4	100	2310.00	934.60	523.38	22.7%	55.0%	14.04	154.07	6.08						

Runs 1 & 14 - Baseline

Run 2 - Controlled spraying only

Run 3 - Spray gun optimized only

Runs 4A & 4B - Controlled spraying + Optimized gun set-up

Table 1.9.2

Spray-Up Optimization Experiment Data Table

Run Parameters														Data					Normalized Surf. Area Emission (g/m2/ kg Resin)
Data ID	Laminate Thick- ness (in.)	Resin Styrene %	Gel Time (min.)	Resin Flow (lb/min)	Air Flow (fpm)	Resin Consumed (g)	Available Styrene (g)	Emission Weight (g)	Emission % of Resin(RW)	Emission % of AS	Surface Area Emiss. (g/m2)	Surface Area Emiss. (g/m2)							
1	0.080	42	30	4	100	7928.00	3345.60	718.50	9.1%	21.5%	19.27	211.51	2.43						
2	0.080	42	30	4	100	5578.00	2353.90	405.60	7.3%	17.2%	14.45	119.40	2.59						
3	0.080	42	30	4	100	8077.00	3408.50	678.20	8.4%	19.9%	18.19	199.65	2.25						
4A	0.080	42	30	4	100	5624.00	2373.30	418.90	7.4%	17.7%	14.93	123.31	2.85						
4B	0.080	42	30	4	100	5595.00	2361.10	402.90	7.2%	17.1%	14.36	118.60	2.67						
10	0.080	42	30	4	100	8070.00	3405.50	763.00	9.6%	22.4%	20.47	224.61	2.84						

Runs 1 & 10 - Baseline

Run 2 - Controlled spraying only

Run 3 - Spray gun optimized only

Runs 4A & 4B - Controlled spraying + Optimized gun set-up

Appendix B

RESEARCH TRIANGLE INSTITUTE

Center for Environmental Analysis

DATE: September 26, 1995

TO: Judy Ford, EPA QA Officer

From: Emery Kong 

Subject: Technical Systems Audit and Performance Evaluation Audit of the CFA Open Molding Styrene Emission Testing

During September 20 and 21, Ms. Shirley Wasson of EPA and I conducted a technical systems audit and a performance evaluation audit of the CFA open molding styrene emission testing at the Dow Chemicals Composites Laboratory in Freeport, Texas. Major activities in the audit included exhaust flow rate verification, THC analyzer performance evaluation, and observation of a typical resin batch application (hand lay up) test run, and observation of analytical procedures for resin properties.

We found that CFA/Dow personnel had a good handle of the experimental procedure and Dow personnel provided a very good analytical support for resin properties determination so that the styrene content and gel time of the resin material can be adjusted to the specific values in the QAPP. However, we found that the exhaust flow rate and THC measurements did not meet the data quality objectives.

This report presents my evaluation of exhaust flow rate measurements. Ms. Wasson concentrated on the THC analyzer performance evaluation. She also received a copy of all data recording sheets for the first three test runs. CFA/Dow started their styrene emission study with the resin batch application; therefore, procedures pertaining to spray gun calibration were not observed. According to Mr. Bob Lacovara of CFA, they are going to complete resin batch application study first, then gel coat spray application study, and finally the resin spray application study. I have talked with Mr. Carlos Nunez and Ms. Wasson about returning to Dow to observe the resin spray application study in late October. CFA and Dow welcome us to observe the resin spray application study. Mr. Nunez will make a decision on this subject.

On September 20, 1995, Dow personnel conducted the third official resin batch application test run in the morning. After resin lamination was complete, Ms. Wasson and I verified the exhaust flow rate at the exhaust duct using a 12-inch standard pitot tube with an ALNOR micromanometer. The arrangement of pressure gauge and sampling parts at the 16" diameter exhaust duct is shown in the attached notes. Velocity measured at Hole 3, just behind the Vortek Velocity Sensor, showed that the centerline velocity was 1370 and 1270 fpm. The calculated flow rates were 1949 and 1861 cfm, which are higher than 1600 cfm monitored by the Vortek velocity sensor.



Because the flow rate measurement was higher than 1600 cfm and the monitoring location is just behind the Vortek velocity sensor, I suspected that turbulence affected the pitot tube readings. I requested Dow technicians to drill two additional holes upstream of the monitoring location (as shown in the attached figure, Holes 1 and 2). Centerline velocity measurements at these two holes showed that the exhaust flow rates were 1356 cfm and 1426 cfm which were lower than 1600 cfm on the Vortek sensor. Additional traverse measurements showed that the flow rates were 1381 cfm at Hole 1 and 1453 cfm at Hole 2. These measurements showed that the actual exhaust flow rate was 1404 cfm, which is 12.5% lower than 1600 cfm. The difference exceeded the data quality objective ± 100 cfm in the QAPP.

In the afternoon, a Dow technician conducted subsequent exhaust flow rate verification using a 18-inch standard pitot tube and an Airdata micromanometer and the result was 1403 cfm. Dow personnel decided to call on their Environmental Service group and Vortek representative to resolve the difference. The Dow Environmental Service personnel used EPA methods 1 and 2 to monitor Δ ps at Hole 5 on Sept. 21. Sixteen traverse points were used, and the result confirmed previous finding that the actual exhaust flow rate as 1400 cfm. The Dow personnel finally accepted the fact that the exhaust flow rate was 1400 cfm, not 1600 cfm. They decided to keep the exhaust flow rate at 1400 cfm and adjust the Vortek sensor to reflect the actual flow rate in the subsequent test runs. This exhaust flow rate correction along with accurate concentration measurement should improve the accuracy of styrene emission rate determination.

The performance evaluation of the THC analyzer indicates that high concentration styrene standards (above 175 ppm) caused a problem in the styrene standard span check and the mid-range span check always showed up higher than the actual concentration of the mid-range styrene standard. This incorrect calibration resulted in higher concentration reading than the actual concentration.

This audit showed that emission measurement and exhaust flow rate monitoring need to be improved to meet the data quality objectives. The following suggestions were provided to the CFA/Dow personnel orally on September 21, 1995 with Ms. Wasson's consensus.

Recommendations:

RTI's Recommendations to improve data quality for the CFA/Dow testing

1. Use propane standards for daily routine calibrations; correlation between styrene standards and propane standard needs to be determined prior to the use of propane standards.

Suggested concentration range for each emission study:

Resin spray up	0-800 ppm styrene or 0-2100 ppm propane
Gel coat spray up	0-500 ppm styrene or 0-1340 ppm propane
Resin hand lay up	0-200 ppm styrene or 0-530 ppm propane

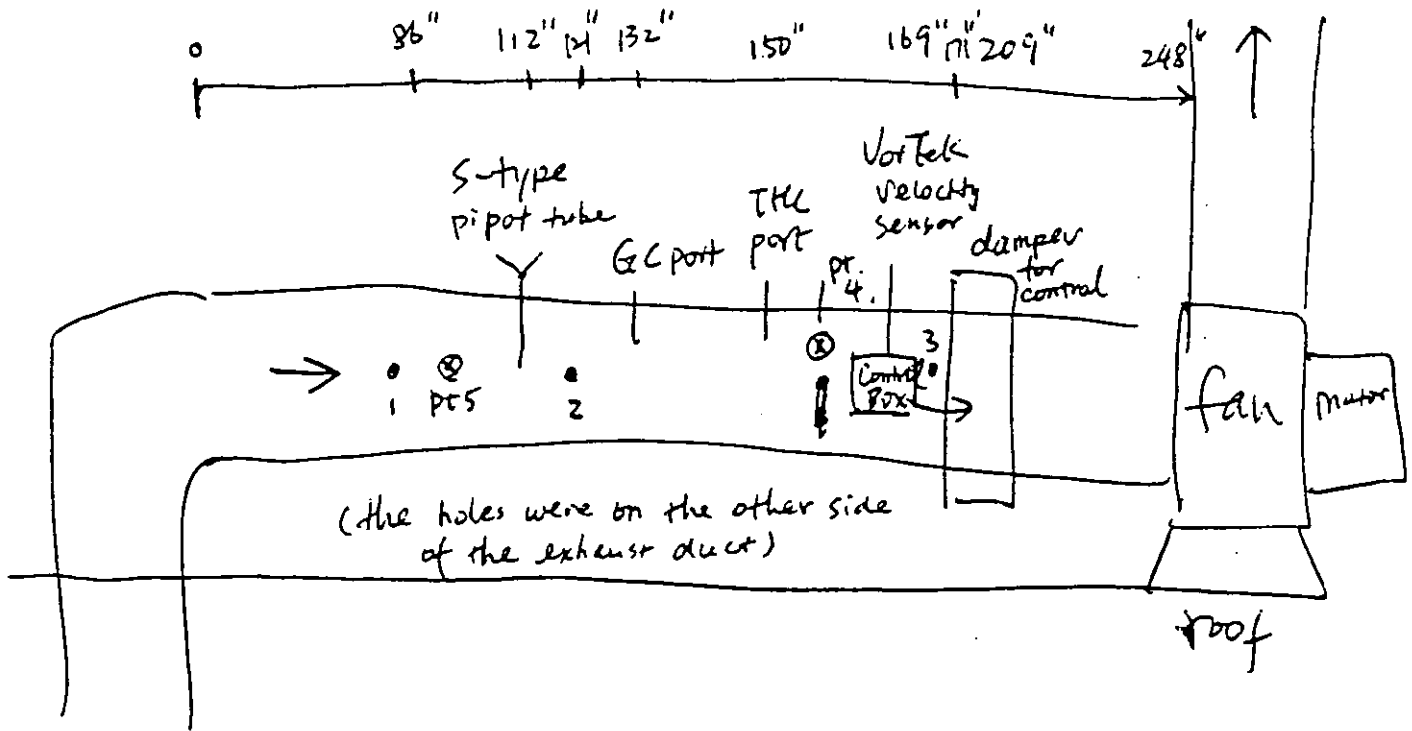
2. Perform pure styrene evaporation tests when propane standards are used.
(Pure styrene evaporation tests are called for in the QAPP before each emission study.)
Suggest boost styrene emission conc. up to 50 ppm (by blowing terry cloth soaked with styrene) for a shorter run 20 to 30 min.
3. After each test run, conduct mid-range and zero-air drift check. [The drift check could be part of the full range calibration (i.e., zero-air, mid-range, and 80% span standard) for this subsequent test run.]
4. Press the calibration button on the scale read out unit to conduct internal calibration check before each test run.
5. Perform weekly stack centerline velocity check to verify the Vortek velocity measurement, and check against the Δp measurement from the incline manometer.
6. Re-analyze EPA's styrene standard and propane standard after Dow switches to a propane standard calibration.
7. Make a respirator available for the operator to protect him from unnecessary exposure to high conc. styrene emissions. (especially during gel coat and resin spray up).

Enclosure (written note from my notebook)

cc: Constance Wall, RTI QA

~~16~~ in ID stack incline manometer in-side of the GC

0.09 inch water S-type pitot tube off-center up on roof



1330 fpm

o am

2/24/95

Hole 3

$$\begin{aligned} 14" \text{ ID} &= 1.069 \text{ ft}^2 \rightarrow 1922 \text{ cfm} \\ 51.5" \text{ circum. } 16.39" \text{ OD} &\Rightarrow 1.466 \text{ ft}^2 \rightarrow 1949 \text{ cfm} \\ \text{Center line } \Delta p &0.9 - 0.11 \text{ inch water at hole 3} \end{aligned}$$

Larry said the Vortek velocity sensor was verified by hot-wire monometer when it was re-installed at the current location. at the hot-wire monometer location is just 1 1/2 inch down stream of the Vortek sensor. Our velocity measurements at this location showed ^{that} high velocity readings in 1330 fpm to 1350 fpm. range which translate to 1950 cfm or 1980 cfm and was much higher than the 1400 cfm recorded at Fanet. Camille system

10:08 am 1270 fpm → ~~1242~~ 1861
 7/20/95 ~~1358~~ cfm

Two additional holes were drilled up-stream of hole 1 and hole 2 on the figure.

Hole 2 initial zero center line 1.
 002 0.08 (7 inches into port)
 in H₂O in H₂O velocity head = 0.06 inch water

Hole 2 680 fpm → 986 cfm

Hole 1 reading every 10 sec. 7 inches in
 almost center line

10:28 am

870

930

900

880

970

940

950

940

940

950

950

930

880

$$\text{Avg } 925 \text{ fpm} \times 1.466 \text{ ft}^2 = 1356 \text{ cfm}$$

Hole 2 reading every 10 sec.

7" in into duct.
 almost center line

10:30 am

990

950

990

990

990

990

990

970

980

970

960

970

950

930

$$\text{Avg } 973 \text{ fpm} \times 1.466 \text{ ft}^2 = 1426 \text{ cfm}$$

(into duct)	Traverse on hole 2		} not used
	12"	.07" water	
	10"	.06	
	8"	.06	
	7"	.05	
	6"	.06	
	4"	.06	
	2"	.06	
	1"	.04	

Traverse on hole 1		(closest to edge of building)
12"	.05	} not used
11	.05	
10"	.06	
9"	.05	
8"	.04	
7"	.05	
6"	.05	
5"	.06	
4"	.06	
3"	.06	
2"	.06	
1"	.06	

Hole 2 (fpm)

12"	980
11"	1000
10"	980
9"	950
8"	950
7"	990
6"	990
5"	1000
4"	1020
3"	1010
2"	1020
1"	1000

between 10:30 - 11:00 am

$$\text{Avg. } 991 \text{ fpm} \times 1.466 \text{ ft}^2 = 1453 \text{ cfm}$$

mini pitot
hole 1 8"
930 fpm
at 4pm

Hole 1	(Fpm)
12"	960
11"	950
10"	930
9"	920
8"	910
7"	890
6"	910
5"	900
4"	910
3"	1010
2"	1000
1"	1020

$$\text{Avg } 942.5 \text{ ft/min} \times \frac{1.466}{\cancel{1.467}} \text{ ft}^2 = \frac{1381}{\cancel{1367}} \text{ cfm}$$

hole 1	mini pitot tube
at 8" mark	920
7 1/2"	880

$$\text{duct outside circumference} = 51.5" = 8.196" \times 2 = 16.39" \text{ OD} \\ = 1.466 \text{ ft}^2$$

$$\text{Avg. of } \left(\frac{1356}{\cancel{1344}} + \frac{1426}{\cancel{1414}} + \frac{1453}{\cancel{1437}} + \frac{1381}{\cancel{1367}} \right) / 4 = \frac{1404}{\cancel{1359}} \text{ cfm}$$

12" tube + ALVER
8" 15:46 16:05

780	1000
720	990
650	910
650	940
720	880
550	900
650	900
640	910
590	910
620	920
650	920
620	930
660	970

18" tube + Airdata

987
1016
957
912
1005
942
913
986
910
897
977
944
990

12" tube + Airdata

983
1019
955
979
946
974
922
936
940
963
943
950
947

18" tube + Airdata

890	950
870	940
820	910
820	920
840	940
870	910
850	930
800	920
810	880
760	860
830	900
880	900
860	880

2 pure styrene wrap test.

Friday

140.22 g evaporated

1600. cfm (Avg)	}	→ 134.6 g (96.0% measured)
7.7 ppm (Avg)		
89 min		

225.14 g

142 min	}	→ 217.5 g (96.6% measured)
7.8 ppm (Avg)		
1600 cfm (Avg)		

Sartorius F61S

Certified by Aldinger Co.
Dallas, TX
8/31/95

15 pm Scale Calibration check

120/95 Std. wt. readout

1 g 1 g

5 g 6 g

10 g 16 g

20 g 36 g

50 g 86 g

100 g 186 g

500 g 686 g

14.815 kg - a 5-gal re

14.826 kg

14821 g

14831 g

14851 g

14901 g

15001 g

~~15002~~ ~~15501~~ ~~15501~~
15502 g

Steel mold used for testing for the first hand layup
run on 9/20/95

Subsequent test run will be ^{building} on the laminate ~~test~~

1:30 PM THA performance evaluation check
9/20/95

zero air ^{THC} 0 - 0.0 ppm

80% span 280 ppm $\rightarrow$ 282 ^{THC} ppm

mid-range span check 175 ppm $\rightarrow$ 193.9 ^{THC} ppm

redo calibration

13:39:30

zero air $\rightarrow$ 0.0 ppm

background $\rightarrow$ 0.5 ppm

80% span 280 ppm $\rightarrow$ 279 ppm

midspan 175 ppm $\rightarrow$ 196 ppm

9/20/95
2:25 pm EPA performance evaluation sta. analysis by THC

zero air

80% span 280 →

performance sta. ~~32.7~~ ppm
31 ppm 32.2

THC reading

13:39 zero air → 0.0 ppm

13:44 80% span 280 ppm → 280 ppm

13:48 mid range 175 ppm → 196 ppm *

14:07 99 ppm → 101 ppm

14:12 mid range 175 ppm → 195 ppm *

span check

of 80% span → 275 ppm
280 ppm

14:22 EPA styrene
sta. 31 ppm → 32.2 ppm

$$\frac{32.2 - 31}{31} = +3.87\%$$

14:52 propane sta. → 10.7 ppm styrene $\times \frac{8}{3} = 28.5$ ppm prop
26.9 ppm $\pm 5\%$
propane

$$\frac{28.5 - 26.9}{26.9} = +5.9\%$$

175 ppm sta verified by GC

run #		run #	
1026	160.28	1033	172.12
1027	162.36	1034	169.20
1028	164.42	1035	166.86
1029	158.41	1036	160.04
1030	166.91		
1031	156.20		
1032	152.42		

/ Avg ~~162.6~~
162.66 ppm

* the mid-r
sta. seems
incorrect.

Continued

33

Hole 2 18" + Arrdata
8" center
4:25 pm

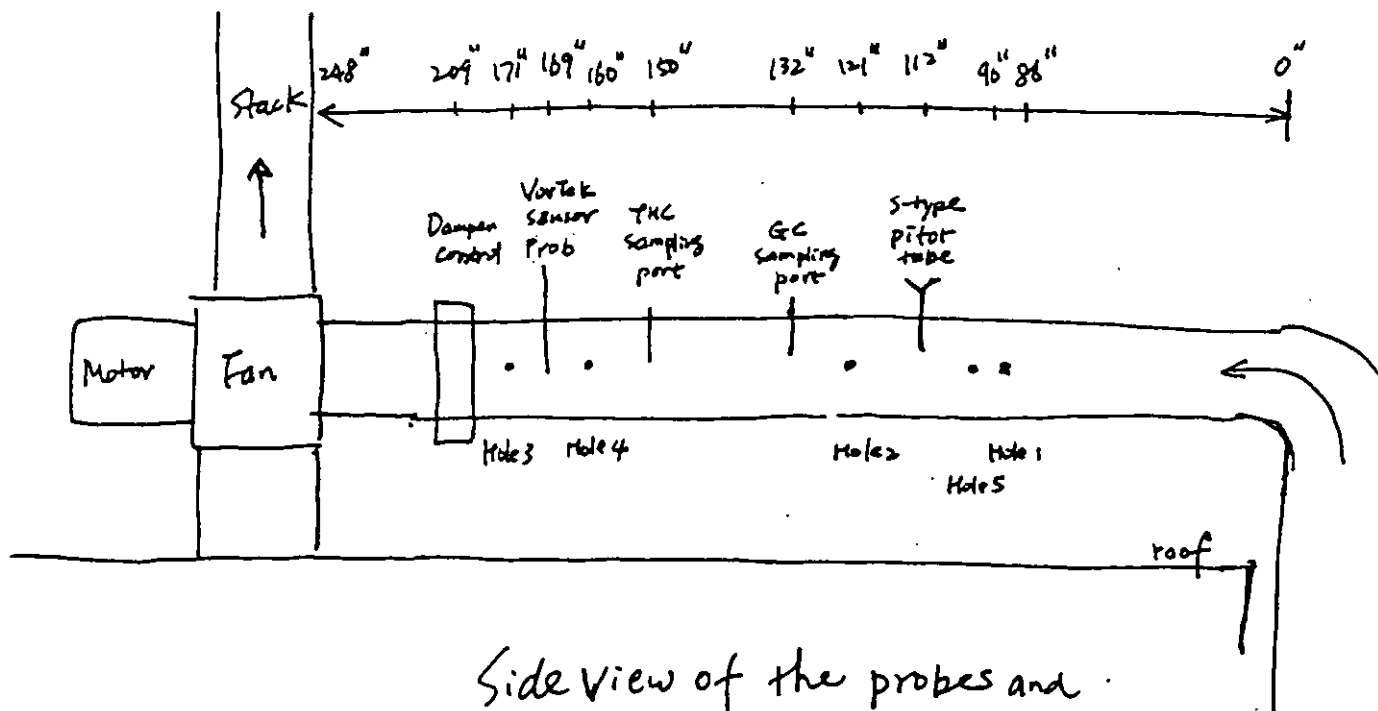
1043
1043
1031
1073
991
993
996
1029
1027
1054
1094
1013
1047

Avg 1033 fpm
x 1.466 ft²
= 1514 cfm

12" + ALWOR

960
970
950
960
940
900
910
970
970
940
980
990
990

Avg = 956 fpm
x 1.466 ft²
= 1401 cfm



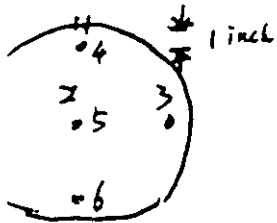
Side View of the probes and
sampling holes on the exhaust
ductwork at the Dow testing facility

Exhaust flow rate measurement Sensor

ANOR CompuFlow
Hot-wire anemometer

Hole 4

7 1/2" up stream of Vortex



~~9:40 am~~

pt. 1 ~~984, 977, 987~~
pt. 2

pt. 2 ~~940~~ 1050
pt. 5 1100

Hole 4 9:35 am

pt. 1	~~970~~ , ⁹⁷⁰ ~~977~~ , 990, 980	Avg 980
pt. 2	1000, 1000, 990	997
pt. 3	970, 920, 920	937
pt. 4	910, 880, 870	887
pt. 5	1040, 1020, 1020	1027
pt. 6	950, 950, 960	953 / 964 fpm

Hole 2 9:40 am

pt. 1	970, 990, 970	977
pt. 2	1020, 1020, 1030	1023
pt. 3	990, 980, 980	983 / 994 fpm

Hole 1 9:45 am

pt. 1	1040, 1030, 1040	1036
pt. 2	950, 960, 970	960
pt. 3	1000, 1010, 1000	1003 / 1000 fpm

Avg 986 fpm
x 1.466
= 1445 cfm

9/21/95

S-type pitot tube 16 pt. velocity traverse

James Heller (Dow Env.)

Rusty Kimbore

Hole 5
(new hole 2"
down stream of
Hole 1)

Hole 5

Pt	Length factor	16" ID	from opening Traverse pt. distance (inch)	sp. H ₂ O
8	0.032		.51 → 1"	~~1.0~~
7	0.105		1.68 1 1/16	
6	0.194		3.10 3 1/8	
5	0.323		5.17 5 3/16	
4	0.677		10.83 10 13/16	
3	0.806		12.90 12 7/8	
2	0.895		14.32 14 5/16	~~0.29~~ 84
1	0.988		15.49 → 15"	~~1.0~~ 84

Side	1	ΔP (in H ₂ O)	Temp (°F)
Start	2	0.09	74.2
probe position	3	0.09	74.0
from	4	0.08	74.0
inside	5	0.08	74.0
to	6	0.09	73.8
outside	7	0.10	74
	8	0.08	74.6
		0.07	76.

Dow Environmental Group
calculated the flow velocity

998 fpm

Top	9	0.08	78.8
	10	0.09	79
from	11	0.09	78
bottom	12	0.09	77
to	13	0.09	76
top	14	0.1	76
	15	0.08	76
	16	0.08	77

16" ID
 $V = 0.667 \text{ ft} = 1.40 \text{ ft}$

$$998 \times 1.40 = 1397$$

Static P - 0.28 in H₂O

DRAFT

AUDIT REPORT

Audit Performed by

Air Pollution Prevention and Control Division
National Risk Management Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

Quality Assurance No.	94029/II
Audit Type	Technical Systems and Performance Audit
Audit Date	September 20-21, 1995
Research Project	Open Molding Styrene Emissions Testing Project
Project Officer	Carlos M. Nunez Emissions Characterization and Prevention Branch (MD-61)
Auditors	Shirley J. Wasson QA Staff, Technical Services Branch (MD-49) Emery Kong Research Triangle Institute Research Triangle Park, NC 27709
Audit Site	The Dow Chemical Company Freeport, TX 77541-3257 Contact: Larry J. Craigie
Auditees	R. Lacovara, Project Director Composite Fabricators Association Arlington, VA 22209-2022 L. Craigie, QA Manager G. Webster, Project Supervisor M. Robertson, Laboratory Technician The Dow Chemical Company Freeport, TX 77541-3257

TABLE OF CONTENTS

- 1.0 Introduction
 - 1.1 Purpose of Audit
 - 1.2 Audit Preparation
- 2.0 Audit Summary
- 3.0 Audit Findings
- 4.0 Conclusions and Recommendations
- 5.0 Corrective Actions
- 6.0 References

Attachments

1.0 Introduction

1.1 Purpose of Audit

This audit evaluated the technical setup and performance of experiments to determine styrene emissions from hand lay up of fiberglass mat and polyester resin in an open molding process. Complete planning for the project is discussed in the Quality Assurance Project Plan (QAPP) for the Composites Fabricators Association "Open Molding Styrene Emissions Testing Project", dated September 1995. The project is being performed during the time period of September-October, 1995, at the site of The Dow Chemical Company, Freeport, TX. Composite Fabricators Association provided the leadership for the project. Dow provided consultation, physical facilities, equipment, operators of equipment and analytical instruments, laboratories, and supplies. The purpose of the project is to determine the styrene emissions from the open molding processes of hand lay up of resin, spraying of resin, and spraying of gelcoat. The auditors observed only the hand lay up portion of the project.

The purpose of the audit was to observe the adherence of project personnel to the QAPP and to check the performance of the critical measurements of exhaust air flow rate, hydrocarbon concentration in the exhaust duct, and weight. Air flow was produced and regulated by a fan and a damper and measured by sensors in the duct using a VorTec-SD system. All sampling ports, the velocity monitoring device, the damper and the fan are located on the roof on a horizontal section of the duct. The total hydrocarbon (THC) analyzer was calibrated per Method 25A using styrene standards connected by stainless steel lines to the calibration port of the analyzer. There was also a gas chromatograph/flame ionization detector (GC/FID) on line which took samples every 2 minutes. Sample probes were located in the exhaust duct and connected by stainless steel lines to the sampling ports of the analyzers. The sample lines were approximately 50 feet long, while the calibration lines were closer to about 15 feet. The audited balance was a Sartorius F61S, capable of reading several-kilogram quantities.

1.2 Audit Preparation and Activities

The QAPP and the responses to QAPP review comments were reviewed. A checklist was prepared, cylinders of styrene and propane were shipped to Dow, and the auditors brought with them to the audit a pitot tube, an incline manometer, an ALNOR micromanometer, and standard weights. The auditors traveled to Freeport on September 19 and spent September 20 and 21 at the Dow site. Hand lay ups were performed in the morning of both days. Exhaust air flow rate was measured by the auditors on both days, and also by Dow and VorTec Co. on the second day. The styrene and propane standards were measured on the first day, and the balance was checked with the standard weights.

EPA project officer Carlos Nunez was on premises during the morning of September 20, and was kept informed of audit progress. A closing meeting at which recommendations were made was held before the auditors left at about 2:30 p.m. on September 21.

After the auditors returned, Mr. Kong produced a preliminary report (see Attachment No. 1). Ms. Wasson reviewed the hardcopy data records for the test runs conducted on 9/18 (mass balance with pure styrene), 9/19 and 9/20 (hand lay ups of resin) (Attachment No. 2), and the electronic data record of the test conducted on 9/20 (see charts). She produced this report and followed up with Mr. Craigie by sending a report describing the correlation measurements between propane and styrene standards conducted in earlier experiments. Mr. Kong reviewed this report.

2.0 Audit Summary

The technical systems audit showed substantial adherence to the QAPP. (See the checklist--Attachment No. 3). The gel time and styrene content were conducted according to written procedures (Attachment No. 5). The standard data sheets were available and used for each run. A check of the calculations showed some minor errors.

The performance audit showed that the value for exhaust air flow rate entered into the Camile data collection system did not agree with measured values within the data quality indicator accuracy goal of ± 100 cfm. The value entered into the Camile system was 1600 cfm, but the value measured by the auditors was 1404 cfm, which is 196 cfm (12.5%) lower than 1600 cfm.

The performance audit also showed that the response of the THC analyzer to the 31 ± 0.62 ppm audit standard met the data quality goal of $\pm 10\%$, despite calibration difficulties. The mid-range calibration check of the THC analyzer did not meet the criteria of the QAPP. Calibration was performed with zero air, and span was set with an IWECO styrene standard of 280 ± 5.6 ppm. A mid-range standard of 175 ± 1.8 ppm was analyzed and found to be 196 ppm, 12% greater than its true value. The QAPP criteria for accuracy of the midrange standard check is 10%. Despite the calibration difficulties, the audit styrene gas was accurately analyzed within 3.9% of its true value.

The performance audit with standard weights showed that the Sartorius balance performs within the QAPP accuracy criteria of ± 0.004 lb (1.8 g).

Project personnel began immediate action to correct problems with the exhaust air flow measurements and with the THC analyzer calibration standards.

3.0 Audit Findings

- 1. Finding: Volumetric air velocity was not verified within the quality assurance objective of ± 100 cfm.**

On the first day of observation, the Camile data acquisition system reported a value of 1600 scfm for the volumetric air flow through the 16 inch diameter exhaust duct. The air flow is controlled by a VorTec air sensing system located in the duct. Because the existing port for velocity measurements was 2½ inches downstream of the VorTec velocity sensing device, turbulence was causing inaccurate anemometer and pitot tube readings. The auditors requested that new ports to be drilled, examined the air flow with a pitot tube at positions upstream of the sensor, and found the air flow to be approximately 1400 scfm through the duct. The system had been calibrated with a hot-wire anemometer but not with a pitot tube since being moved from its previous location with the other experimental apparatus in early summer, 1995. Also a computer board had been replaced the week before the observers arrived, and the VorTec had not yet been recalibrated.

- 2. Finding: The styrene mid-range calibration checks did not meet the $\pm 10\%$ criteria required by the QA plan.**

The procedure followed by the analyst performing the total hydrocarbon analysis was to perform a zero and span calibration with zero air and the nominal 280 ppm styrene standard in air. He then checked the agreement of the analysis of the mid range and low calibration gases with their certified values. These were required to agree within 10% of their true concentration. On the day of the audit (9/20/95, about 1 pm.), the span styrene cylinder standard was replaced with a new span standard, and a zero and span calibration was performed. The 175 ppm mid-range standard read 196 which was in error +12%, and the low standard, 99 ppm, read 101, off +2%. Thus the mid-range standard failed the calibration check.

Despite the failure of the mid range check standard, project personnel were able to analyze the styrene audit gas within +3.9% of its value. Using the above calibration curve, the concentration determined by the Camile system was 32.2 ppm for the 31.0 ± 0.62 ppm gas. A propane standard brought from RTI was also measured using the THC analyzer calibrated with styrene. Propane read 10.7 ppm styrene. Assuming a theoretical conversion factor of 8/3, the propane concentration was determined to be 28.5 ppm by project personnel for the 26.9 ± 1.3 ppm propane standard, a difference of +6%.

3. **Finding: The Sartorius balance used for weighing the resin was within tolerance limits of ± 0.004 lb (1.8 g), as required by the QA plan. The balance was certified as required.**

The Sartorius Model F61S balance used to weigh the resin before and after application read within 1 gram of the standard gram weights which were placed on the balance additively in the order 1, 5, 10, 20, 50, 100, and 500 grams. The balance had been certified by Aldinger Co., Dallas, TX, on 8/31/95.

4. **Finding: CFA/Dow personnel were prepared to perform the experimental procedure, and Dow personnel provided good analytical support for resin properties determination.**

The auditors observed two resin batch application hand lay ups. Also observed were the adjustments to the styrene content and gel time of the resin material to the values specified in the QA plan. Auditors received copies of the Dow work instruction procedures for the laboratory, the Laminator's Hand Batch Experiment Procedure, and the THA and GC Technician Experiment Parameters Check List. (See documentation in Attachment Nos. 2 and 5.) The QA plan was in place and available, custom blank work sheets had been prepared, and personnel were trained and experienced.

5. **Finding: Documentation of calibration standards, GC output, and verification of data entry and calculation should be improved.**

The Resin Analysis Work Sheet and the Resin Batch Work Sheet appear to contain all necessary information for determination of gel time, styrene content, and description of the run. The Camile system contains the time, temperature, THC analyzer concentration data, and airflow data, but not the GC data. GC output is on paper tape. The only record of it is in handwritten notes in the loose leaf project notebook. The paper tapes should also be preserved for the record, and for use in verifying the data entries. In checking the calculations for the work performed 9/18 and 9/19, there appear to be a few errors. The time span that data is recorded for the GC on Run 091895A is 132 minutes, not 142 minutes. The time span for Run 091895B is 88 minutes, not 89 minutes. For Run 091995B, the average for the concentration of the GC is 26.39 ppm, not 25.87 ppm.

The cylinder numbers linking specific styrene standards with the electronic records of the THC analyzer calibrations are not in the data records in the project notebook.

The baseline recorded on the Resin Batch Work Sheet of Run 3A, Block 2, run 09/20/95, lists a THA baseline of 0.5 ppm styrene, but the baseline is not subtracted from the 15.57 ppm average for the styrene concentration on Calsheet.xls92095, and the baseline is listed as "0" on the sheet. The effect of not subtracting background will be to report artificially high styrene emission factors.

6. **Finding:** Emission factors calculated from GC results and revised flow rate data appear reasonable and are consistent with other recent experimental results.

See Table 1. As before, these emission factors are higher than those in AP-42.

Table 1. Emission Factors Calculated from the First 3 Runs*

Run	Run Characteristics	Emission Factor (As % Available Styrene)
091995A	35.62% styrene 30.55 minutes gel time 1 ply laminate 50 fpm air flow rate (low)	21.6
091995B	42.94% styrene 14.45 minutes gel time 2 plies laminate 100 fpm air flow rate (high)	11.4
092095A	42.94% styrene 14.45 minutes gel time 1 ply laminate 50 fpm air flow rate (low)	18.9

* These figures are not background corrected.

4.0 Conclusions and Recommendations

The auditors concluded that the project was proceeding according to plan, but that it had two problems which required immediate corrective action, the measurement of exhaust air flow rate and the acquisition of stable standards for the analyzers. There were a number of specific recommendations.

1. Use propane standards for daily routine calibrations. Determine a correlation between styrene standards and propane standards before propane standards are used. The suggested concentration range for each emission study is as follows:

Resin spray up	0-800 ppm styrene or 0-2100 ppm propane
Gel coat spray up	0-500 ppm styrene or 0-1340 ppm propane
Resin hand lay up	0-200 ppm styrene or 0-530 ppm propane

Perform pure styrene evaporation mass balance tests when propane standards are in place. (Pure styrene evaporation tests are called for in the QAPP before each emission study.) We suggest that the styrene concentration be boosted to >50 ppm (by blowing a terry cloth towel soaked with styrene with a fan) for a shorter run of 20 to 30 minutes.

Re-analyze the audit styrene and propane standards left at the site by EPA and RTI to check against the new propane standards and the styrene correlation curve.

2. Conduct a mid-range and zero-air drift check after each test run. Or, make the drift check part of the full-range calibration for the next test run.
3. Enter the correct exhaust air flow rate into the Camile system, and check the centerline velocity with a pitot tube at least weekly to verify the VorTek velocity measurement. Check against the Δp measurement from the incline manometer.

Because experiments had been conducted on 9/18, 9/19, 9/20, and 9/21 with the erroneous exhaust air flow rate entered into the Camile system, recalculate the experimental results of those days using the correct exhaust air flow rate measurement. Calculate the results using both the THC analyzer concentration data and the GC/FID concentration data and compare them. Correct the average concentrations for background.

4. Press the calibration button on the Sartorius balance readout to conduct an internal calibration check before each test run.
5. Review documentation and verification procedures for project.

5.0 Corrective Actions

Project personnel began corrective actions immediately upon discovery of the problems with the measurement of exhaust air flow rate and styrene stability. The project director and QA manager immediately called in technical personnel from VorTec Co. and from Dow's environmental group to assess with the auditors the measurement of the exhaust air flow rate. The **VELOCITY DETERMINATION** sheet of 9/21, signed by James Heller, confirmed that the rate entered into the Camile system was low. (See attachment.) The velocity measurement was conducted in a new port (port number 5 in Kong's notes) upstream of all sampling probes so that the velocity was measured without obstructions. The velocity determined was 16.64 ft/sec (998 fpm). The cross section of the 16" diameter duct was 1.396 ft², to give a volumetric flow rate of 1394 scfm.

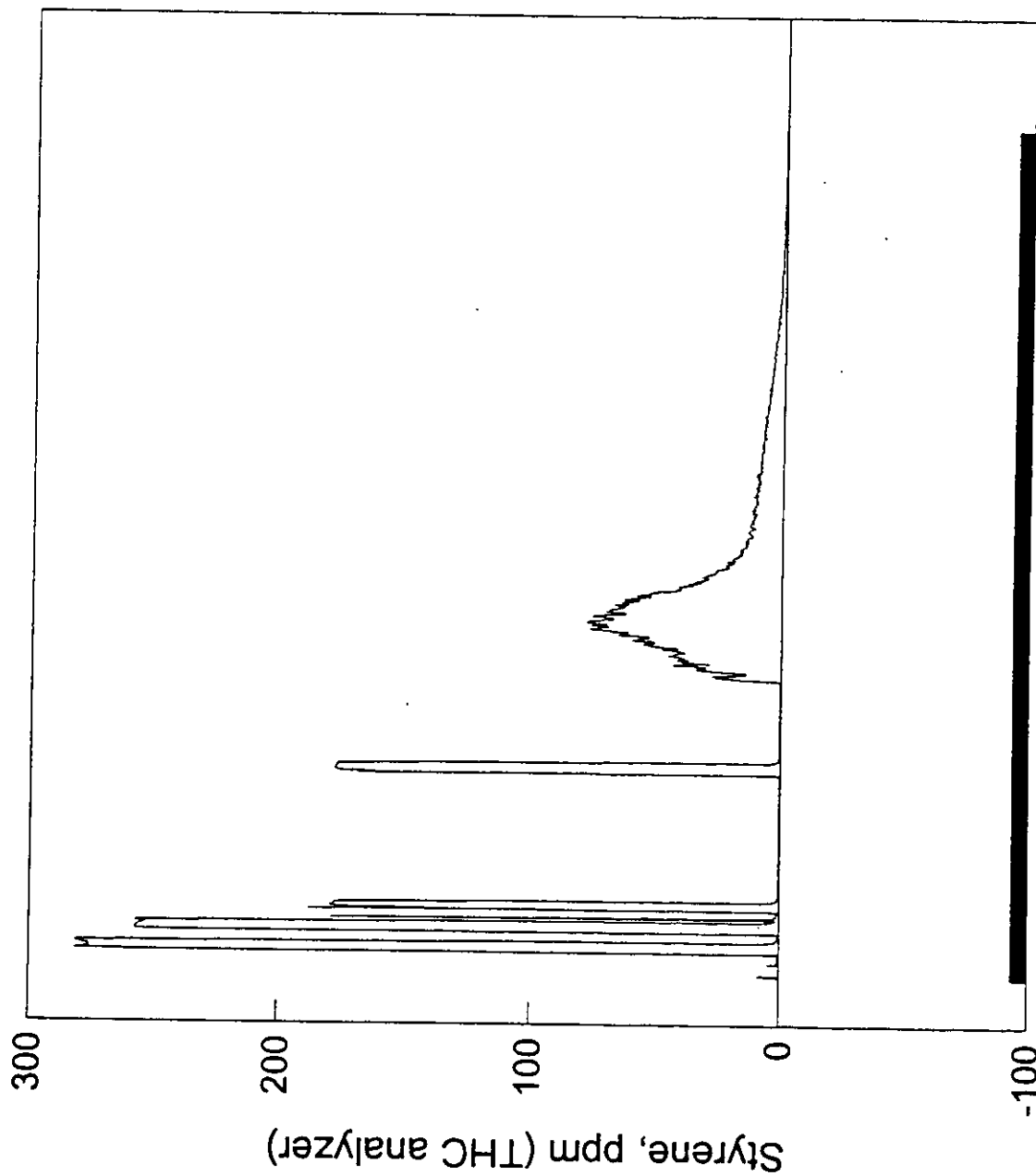
Because the calibration problems began when a new span standard was introduced, it was assumed that instability of the higher concentration styrene standards was responsible for the calibration mid range check standard failure. A number of new cylinders of styrene checked on 9/21 were also rejected by project personnel for poor performance. They concurred that propane standards may be more stable than styrene standards and would be suitable standards to consider for use in this project. They made arrangements to order the standards and to follow our suggestions for validating their use.

Project personnel agreed to implement our other suggestions.

6.0 References

1. Quality Assurance Project Plan, "Open Molding Styrene Emissions Testing Project", Composite Fabricators Association, September 1995, QTRAK No. 94029/APPCD Category II.
2. 40 CFR, Ch. 1, Pt. 60, App. A, Method 25A, "Determination of Total Gaseous Organic Concentration Using a Flame Ionization Analyzer".

Data of Run 092095A

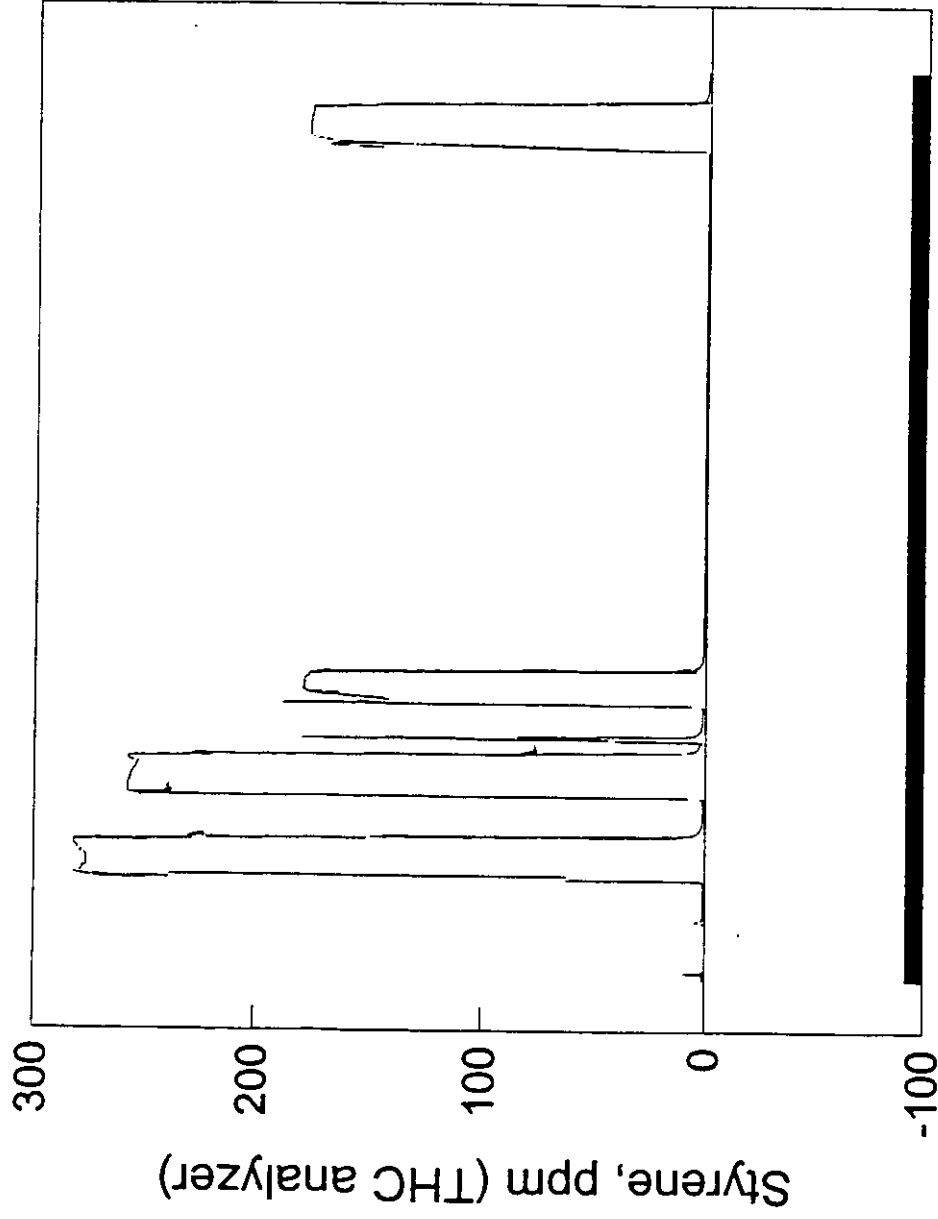


— Plot of F2 to F4000

TIME (2-sec intervals)

Cal Curve & Chk Std for 092095A Data

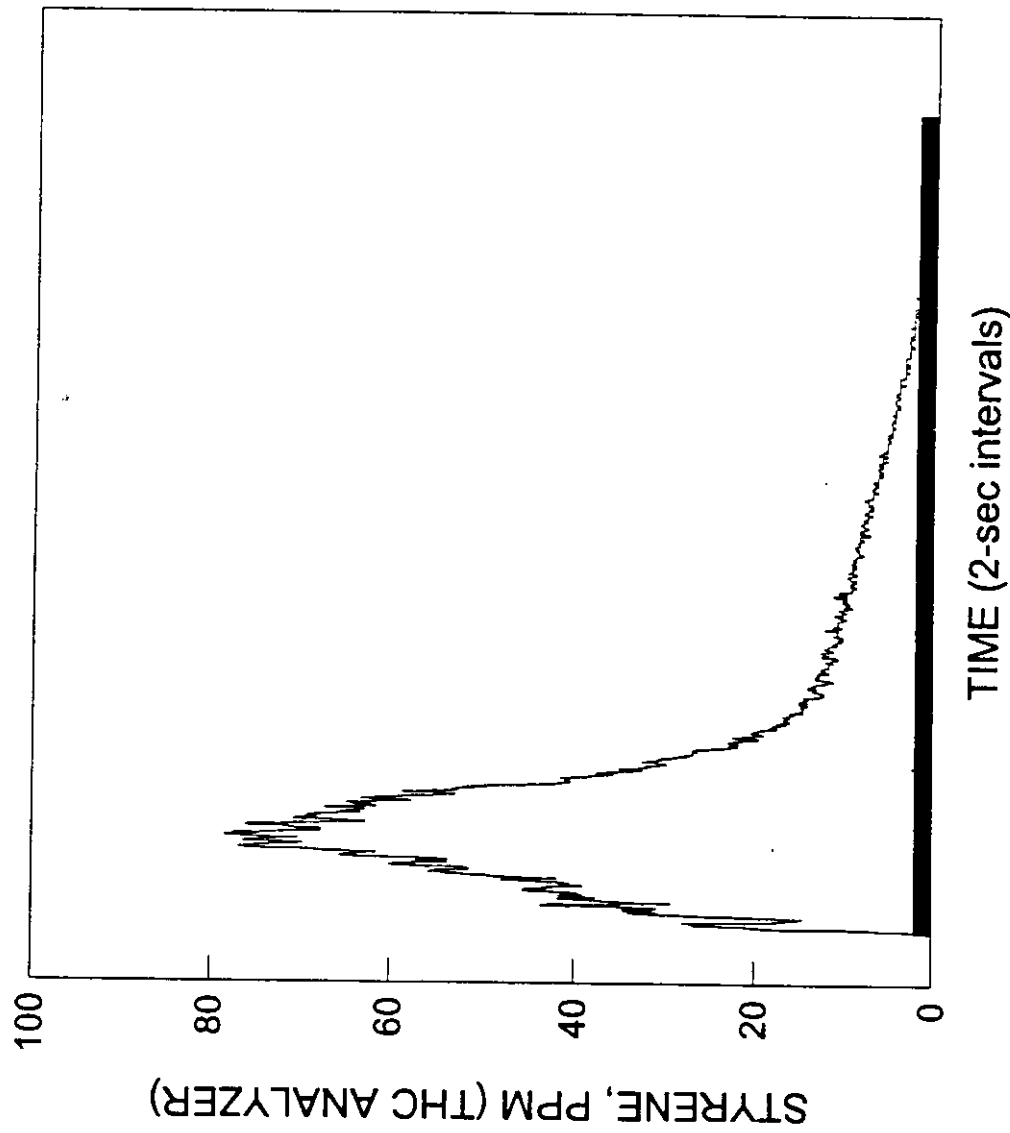
(261 ppm, 175 ppm styrene standards)



Sequence: Span, Span (or span check), Midrange chk, Midrange chk

092095A DATA

42.94% styrene, 14.45 min geltime



— PLOT OF F1391 TO F3768

1 ply laminate, 50 fpm flowrate (low)

15.5662 ppm average for time 08:48:54 to 10:09:02; 15.0546 ppm average (bkg subtracted)

Attachments

1. Preliminary report by Emery Kong dated September 26, 1995
2. Data records for 9/18, 9/19, and 9/20/95 for project experiments
3. Checklist from audit
4. **Velocity Determination** report from Dow environmental personnel
5. Dow work instruction operating procedures
 - a. Work Instruction for Sunshine Gel Timer
 - b. Work Instruction for the Determination of Solids Content in Epoxy Vinyl Ester Resins
6. Certified values for styrene standards in use at the time of audit

TECHNICAL SYSTEMS AUDIT QUALITY ASSURANCE CHECKLIST

National Risk Management Research Laboratory (NRMRL)

Air Pollution Prevention and Control Division

U.S. Environmental Protection Agency

Research Triangle Park, NC 27711

Audit Subject: Open Molding Styrene Emissions Project

Date: September 20 and 21, 1995

Contractor: None

Auditors: Shirley Wasson and Emery Kong

Location: Dow Chemical, Freeport, TX

Auditor Affiliation: EPA and RTI

The primary objective of the project is to measure styrene emissions from the open molding process to determine at the 95% confidence level which factors are significant in influencing styrene emissions and to estimate the magnitude of their effects. The spray application will be conducted in manner that represents common shop practices. (Project No. 6314-017-5)

AUDIT QUESTIONS	RESPONSE			COMMENTS
	Y	N	NA	
A. GENERAL				
1. Is a copy of the approved quality assurance (QA) plan maintained at the field site? If not, briefly describe how and where QA and quality control (QC) requirements and procedures for the project are documented.	✓			The QAPP was available in the room where experiments were conducted.
2. Are written and approved operating procedures (OPs) used in the project? If yes, list them below and note whether they are available to all users in the project. If not, briefly describe how and where the project procedures are documented. • Laminator's Hand Batch Experiment Procedure • THA and GC Technician Experiment Parameters Check List • Work Instruction for Sunshine Gel Timer • Work Instruction for the Determination of Solids Content in Epoxy Vinyl Ester Resins	✓			Procedures were available to appropriate project personnel.

TECHNICAL SYSTEMS AUDIT QUALITY ASSURANCE CHECKLIST *(continued)*

Audit Subject: Styrene Emissions from Open Molding Processes

Lead Auditor/Affiliation: Wasson/EPA

Date: September 19 and 20, 1995

AUDIT QUESTIONS	RESPONSE			COMMENTS
	Y	N	NA	
3. Are standard worksheets used to document each experimental run? If yes, does the record show the data ID designation; including the block number, run number, and date. If no, briefly describe how data are recorded. <i>(Section 5.0)</i>	✓			The Resin Batch Work Sheet contains all indicated information as the first four entries.
4. Are there established procedures for assessing whether quality objectives and measurement performance criteria are being met? If yes, briefly describe them. Are these assessments documented and consistent with the approved QA plan?	✓			The THA and GC Technician Experiment Parameters Check List is completed before each run, and verifies that all experiment parameters have been checked before the run starts.
5. The QA plan states that if one or more of the QA objectives are not met, specific experiments will be repeated and/or follow-up will be designed to examine the parameters relating to the QA objective. Evaluate adherence to the policy.	✓			Corrective action was immediately initiated for the problems identified during the audit.
Additional Questions or Comments:				

TECHNICAL SYSTEMS AUDIT QUALITY ASSURANCE CHECKLIST *(continued)*

Audit Subject: Styrene Emissions from Open Molding Processes

Lead Auditor/Affiliation: Wasson/EPA

Date: September 19 and 20, 1995

AUDIT QUESTIONS	RESPONSE			COMMENTS
	Y	N	NA	
B. SAMPLE CUSTODY				
1. Is a separate diskette used for each experimental run? If yes, is the appropriate ID designation recorded on the diskette label? Does the information contained on the diskette include the appropriate calibration data: either 80% of the span or the mid-range standard check? <i>(Section 5.0)</i>	✓	✓		Data are stored on the hard drive. Backup diskettes of all of the day's runs are prepared at the end of each day and stored in a place away from the experimental area.
Additional Questions or Comments:				
C. TEST FACILITY and EXPERIMENTAL DESIGN				
1. Sampling will be conducted using EPA Method 25A. The analytical units will use sampling probes in the form of pitot tubes inserted into two sampling ports located in the exhaust duct. Does the location(s) of the sampling ports allow for characterization of different sections of the duct? Have the operators verified that styrene concentrations do not vary across the duct? If not, how is the possibility of varying styrene concentrations and their effect on the end use of the data or the project objective(s) addressed? <i>(Section 1.6)</i>	✓	✓		There are several available ports along the ductwork. If more are needed, they can be readily drilled. A traverse was conducted from the top and from the side of the duct to determine the Δp at each location. It varied from 0.08 to 0.10 inches of water. The Reynolds number calculated by one of the auditors indicated that the airflow in the duct is turbulent, therefore stratified styrene in the duct may not contribute much error compared to other measurements.

TECHNICAL SYSTEMS AUDIT QUALITY ASSURANCE CHECKLIST *(continued)*

Audit Subject: Styrene Emissions from Open Molding Processes

Lead Auditor/Affiliation: Wasson/EPA

Date: September 19 and 20, 1995

AUDIT QUESTIONS	RESPONSE			COMMENTS
	Y	N	NA	
2. Indicate below which of the gel coat formulas are used in the gel coat spray test: (Section 1.7.2) • •			✓	The gel coat spray test was not observed by the auditors.
3. Indicate below which of the four resin formulas are used in the resin spray test and in the resin batch test: (Section 1.7.2)				Resin batch identifications in the worksheet records indicate which resin formula is used.
4. The QA plan indicates that the styrene content for both the resin and gel coat will be determined before the initiation of each of the individual studies. When and how are samples taken for styrene content analysis and gel time determination? (Section 3.1.2)				Samples are taken for styrene content analysis and gel time determination usually the day before a batch is needed for a run, then adjustment to styrene content and gel time is made to individual 5-gallon batches.
5. Are test run times affected by the gel time? If yes, briefly describe any corrective actions. (Section 3.1.3)	✓			Test run times are determined by how long is required for the THC concentration to return to background.
6. Are measurements for the resin/gel coat usage during a spray test taken from a container? If yes, verify that the pump system starts and stops at the same position. Otherwise, explain how the possible introduction of error into this measurement (when considering the amount of material in the system) is addressed. (Section 3.1.7)			✓	The auditors did not observe any spray tests.

TECHNICAL SYSTEMS AUDIT QUALITY ASSURANCE CHECKLIST *(continued)*

Audit Subject: Styrene Emissions from Open Molding Processes

Lead Auditor/Affiliation: Wasson/EPA

Date: September 19 and 20, 1995

AUDIT QUESTIONS	RESPONSE			COMMENTS
	Y	N	NA	
7. Do all sampling episodes or runs deliver concentrations that are within the calibration range of each analytical unit? If no, indicate the run number and whether or not the data are retained or invalidated. If data are retained, are off-scale responses appropriately acknowledged and documented? <i>(Section 6.1; RTI comment #18)</i>	✓			There were no off-scale responses observed.
Additional Questions or Comments:				

TECHNICAL SYSTEMS AUDIT QUALITY ASSURANCE CHECKLIST *(continued)*

Audit Subject: Styrene Emissions from Open Molding Processes

Lead Auditor/Affiliation: Wasson/EPA

Date: September 19 and 20, 1995

AUDIT QUESTIONS	RESPONSE			COMMENTS
	Y	N	NA	
D. INSTRUMENT CALIBRATION and CALIBRATION STANDARDS				
1. The acceptable accuracy for calibration checks using the 80% of scale span gas is $\pm 10\%$ from the predicted response. The QA plan states that accuracy checks will not be conducted during actual data collection. If the total hydrocarbon analyzer (THA) requires recalibration before the second run of the day, what criteria are used in deciding whether or not the previous test should be invalidated? <i>(Section 6.1)</i>				The auditors recommend that zero and mid range drift checks be conducted after every run and that the criteria specified in Section 6.1 of the QAPP be applied.
2. The QA plan states that all gas standards have a shelf-life of at least six months. RTI has found that styrene standards above 200 ppm are unstable; the concentration decreases with age on a time scale of weeks. Review the documentation that verifies the concentration of the 174-, 280-, and 350-ppm calibration standards. Briefly describe the procedure used to evaluate the stability of the styrene concentration for each standard.				Documentation attached for the styrene standards. Stability in question. Auditors proposed propane standards.
3. Evaluate changes in the linearity of the daily calibration for the THA. Briefly describe corrective actions for episodes of nonlinearity.				Addressed in main body of report.
4. For the catalyst flow rate calibration, is the specific gravity of the catalyst used to convert volume to mass? If so, briefly describe how the specific gravity is determined.			✓	Spray operations not observed.

TECHNICAL SYSTEMS AUDIT QUALITY ASSURANCE CHECKLIST *(continued)*

Audit Subject: Styrene Emissions from Open Molding Processes

Lead Auditor/Affiliation: Wasson/EPA

Date: September 19 and 20, 1995

AUDIT QUESTIONS	RESPONSE			COMMENTS
	Y	N	NA	
5. Evaluate the consistency between concentration results using the GC and the THA. <i>(Section 4.3.2)</i>				The concentration results from the GC varied from +16.4% to -7.1% compared to the results from the THC analyzer during the time period 9/18 through 9/20. The auditors expect improvement in consistency with the introduction of propane standards.
Additional Question or Comments:				
E. DATA REDUCTION				
1. Briefly describe how the styrene emissions, as opposed to the styrene concentrations, are determined.				See Section 3.3 (page 26) of QA plan.
2. Is the maximum styrene concentration a surrogate for the total emissions?	✓			
3. Are the concentrations measured by the THA integrated to determine the total grams of styrene emitted?		✓		An average concentration was calculated for the duration of the test run.
4. How is uncertainty in the total emissions calculated or determined?				ANOVA

TECHNICAL SYSTEMS AUDIT QUALITY ASSURANCE CHECKLIST *(continued)*

Audit Subject: Styrene Emissions from Open Molding Processes

Lead Auditor/Affiliation: Wasson/EPA

Date: September 19 and 20, 1995

AUDIT QUESTIONS	RESPONSE			COMMENTS
	Y	N	NA	
Additional Questions or Comments:				
F. INTERNAL QC CHECKS				
1. The manometer located in the vent hood stack is used to monitor changes in air flow through the total temporary enclosure (TTE). Are there any indications that the flow is not constant? If yes, what was the frequency of in-duct S-tube differential pressure checks?		✓		The manometer is checked periodically and usually reads about 0.10 inches of water. The auditors recommended that this reading be added to the run checklist.
2. A summary of physical measurements is given in Table 1.7.1 of the QA plan. Verify that the frequency for conduct of all critical measurements is as outlined. Note deviations from the approved plan and evaluate documentation approving the deviation from the approved plan.				All applicable critical measurements were observed except wet laminate thickness and air flow over mold. (Measurements pertaining to gelcoat and resin spray up experiments were not observed.)
3. The QA plan states that wet laminate/film thickness, resin/gel coat styrene content, gel time, resin/gel flow rate, air flow over mold and ambient temperature are measurements of the process which must be controlled in order to derive the necessary resolution from the collected data. Using Table 3.1 verify the adherence to QA objectives for each of the above.				Wet laminate thickness and air flow over mold measurements were not observed. Other critical measurements met criteria with the exceptions noted in the body of the report. (Measurements pertaining to gelcoat and resin spray up experiments were not observed.)

TECHNICAL SYSTEMS AUDIT QUALITY ASSURANCE CHECKLIST (continued)

Audit Subject: Styrene Emissions from Open Molding Processes

Lead Auditor/Affiliation: Wasson/EPA

Date: September 19 and 20, 1995

[illegible]

Mr. Larry Craigie, Dow Chemical Company
Mr. Bob Lacovara, Composites Fabricators Association

AUDIT OF QAPP FOR THE COMPOSITES FABRICATORS ASSOCIATION OPEN MOLDING STYRENE EMISSIONS TESTING PROJECT

Submitted by
Bill Davis
10-26-95

Audit Objective: The purpose of this audit was to determine whether, or not, sampling, analyses, and data handling procedures were being followed as prescribed by the quality assurance project plan (QAPP).

The audit found that the QAPP has been conducted by operating personnel as described by the plan with calibration and emission values being well documented. However, there have been some exceptions to the QAPP as originally described. They are as follows:

1.) Section 6.1 Total Hydrocarbon Analyzer Calibration Procedure

Exception to the $\pm 10\%$ response from the predicted response.

During the calibration checks for hand lay-up emission tests the following styrene standards were used: 175 ppm, 99 ppm, and 49 ppm.

About 75% of the time, including calibration checks and drift checks, the THA value for the 49 ppm standard was outside the $\pm 10\%$ specified required accuracy from the predicted response. The values outside the $\pm 10\%$ specification averaged 5.5 ppm; the maximum allowable being 4.9 ppm.

The testing was not stopped for the following reasons:

- a.) the THA, calibrated by the standards listed previously, when used to check a styrene standard provided by the EPA, yielded a value within ± 2 ppm from the stated concentration of 31 ppm styrene,
- b.) the THA, calibrated by the standards listed previously, yielded an approximate 95% recovery for the styrene mass balance checks performed before the hand lay-up part of the study,
- c.) the same standards were used when EPA and RTI personnel were present during the initial phase of testing. No negative comments were made about the THA calibration. The EPA personnel did suggest that propane standards be used in place of styrene standards since propane standards are essentially stable throughout their life.
- d.) and finally, the total styrene emissions per run obtained by the gas chromatograph compared quite favorably with those obtained by the THA.

2.) Section 6.3 Air Flow Through the TTE Calibration

Exception to method used to verify the air flow through the TTE

An Airdata Multimeter Electric Micromanometer was used to determine air flow through the TTE each Monday during test runs. The Airdata Multimeter Electric Micromanometer is set to perform as a pitot tube. Traverse readings are taken one inch from each side of the duct wall and in the middle of the duct. At each position, three air flow measurements were taken and averaged. The resulting six averaged reading values were then averaged to determine the air flow through the TTE.

Early in the study, this method for determining air flow was performed in conjunction with air flow measurements taken by the EPA using a pitot tube. The two methods were found to be comparable at that time.

3.) Section 3.1.5 Air Flow

Exception to verifying air flow prior to the start of individual studies.

The air flows over the mold were not verified before the hand lay-up study as described in Table 3.3, Quality Assurance Objectives for Critical and Non-Critical Measurements. However, prior to any testing, the dampers were adjusted and settings marked to maintain the required air flows over the mold.

After the hand lay-up study was complete and prior to the start of the gel coat study, the air flows were verified as described in Table 3.3. That verification was used for both the hand lay-up and gel coat study.

4.) Section 6.1 Total Hydrocarbon Analyzer Calibration Procedure

Exception to using styrene standards for determining total styrene emissions.

At EPA's personnel recommendation, the styrene standards were replaced with propane standards after the hand lay-up portion of the study. Prior to starting the gel coat study the propane-to-styrene correction factor was determined to be 0.453 for the Thermo Environmental Instruments, Inc. Model 51 Total Hydrocarbon Analyzer. Two styrene mass balance checks yielded recoveries greater than 99% using the determined correction factor.

5.) Section 6.4.1 Spray Gun's Flow Rate Calibration

Exception to calibrating the spray gun's flow rate prior to each gel coat test run.

The spray gun's flow rate was not checked for calibration during the first five gel coat test runs. However, the pressures and tip sizes required to obtain the desired flow rates for each gel coat used were determined prior to the gel coat study. These settings were used during the first five gel coat test runs. Subsequent gel coat test runs have had the spray gun's flow rate checked for calibration. All of the flow rates have been correct for all the gel coats at both flow rates used with no adjustments to the prior determined pressures and tip sizes. This is a strong indication that the spray gun's flow rates for the first five gel coat test runs were within the required limits.

A massive amount of data has been collected, and overall the data quality has met or exceeded the criteria set forth in the QAPP.

If you should have any questions, please feel free to contact me at any time.

A handwritten signature in black ink, appearing to read "Bill Davis". The signature is fluid and cursive, with the first name "Bill" and last name "Davis" clearly distinguishable.

Bill Davis
QAPP QA Coordinator

**Stack Testing Team
Texas Environmental Analytical Laboratory
Dow Chemical USA
Freeport, Texas**

Name: Gary Webster
Dept: Resins R&D
Bldg: B-1603
Source: B-1603 Duct

Date: October 4, 1995
Report: B1603-Duct-0995-0089
Testing Date: September 21, 1995
Charge: 1262

FLOW RESULTS FOR B-1603 DUCT

Purpose The flow was measured in the B-1603 Duct to check the pitot tube in the duct.

Personnel The Teal stack testing team consisted of James Heller and Rusty Kimbrell.

Methods The flow was measured using EPA method 2. Moisture was determined based on relative humidity. The oxygen content was assumed to be 20.9%, wet basis.

Results

PARAMETER	RESULT
Duct Temp (F)	76
Barometric Press (inches Hg)	29.95
Static Pressure (inches H ₂ O)	-0.28
Stack moisture content (percent)	1.8
Stack velocity (ft/sec)	16.6
Stack flow (actual cubic feet/hr)	8.34×10^4
Stack flow (dry std cubic feet/hr)	8.04×10^4

Leslie E. Bates 2/5/96
Leslie E. Bates/Date
Environmental Services

C. A. Roorda 2/5/96
Reviewed by/Date

xc: C. A. Roorda, B-2009

VELOCITY DETERMINATION

Facility/Unit: Resin R.DRun #: 1Sample Date: 9-21-95Description: duct velocityBarometric Pressure (P_{bar}): _____ "HgStack Temp. Sensor ID: I-1Stack Gas Molecular Wt. (M_s): _____Absolute Stack Temp. in °R = (T_s)

Traverse Pt.	ΔP (in H ₂ O)	Temp. (°F)
1	0.30 .10.09	84 74
2	0.30 .09	84 74
3	0.28 .08	74
4	0.28 .08	74
5	0.30 .09	73.8
6	0.32 .10	74
7	0.28 .08	75
8	0.26 .07	76
9	0.28 .08	77
10	0.30 .09	79
11	0.30 .09	78
12	0.30 .09	77
13	0.30 .09	76
14	0.32 .10	76
15	0.28 .08	76
16	0.28 .08	77
17		
18		
19		
20		
21		
22		
23		
24		

Velocity Calculation:

1. Sum the square roots of all Δp 's and divide this by n, the number of Δp 's.

$$Avg. \sqrt{\Delta p} = \frac{\sum \sqrt{\Delta p}}{n}$$

$$Avg. \sqrt{\Delta p} = \frac{(4.694)}{(16)} = .293 \sqrt{\text{H}_2\text{O}}$$

2. Obtain the Pitot Tube Coefficient (C_p) for the probe used. $C_p = 0.84$. Probe No. I-1

3. Calculate Absolute Stack Press.:

$$\begin{aligned} \text{Measured Gauge Pressure} &= (P_g) \\ &= -0.28 \text{ "H}_2\text{O (may be + or -)} \\ &\times 0.07355 = -0.02 \text{ "Hg} \end{aligned}$$

$$\text{Absolute Stack Pressure} = (P_s)$$

$$\begin{aligned} P_s &= P_g(\text{"Hg}) + P_{bar}(\text{"Hg}) = \\ &(-0.02) + (29.95) = 29.93 \text{ "Hg} \end{aligned}$$

4. Calculate velocity, v_s , in ft/sec as shown below.

$$v_s = \left(85.49 \text{ ft/sec} \left[\frac{(\text{lb/lb-mole})(\text{"Hg})}{(^{\circ}\text{R})(\text{"H}_2\text{O})} \right] \right) (C_p) \sqrt{\frac{(T_s)_{avg.}}{(M_s)(P_s)}} (avg \sqrt{\Delta p})$$

$$v_s = (85.49)(0.84) \sqrt{\frac{(536^{\circ}\text{R})}{(28.64)(29.93 \text{ "Hg})}} (.293) = 16.64 \text{ ft/sec}$$

Signature/Date: James P. MillerChecked By/Date: 9-21-95

Report #: _____

TRAVERSE POINTS LAYOUT FOR CIRCULAR STACKS

Facility: _____

Date: 9-21-95

TRAVERSE POINT #	LENGTH FACTOR	STACK ID (in.)	TRAVERSE POINT DISTANCE (Decimal-in.)	TRAVERSE POINT DISTANCE (Fraction-in.)	PORT EXTENSION (in.)	PROBE LENGTH (in.)
1	0.032	x 16	= .51	$\frac{1}{2} \approx 1"$	+	=
2	.105	x 16	= 1.68	$1 \frac{1}{16}$	+	=
3	.194	x 16	= 3.10	$3 \frac{1}{8}$	+	=
4	.323	x 16	= 5.17	$5 \frac{3}{16}$	+	=
5	.677	x 16	= 10.83	$10 \frac{13}{16}$	+	=
6	.806	x 16	= 12.90	$12 \frac{7}{8}$	+	=
7	.895	x 16	= 14.32	$14 \frac{5}{16}$	+	=
8	.968	x 16	= 15.49	$15 \frac{1}{2} \approx 15"$	+	=
9		x	=		+	=
10		x	=		+	=
11		x	=		+	=
12		x	=		+	=
13		x	=		+	=
14		x	=		+	=
15		x	=		+	=
16		x	=		+	=
17		x	=		+	=
18		x	=		+	=
19		x	=		+	=
20		x	=		+	=

Signature / Date _____

Checked by / Date _____

Draft

MEMORANDUM

Date: November 16, 1995

To: Geddes Ramsey

From: Emery J. Kong

Subject: Second Performance Audit for the CFA's Styrene Emission Study at the Dow Chemical Freeport Facility between November 13 and 15, 1995.

The U.S. EPA and Research Triangle Institute (RTI) personnel conducted a performance audit on the Composites Fabricators Association's (CFA) styrene emission study at the Dow Chemical Company's Composites Research Laboratory in Freeport, Texas between September 20-21, 1995. Following the audit, the EPA and RTI auditors made several recommendations to CFA and Dow to improve their emission measurement and data quality. Two major recommendations were (1) to set correct exhaust flow rate to the Camile data requisition system and (2) to use propane standards for routine instrument calibration because styrene standards might not be stable at concentrations higher than 200 ppm.

This report documents and summarizes the results of a second performance audit conducted by Emery Kong of RTI on behalf of the EPA. The audit was performed between November 13 and 14, 1995, at the Dow Chemical facility before the resin sprayup experiment. The audit included verification of the exhaust flow rate from the enclosure and the performance of the Thermal Environmental Instruments, Inc. Model 51 THC analyzer. The verification showed that the average exhaust flow rate was at 1,474 cfm, which was in agreement with the Camile system readout, and the propane-to-styrene conversion factor was 0.4355, which is similar to 0.435 that Dow personnel determined earlier. The new conversion factor was provided to Dow personnel for future calibration.

Two resin sprayup test runs were conducted on November 15, 1995. By observing the amount of overspray on the floor and on the wall cover, I concluded that the spraying techniques did not represent typical or normal application conditions in the shop. In order for the test results to be considered baseline emissions, the amount of overspray should increase.

The results of this audit indicate that the Dow and CFA personnel have made substantial improvement on their styrene emission measurement and exhaust flow rate measurement and these two critical measurements were within the accuracy specified in their Category II quality assurance project plan (QAPP). However, the spraying should extend beyond the flange in order to simulate normal spraying technique. Otherwise, the test results generated using the current spraying technique should not be considered baseline emission and should be considered controlled spraying emissions.

The following sections describe the audits performed for the exhaust flow rate and the propane and styrene standards on the THC analyzer.

(1) Exhaust flow rate

The exhaust flow rate was verified using a standard pitot tube and a micromanometer at the exhaust stack on the roof between 4 and 4:30 pm on November 13, 1995. The Dow personnel determined the exhaust flow velocities in the stack using a 16-inch standard pitot tube and an Airdata Model 8420 electronic micromanometer. The first velocity measurement averaged 1,007 ft/min and the calculated exhaust flow rate was 1,476 cfm assuming a cross-sectional area of 1.466 ft². A second velocity measurement 15 minutes later gave an average of 1,005 ft/min or 1,474 cfm. These two flow rate measurements were in agreement with the average flow rate, 1,470 cfm, determined from the Camile system between 2:24 pm and 4:34 pm on November 13, 1995. The exhaust flow rate was verified to be within 100 cfm as required in the QAPP.

(2) Styrene emission measurement

The propane-to-styrene conversion factor developed by the Dow personnel on the THC analyzer for a series of propane standards (prepared by IWECO, Inc. on September 29, 1995) and a series of styrene standards (prepared by IWECO, Inc. on August 30, 1995) was 0.453. The conversion factor was different from a theoretical value of 3-to-8 carbon ratio (0.375) for propane and styrene and from a conversion factor of 0.3722 RTI got on a Ratfisch THC analyzer in June 1995. There was a concern from the EPA QA officer that the conversion factor developed on the Thermal Environmental Instruments, Inc. Model 51 THC analyzer was not correct.

I asked Mr. Webster of Dow to perform the following verification on the model 51 THC analyzer and used the results to determine a conversion factor.

- Enter zero air to the THC analyzer to set a zero. (The concentration range on the THC analyzer was 0 to 1,000 ppm styrene and the all calibration gas flow rates were 4.5 scfh at a back pressure of 9 psig.)
- Manually span the THC analyzer using a 1,800 ppm propane standard and assign 675 ppm equivalent styrene (based on a 0.375 theoretical ratio) to the full span.
- Span check all available propane standards.
- Fit a calibration line through the certified and measured concentrations for all propane standards.
- Span check all available styrene standards using the existing full span from the propane standards.

➤ Fit a calibration line through the certified and measured concentrations for all styrene standards.

➤ Calculate a propane-to-styrene conversion factor from the ratio of the slopes of these two calibration lines.

The results of this verification is shown in the following tables and figure. The new conversion factor, 0.4355, was provided to the Dow personnel to convert propane standards to equivalent styrene concentration in the THC calibration procedure so that the measured emissions can be expressed as equivalent styrene concentration.

Table 1. Calibration Line for Propane Standards on 11/14/95

Time	Propane, ppm	As styrene, ppm (based on a 3/8 carbon ratio) X	THC reading, ppm as styrene Y	Selection on THC analyzer
10:12 am	1,800 (Dow, K779751)	675	675	Manual spanning
10:15 am	1,066 (Dow, LK-435476)	400	388	Span check
10:19 am	1,066 (Dow, LK-435476)	400	392	Span check
10:21 am	667 (Dow, LK-268949)	250	246	Span check
10:26 am	160 (Dow, LK-441142)	60	56.9	Span check
10:30 am	400 (Dow, H-012074)	150	144	Span check
10:35 am	267 (Dow, LK-431574)	100	96.4	Span check
10:39 am	454 (RTI, A-009797)	170	161	Span check
10:43 am	26.9 (RTI, A12158)	10	8.9	Span check
$Y=0.373628X-3.868216$, $r^2=0.99967$				

Table 2. Calibration Line for Styrene Standards on 11/14/95 (using existing full span based on 1,800 ppm propane standards).

Time	Styrene, ppm X	THC reading, ppm as styrene Y	Selection on THC analyzer
1:07 pm	49 (Dow, CC-9565)	36.5	Span check
1:12 pm	99 (Dow, CC-108922)	79.7	Span check
1:17 pm	349 (Dow, CC-20237)	304	Span check
1:24 pm	560 (Dow, CC-112889)	475	Span check
1:27 pm	31 (EPA, ALM-057764)	25.7	Span check
1:37 pm	81.5 (RTI, BAL-3703)	49.1(excluded from standard curve fitting)	Span check
Y=0.857957X-2.09281, $r^2=0.99955$			

Conversion factor from propane to styrene = ratio of slopes = $0.373628/0.857957$
 $=0.4355$. The new conversion factor, 0.4355, is 96.14 percent of the previous conversion factor,
0.453, calculated by Dow. This implies that the previous styrene measurements were 4 percent
off; however, the difference was within 10 percent of the measurement and might not warrant a
revision of previous measurements.

cc: Shirley Wasson, EPA/APPCD
Carlos Nunez, EPA/APPCD
Larry Craigie, Dow
Bob Lacovara, CFA

Verification of propane to styrene conversion factor on 11/14/95

conversion factor from propane to styrene
 = ratio of slopes

$$= \frac{0.873628}{0.857957} = 0.4355$$

span check styrene standards
 using existing propane fullspan

$$Y = 0.857957 X - 2.09281$$

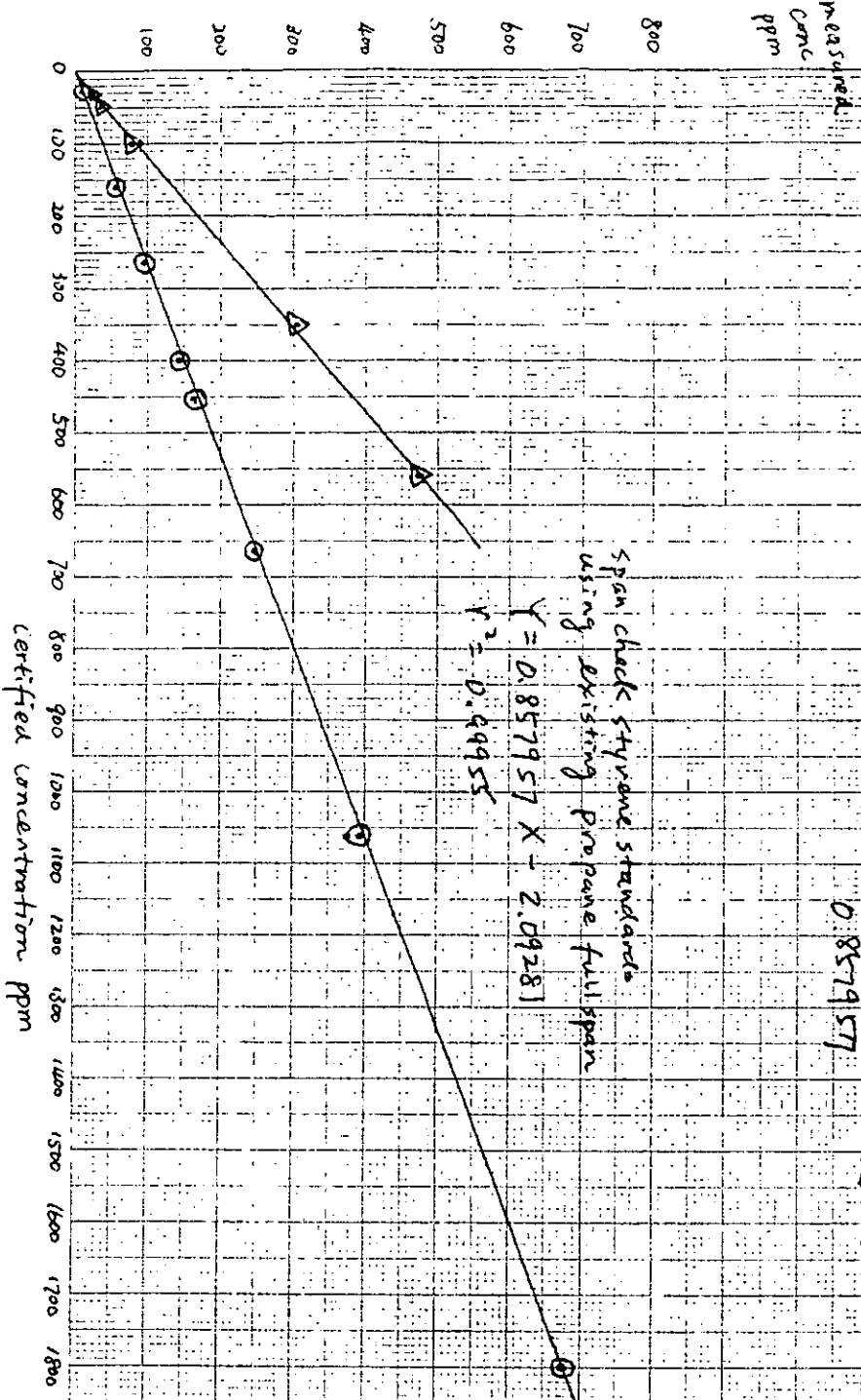
$$r^2 = 0.99955$$

Propane standards calibration
 curve span at 1800 ppm propane
 (or 675 ppm as styrene)

$$Y = 0.373628 X - 3.868216$$

$$r^2 = 0.99967$$

(1800 ppm propane was
 calculated to styrene using
 3/8 carbon ratio and
 entered to TMA fullspan)



Appendix C

QUALITY ASSURANCE PROJECT PLAN
FOR THE
COMPOSITES FABRICATORS ASSOCIATION
OPEN MOLDING STYRENE EMISSIONS TESTING PROJECT

September 1995

Revision 5.0

TABLE OF CONTENTS

Section 0.0	Introduction / Signature Page	p. 5
Section 1.0	Project Description	p. 7
Section 2.0	Project Organization and Responsibilities	p. 19
Section 3.0	Data Quality Indicator (DQI) Goals for Critical Measurements	p. 21
Section 4.0	Site and Sampling Procedures	p. 27
Section 5.0	Sample and Data Custody	p. 33
Section 6.0	Calibration Procedures and Frequency	p. 34
Section 7.0	Analytical Procedures	p. 39
Section 8.0	<i>Data Reduction, Validation and Reporting</i>	p. 41
Section 9.0	Internal Quality Control Checks	p. 48
Section 10.0	Audits	p. 50
Section 11.0	Data Quality Indicators	p. 51
Section 12.0	Corrective Action	p. 52
Section 13.0	References	p. 53
Section 14.0	Appendix	p. 54

List of Tables

Table 1.7.1.1	Resin Spray Application Emission Study
Table 1.7.1.2	Gel Coat Spray Application Emission Study
Table 1.7.2.1	Resin Batch Application Emission Study
Table 1.7.3.1	Summary of Physical Measurements for Styrene Emission Study
Table 3.1	Quality Assurance Objectives for Critical and Non-Critical Measurements
Table 3.2	Capture Efficiency of Analytical Equipment
Table 8.1	Coefficient Designations for Factor Levels
Table 8.2	Terms of the Parameter estimates for the Model
Table 8.3	Evaluation of the Model: Effects Table
Table 8.4	ANOVA Table for Lack-of-Fit

List of Figures

Figure 1.6.1	Temporary Total Enclosure
Figure 4.2.1	Calibration Check for the Total Hydrocarbon Analyzer, 80% of Span
Figure 4.3.1.1	Simplified Piping Design for Calibration of GC and Sampling
Figure 4.3.1.2	Piping Design for Calibration and Sampling
Figure 8.1	Example of an Interaction Profile

Section 0.0 INTRODUCTION

0.1 Purpose Of The Quality Assurance Project Plan (QAPjP)

The purpose of this QA Project Plan is to describe the objectives of the CFA Open Molding Styrene Emissions Testing Project, and to relate the intended measurements to those objectives. This plan will detail specific measurements and quality assurance procedures required to achieve the goals of the project.

0.2 Quality Assurance Category

This is a Category II project which will produce results that complement other inputs. This project is of sufficient scope and substance that the results may be combined with those from other projects of similar scope to produce information for making rules, regulations or policies. In addition, this is a high visibility project in the composites industry and will be used to provide input to both Federal and State rule making agencies.

0.3 QA Project Plan Approval Form (Signature Page)

QUALITY ASSURANCE PROJECT PLAN APPROVAL PLAN FORM

QA ID No: 001 Project Category: Category II Workplan No: 1Contractor: Composites Fabricators Association / Dow Chemical, Freeport, TXQA Project Plan Title: CFA Open Molding Styrene Emissions Test ProjectRevision Date: September 9, 1995, Revision 5.0

COMMITMENT TO IMPLEMENT THE ABOVE QA PROJECT PLAN:

<u>R. Lacovara</u>	<u>[Signature]</u>	<u>9-14-95</u>
PROJECT DIRECTOR (PRINT)	SIGNATURE	DATE
<u>L.J. Craigie</u>	<u>[Signature]</u>	<u>9-11-95</u>
QA MANAGER (PRINT)	SIGNATURE	DATE
<u>B. Davis</u>	<u>[Signature]</u>	<u>9-11-95</u>
QA COORDINATOR (PRINT)	SIGNATURE	DATE
<u>T. COWLEY</u>	<u>[Signature]</u>	<u>9-18-95</u>
PROJECT MANAGER (PRINT)	SIGNATURE	DATE
<u>G. WEBSTER</u>	<u>[Signature]</u>	<u>9/19/95</u>
PROJECT SUPERVISOR (PRINT)	SIGNATURE	DATE
<u>PAUL L. WYKOWSKI</u>	<u>[Signature]</u>	<u>9/19/95</u>
PROJECT LEADER (PRINT)	SIGNATURE	DATE

APPROVAL TO PROCEED IN ACCORDANCE WITH THE ABOVE QA PROJECT PLAN:

<u>CARLOS M. NUNEZ</u>	<u>[Signature]</u>	<u>9-14-95</u>
EPA PROJECT OFFICER. (PRINT)	SIGNATURE	DATE
<u>SHIRLEY WASSON</u>	<u>[Signature]</u>	<u>9-14-95</u>
FOR NANCY ADAMS	SIGNATURE	DATE
EPA QA OFFICER (PRINT)	SIGNATURE	DATE

OTHER AS APPROPRIATE (PRINT)	SIGNATURE	DATE

OTHER AS APPROPRIATE (PRINT)	SIGNATURE	DATE

Section 1.0 PROJECT DESCRIPTION

1.1 Background

The development of air emission standards for the reinforced plastic composites industry and the need for pollution prevention implementation will require definitive baseline data on styrene emissions from the open molding process.

The purpose of this study is to measure styrene emissions from polyester resin spray-up application, polyester gel coat spray application and polyester resin hand batch application. The results will be reported as emissions by percent weight of styrene available, percentage of resin or gel coat weight and emissions weight per surface area.

The polyester resin spray-up application is defined as the use of a "chopper gun" to apply a laminate. The chopper gun dispenses polyester resin, catalyst and chopped glass fibers. An airless/air assist external mix spray gun has been selected for this program. Continuous strand fiberglass roving is fed to a chopper unit mounted on the spray gun and is cut into chopped fiber lengths of approximately 1.5" long. The chopped fiber is ejected from the chopper unit and is captured by the resin fan pattern a short distance from the spray gun. The mixture of the catalyzed resin and chopped fiber is deposited on the mold by the spraying action.

The polyester gel coat spray application will use the same airless/ air assist external spray gun as in the spray-up application, however, with the chopper unit removed. The gel coat and catalyst are again externally mixed by impingement after exiting the spray nozzles. This airless/air assist spray gun has been selected as representing the most commonly used equipment in the industry, according to the CFA 1994 Benchmarking Survey.

The spray application will be conducted in a manner which represents common shop practices. Overspray will be produced in a manner consistent with many actual production operations. A study of video taped spray-up and gel coating operations indicated a fairly consistent pattern of overspray off mold edges. The observations reveal the average spray stroke extending approximately 6 inches off the edge of the mold. The time from leaving the edge of the mold to returning to the edge is between 0.32 and 0.78 seconds, with an average off-mold time of 0.55 seconds per stroke.

The mold used in these experiments has an edge dimension of 288 lineal inches. Assuming a resin or gel coat fan pattern width of 8 inches, the result is 36 strokes off the mold for a total "off-mold" spray time of 19.8 seconds. The approximate overspray area (disregarding spray angles) will be 1728 square inches or 12 square feet of "off-mold"

spray. Follow-up testing will be conducted to examine the effects of minimizing overspray and to compare common spraying practice and best spraying techniques.

The polyester resin hand batch application produces a hand lay-up laminate where the resin and catalyst are manually mixed in a container and applied to the fiberglass reinforcement with a paint roller or brush. The saturated chopped strand mat is then compacted and air bubbles removed by the manual use of an serrated roller.

The accurate characterization of styrene emissions from this project will establish a baseline for subsequent studies to explore emissions reduction methods. A comprehensive Quality Assurance Plan to support the testing program will be in effect to prevent flawed data from leading to either ambiguous or misleading conclusions. Such conclusion could lead to incorrect methods of addressing emissions reduction in subsequent studies.

Investigations of available literature reveal that styrene emissions testing which has been done in the field presents an erratic and unacceptable range of results, which may be due to the uncontrolled environments in which the studies were conducted. This study will control environmental variables in order to isolate baseline emissions from the process.

1.2 Data Quality Objectives

The primary project objective is to measure styrene emissions from the open molding process and determine which factors are significant in influencing the styrene emission at the 95% confidence level and estimate the magnitude of their effects. The results from this study would provide the foundation for further study of the most significant factors to obtain a detailed analytical model.

Variables to be studied from the two different spray applications include film thickness, styrene content; and gel time of the laminate or gel coat along with spray gun flow rate and air flow over the mold surface. Variables to be examined in the resin batch application study include the same factors as above except for the spray gun flow rate.

These application methods and process variables represent a typical set of parameters found in the FRP composites industry. The first phase of the study is focused on establishing baseline emission levels during typical processing circumstances. No attempts will be made to reduce styrene emissions during these experiments.

1.3 Intended Use of the Data

This study is designed to determine if a specified factor does have a statistically significant effect on the response, and if that is the case, then determine the magnitude of the effect.

The data and results of this study would establish a benchmark for further study of those effects which are significant and not require that additional resources be spent on the non-significant factors. The results from this may be used as part of an extended study to establish a more detailed empirical model through the use of a central-composite design (1, 3) or provide the basis for establishing an engineering model for styrene emissions.

1.4 Scope of Work

The project will provide a database to the open molding composites industry and will be used to evaluate future pollution prevention methods in the form of source reduction. The data developed from this project, along with other testing results, may be used to develop models for styrene emissions from the open molding process.

1.5 Schedule

The project will take 20 - 30 working days to complete, with two (2) or three (3) experiments per day being conducted. For example, Day 1- Run No.1 & Run No. 2; Day 2 - Run No. 3A and 4A. In addition, at least three (3) days of pre-trials will be conducted to verify equipment operating procedures and calibrate measurement equipment.

It is anticipated the testing will begin in August 30, 1995 and proceed through October 1995.

1.6 Test Facility

The testing will be carried out at the Dow Chemical Composites Laboratory, in Freeport, Texas. The test area is located in a composites applications laboratory. An 8' tall test enclosure consisting of a 12.5' X 15' four sided total temporary enclosure (TTE) (see Figure 1.6.1) covered by a 12.5' X 15' exhaust hood has been erected in the laboratory. The walls of the enclosure are clear mylar sheeting, with access doors on three sides. Natural draft openings (NDO's) are arranged in accordance with EPA Method 204. (See Figure 1.6.1). The NDO's are baffled to prevent the incoming air from flowing over the mold surface, while still providing the required 200 fpm flow through the opening. A total airflow of approximately 1600 cfm will be maintained through the enclosure with an electronic airflow traverse probe utilizing a VorTek™ velocity sensing system and Camille ® Data Collection System. See Appendix, Section 14, for description of air flow velocity sensor.

A secondary blower will provide a known air flow over the mold surface. This blower is mounted outside of the test enclosure and draws air from within the test area, returning it through two (2) ducts which direct a uniform flow of air across the mold surface. The air flow across the mold will be calibrated to high and low velocities of 100 fpm and 50 fpm, respectively.

A three sided mold of 30 ft² will be positioned in the test enclosure.

The objective of the experiments is to quantify styrene emissions from each of the three processes. Measurements will be taken with a Varian 3700 gas chromatograph (GC), equipped with a flame ionization detector and a Thermo Environmental Instruments, Inc. Model 51 heated Total Hydrocarbon Analyzer (THA), using EPA Method 25A. See Appendix, Section 14, for specifications of the THA. The gas chromatograph is configured to cycle samples every 120 seconds, whereas the Total Hydrocarbon Analyzer provides continuous measurement capability. Both analytical units will use sample probes in the form of pitot tubes in the enclosure exhaust duct. The THA sample probe is a "rake" type pitot tube having three (3) sample points. The sample points are a hole located in the center of the duct and two holes located 10% of the duct diameter from the edge of the duct. The GC sample point is a "S" type pitot tube located in the center of the duct.

The GC signal output will be linked to a Hewlett-Packard Integrator, which will provide a print copy of data during the 120 second sample cycle. The continuous THA measurements will be linked to a Dow Camille® Data Acquisition System. The Camille® system will record data points at 1 second intervals, storing the data to a floppy disk. In addition the Camille® system allows real time viewing of the incoming data.

Two (2) sampling ports will be located in the exhaust duct. One probe each will be sampled by the GC and the THA. The results of the capture efficiency testing for the THA are discussed in section 3.2.

The temperature in the test site will be maintained at 75±4°F. The plant heating and air conditioning system will be used for temperature control. Ambient air temperature measurements will be recorded during the experimental runs. Temperature in the test enclosure will be recorded continuously by the data acquisition system.

The weight of resin or gel coat used will be measured using a precision balance.

The general experimental procedure is as follows:

1. The instrumentation will be calibrated.
2. Baseline measurements will be established.
3. Mold, materials and spray unit will be moved to test location.
4. Initial weight of resin or gel coat is recorded.
5. Application of resin or gel coat on the mold will take place.
6. Final weight of resin or gel coat is recorded.

7. GC and THA readings will be discontinued when styrene levels reach preceding baseline levels.
8. Data will be recovered and stored.
9. Test area, mold and spray unit will be prepared for subsequent experiment.

Pretrial testing experiments were conducted to determine the capture efficiency of the exhaust system. An open pan, with an absorbent media, containing measured amount of styrene will be placed in direct air flow in the enclosure in order to evaporate the contents. The known weight of styrene will then be compared to the results of the instrumentation readings.

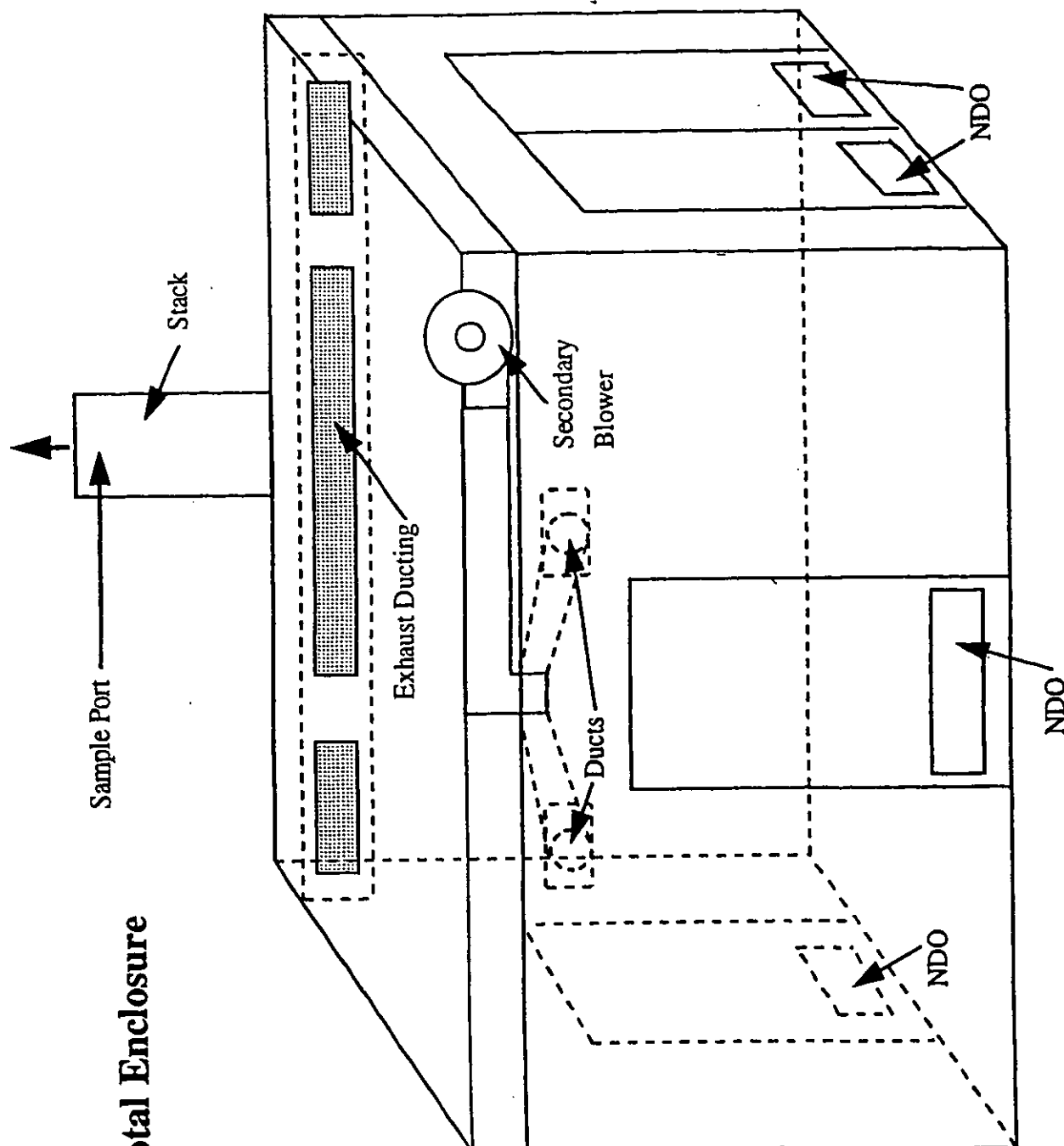


Figure 1.6.1
Temporary Total Enclosure

1.7 Experimental/Test Matrix Design

1.7.1 Critical and Non-Critical Measurements

Critical measurements are those which effect or may effect the overall objectives of the project. There are two types of critical measurements in this project. First is the direct measurement of styrene emissions, using the total hydrocarbon analyzer and EPA Method 25A. Second are measurements of the process which must be controlled in order to derive the necessary resolution from the collected data. These measurements include wet laminate/film thickness, resin/gel coat styrene content, gel time, resin/gel flow rate, air flow over mold, and ambient temperature.

Non-critical measurements involve additional means of measuring styrene emissions, including emissions measurements with the gas chromatograph. These measurements will be used to support the THA measurements, verify the function of the testing set-up and validate the quality of data collected.

Table No. 1.7.1 lists critical and non-critical measurements and their measurement frequency for this study.

1.7.2 Experimental Design for Spray-up Applications

The proposed experimental programs described in Tables 1.7.2.1 and 1.7.2.2 are called blocked, 5 factor, 2 level, half fractional experiments. This experiment scheme is a class of screening designs for estimating the relative magnitude of the factors response. Screening designs assume that the response (Y) is a linear function of the factors.

$$Y = \beta_0 + \sum_{i=1}^5 \beta_i X_i + \sum_{i=1}^4 \sum_{j=2}^5 \beta_{ij} X_{ij} + \sum_{i=1}^3 \sum_{j=2}^4 \sum_{k=3}^5 \beta_{ijk} X_{ijk} + \sum_{i=1}^2 \sum_{j=2}^3 \sum_{k=3}^4 \sum_{l=4}^5 \beta_{ijkl} X_{ijkl} + \beta_{12345} X_{12345}$$

In the experimental programs listed, the use of blocking will cause the two-factor interactions (the product of the two effects) to be confounded with each other. Confounding is the overlapping of terms such that two or more effects cannot be distinguished from each other. Although the three factor interactions would be negligible compared to the main effects. If necessary, the interactive effects may be resolved from each other with a follow-up study called a reflective design. Blocking is a term for accommodating the possible effects for day-to-day changes in uncontrolled environmental factors. Two runs will be repeated in order to estimate the variance of the measurement system and also estimate the lack-of-fit for the model(1, 2, 3, 8, 9). The column labeled "Pattern" is the coding system of the signs of the coefficients typically used to designate

the low (-1) and high (+1) values in the design. Refer to Table 8.1 for the key to the designation of factor levels.

The four resin and four gel coat formulas documented in Section 14.4 will be used in the resin spray-up tests.

1.7.3. Batch Application Study

The design for the Resin Batch Application study is listed in Table 1.7.3.1. This screening study is a blocked 4-factor, 2 level full factorial design. Sixteen (16) experiments with a 4-factor design will allow all effects and interactions to be fully resolved from one another. The same assumption of linearity applies to this study and four runs will be repeated to estimate the experimental variance and lack-of-fit.

The four resin formulas documented in Section 14.4 will be used in the resin batch application study.

Table No. 1.7.1
Summary of Physical Measurements for
Styrene Emission Study

Measurement	Measurement Classification	Measurement Designation	Measurement Frequency	Measurement Site
Styrene Emissions (THA)	Critical	Stack -EPA Method 25A	Continuous (2 second interval data points)	Vent Hood Stack
Styrene Emissions (GC)	Non-critical	Stack - GC Measurement	120 Second Interval	Vent Hood Stack
Wet Laminate Thickness	Critical	Wet Mil Gauge	Each Experimental Run	Mold Surface on center of each panel
Wet Film Thickness	Critical	Wet Mil Gauge	Each Experimental Run	Mold Surface on center of each panel
Styrene Content	Critical	Dow Work Instructions	Each Emission Study	Laboratory analysis
Gel Time	Critical	Dow Work Instructions	Each Emission Study	Laboratory analysis
Resin Flow Rate	Critical	Spray Gun Calibration	Each Experimental Run	Chopper gun
Air Flow Over Mold	Critical	Hot Wire Anemometer	Prior to Each Experimental Study	Velocity at Mold Surface
Temperature	Critical	Thermocouple	During Each Experiment	Within TTE
Mass Balance-Styrene Recovery Check	Critical	EPA Method 25A/Weight	Prior to Each Study	Within TTE
Air Flow Through TTE	Critical	Velocity Sensor	Continuous (1 second interval data points)	Vent Hood Stack
Resin/Gel Coat Weight	Critical	Precision Balance	Each Experimental Run	Spray Unit Outside TTE

Table No. 1.7.2.1
Resin Spray Application Emission Study

Block (Day)	Run No.	Pattern	Laminate Thickness (in.)	Styrene %	Gel Time (min.)	Resin Flow (lb/min)	Air Flow (fpm)
			X ₁	X ₂	X ₃	X ₄	X ₅
1	1	---++	.040	35	30	4	100
1	2	++++-	.080	42	15	2	50
2	3A	-++-	.040	42	15	2	50
2	4A	++++	.080	35	30	4	100
3	5	-++-	.040	42	30	2	100
3	6	+++-	.080	35	15	4	50
4	4B	++++	.080	35	30	4	100
4	3B	-++-	.040	42	15	2	50
5	7	---++	.040	35	15	4	50
5	8	++++	.080	42	30	2	100
6	9	-++-	.040	35	15	2	100
6	10	+++-	.080	42	30	4	50
7	11A	-++-	.040	42	30	4	50
7	12A	++++	.080	35	15	2	100
8	13	-----	.080	35	30	2	50
8	14	+++++	.040	42	15	4	100
9	11B	-++-	.040	42	30	4	50
9	12B	+++-	.080	35	15	2	100
10	15	-----	.040	35	30	2	50
10	16	+++++	.080	42	15	4	100

Table 7.2.3
Gel Coat Spray Application Emission Study

Block (Day)	Run No.	Pattern	Laminate Thickness (in.)	Styrene %	Gel Time (min.)	Resin Flow (lb/min)	Air Flow (fpm)
			X ₁	X ₂	X ₃	X ₄	X ₅
1	1	---++	.018	35	20	4	100
1	2	+++--	.024	40	10	2	50
2	3A	-++--	.018	40	10	2	50
2	4A	+--+++	.024	35	20	4	100
3	5	++--+	.024	40	20	2	100
3	6	+---+	.024	35	10	4	50
4	4B	+--+++	.024	35	20	4	100
4	3B	-++--	.018	40	10	2	50
5	7	--++-	.018	35	10	4	50
5	8	-+--+	.018	40	20	2	100
6	9	--++-	.018	35	10	2	100
6	10	++-+-	.024	40	20	4	50
7	11A	-+--+	.018	40	20	4	50
7	12A	+--++	.024	35	10	2	100
8	13	+---	.024	35	20	2	50
8	14	-++++	.018	40	10	4	100
9	11B	-+--+	.018	40	20	4	50
9	12B	+--++	.024	35	10	2	100
10	15	---	.018	35	20	2	50
10	16	+++++	.024	40	10	4	100

Table No. 1.7.3.1
Resin Batch Application Emission Study

Block (Day)	Run No.	Pattern	Laminate Thickness (in.)	Styrene %	Gel Time (min.)	Air Flow (fpm)
			X ₁	X ₂	X ₃	X ₄
1	1	---+	0.041	35	30	50
1	2	+++	0.088	42	15	100
2	3A	++-	0.041	42	15	50
2	4A	+++	0.088	35	30	100
3	5	-+-	0.041	42	30	50
3	6	+++	0.088	35	15	100
4	4B	+++	0.088	35	30	100
4	3B	++-	0.041	42	15	50
5	7	+++	0.041	35	15	50
5	8	++-	0.088	42	30	100
6	9	--+	0.041	35	15	50
6	10	+++	0.088	42	30	100
7	11A	++-	0.041	42	30	50
7	12A	++-	0.088	35	15	100
8	13	+++	0.088	35	30	100
8	14	+++	0.041	42	15	50
9	12B	++-	0.041	42	30	50
9	11B	++-	0.088	35	15	100
10	15	----	0.041	35	30	50
10	16	++++	0.088	42	15	100

Section 2.0
PROJECT ORGANIZATION AND RESPONSIBILITIES

The Open Molding Styrene Emissions Study is sponsored by the Composites Fabricators Association under the auspices of the Clean Air Management Partnership. The testing project will be directed by R. Lacovara, CFA, with T. Cowley, Dow, serving as Project Manager and G. Webster, Dow acting as Project Supervisor. The assigned Quality Assurance Manager is L. Craigie, Dow, who is associated with the project in the capacity of QA management. Experimental design and data reduction is assigned to P. Wykowski, Dow Project Leader.

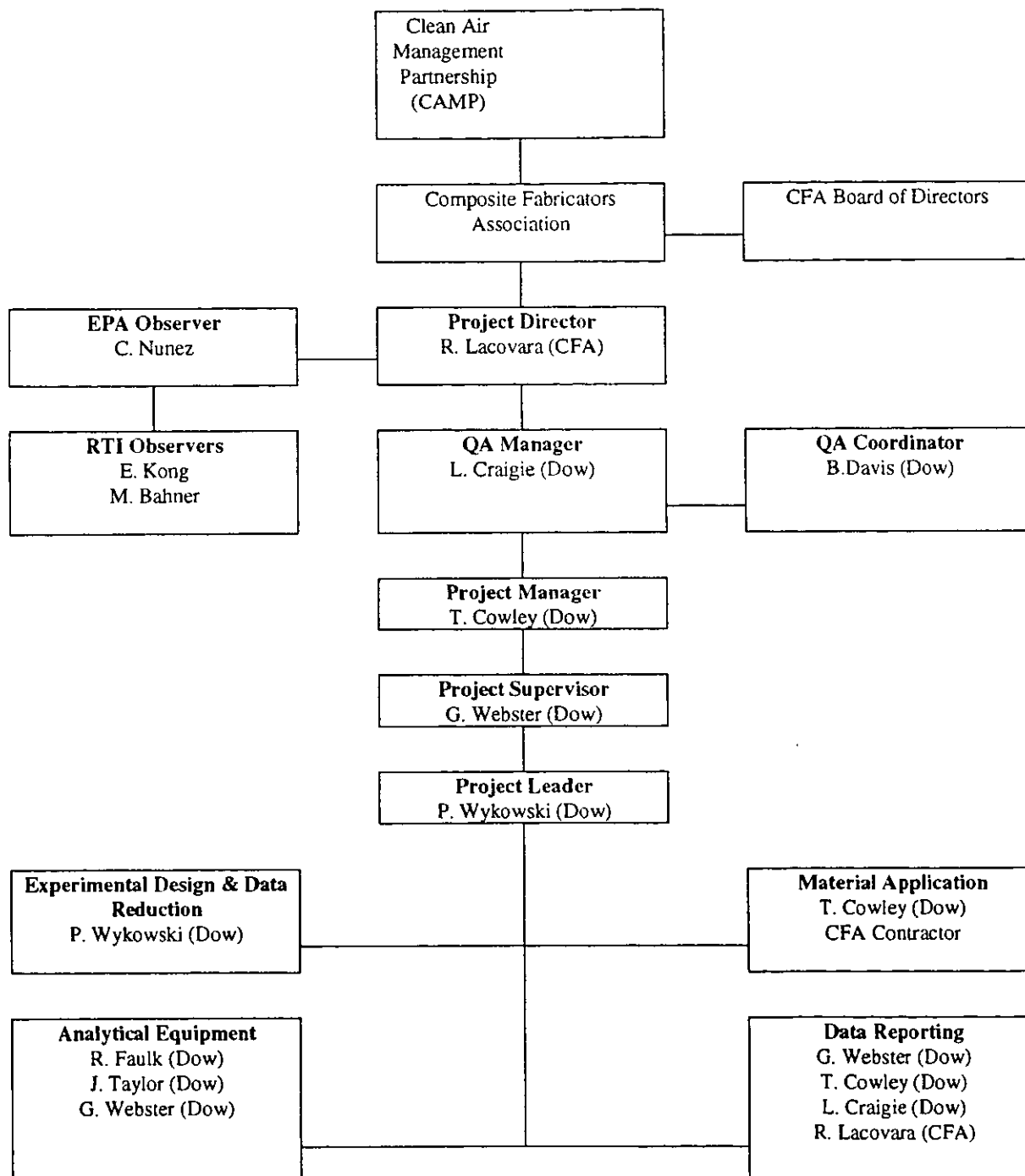
Measurement and analytical equipment selection and installation will be managed by A. Faulk Jr., Supervisor of Dow Instrumentation Services. Reporting to Mr. Faulk is J. Taylor, who is responsible for the configuration/calibration and operation of the measurement equipment.

Supervision of the experiments will be assigned to T. Cowley, Dow and R. Lacovara, CFA, who will direct a CFA contracted applications technician. Data reduction will be assigned to P. Wykowski with review by L. Craigie, Project Quality Assurance Manager. Data reporting will be assigned to T. Cowley and G. Webster. Final report will be written by T. Cowley, R. Lacovara, L. Craigie and P. Wykowski. Mr. Davis will be the QA Coordinator and will conduct the audits described in Section 10.

EPA/AEERL, Pollution Prevention Branch, represented by Carlos Nunez has been invited to participate in the planning and observe the testing, along with EPA contractor, Research Triangle Institute representatives Emery Kong and Mark Bahner.

A Flow Chart indicated as Section 2.0 Project Organization describes the organizations and personnel involved in the emissions testing study.

Section 2.0 Project Organization Chart



Section 3.0

DATA QUALITY INDICATOR (DQI) GOALS FOR CRITICAL MEASUREMENTS

3.1 Determining QA Objectives

The primary objective is to establish a baseline value for styrene emissions from typical open mold processes under controlled environmental conditions. Correlation and specified precision between the two (2) measurement methods will be a secondary objective with the THA as the principle measurement instrument used according to EPA Method 25A. The GC will be used to augment the THA data.

During pre-trial experiments, variation between the two (2) measurement methods has been shown to occur. If this variation is maintained within specified precision limits, QA objectives will be considered to have been satisfied.

The factor levels for the experimental variables under investigation have been established as values most typically found in commercial facilities. The range in magnitude of factor levels have been chosen such that these ranges would most likely be found in a commercial setting, would be broad enough in magnitude to detect a possible effect on the styrene emissions, and their differences in factor levels would be attainable by typical commercial equipment. This study should be representative of the effects on specific factors on the emission levels. However, many other factors not identified at this time may exhibit effects should another study be done at another location with slightly different equipment.

Propagation of errors would be taken into consideration in the analysis of variance and lack-of-fit tables. Also, the contrasts calculated from the screening study would also help estimate the contribution of the factor to the variance of the response.

Table 3.1 is a summary of the critical measurements of factor effects and their responses. The justification of the choice of effect levels are given in the following subsections.

3.1.1 Laminate/Gel Coat Thickness

In the spray-up laminate experiments, a chop mil gauge will be used during the application to determine the rate of build-up and extent of thickness. A special continuous strand gun roving with red tracer strands will be employed to give the operator a visual indication of the general laminate thickness and distribution across the mold surface. During the course of spray application the operator will check the thickness at three specified locations on the laminate with the chop mil gauge while building the laminate to the specified thickness.

The mean thickness will be calculated from the measurements and compared against each other with a one-tail test at the $\alpha = 0.05$ confidence level for 2 degrees of freedom for which the student's $t_{0.05,2} = 2.760$. The estimated standard deviation required for the

hypothesis $H_0: m_1 = m_2$ and either, $H_1: m_1 < m_2$ or $H_1: m_1 > m_2$ is estimated to be $\pm 0.010''$ with the tolerance around the factor levels being $\pm 0.0012''$.

In the hand lay-up laminate experiments the primary thickness control will be the thickness of the chopped strand mat reinforcement. One (1) ply of 1.5 oz/ft^2 mat will be used for the thin laminate and two (2) plies of 1.5 oz/ft^2 mat will be used for the thick laminate. Typical overlaps and build-ups are expected in corner areas of the mold.

For the gel coat experiments a standard gel coat mil gauge will be used to measure the thickness build-up during the application and to record the final gel coat wet film thickness. Mil gauge readings will be taken in specified location in the center of each of the three panels of the mold surface and averaged. The wet film thickness will be recorded on the experiment report sheet. Based on the hypothesis treatment as given above, the specified tolerance (by standard deviation) is $\pm 0.002''$.

3.1.2 Styrene Content

The styrene content of the polyester resin and polyester gel coat used in these experiments has been formulated to the specified styrene content of $\pm 1.5\%$ by the suppliers of the materials. A QA certification analysis of styrene content is provided for each formulation of material. A measurement of the styrene content shall be performed according to the method, Determination Of Non-Volatile Content, prior to the initiation of each of the individual studies. The determination will be made in the Dow analytical laboratory using Dow work instructions and with calibrated equipment according to written procedures. See Section 7.1.

The stated 95% confidence interval of the method is $\pm 0.34\%$ which sufficiently resolves the styrene content levels for this study,

3.1.3 Gel Time

The interval from catalyzation to gelation will be controlled by the percentage of MEKP catalyst introduced into the resin or gel coat. This test will be performed on a 100 g mass of the sample with a Sunshine Gel Timer and thermal control according to specified work instructions and calibration procedures prior to the individual studies. See Section 7.2. The catalyst level will be adjusted to obtain the specified gel time within a $\pm 3.5 \text{ min.}$ of the target, to stay within the 95% confidence interval from the midpoint value of 22.5 minutes. The spray equipment will then be adjusted to deliver the percent catalyst required to achieve the specified gel time. The resin/gel coat to catalyst ratio of the spray gun will be determined through a standard weight calibration of the spray gun output. The catalyst formulation shall remain consistent throughout the individual study.

In the case of the Resin Batch Application, the specified amount of catalyst will be measured on a calibrated analytical balance with the calibration documentation available. The catalyst will then be manually mixed with the resin immediately prior to application.

3.1.4 Resin Flow

The output of the spray gun will be determined during the standard calibration of the spray equipment. The output will be controlled by a combination of spray tip orifice size and pump pressure setting. Standard calibration consists of spraying into each of 3 containers for 15 seconds and weighing the output. Based on the confidence limit criteria as shown in Section 3.1.1, the measured output then requires that the mean of the three measurements are ± 0.15 lb(68 g) of the target level with any one measurement ± 0.125 lb(57 g) of the mean value. The mean weight is then converted into a flow rate in pounds per minute (lbs/min).

<u>Flow Rate</u>	<u>Target Resin Mass for 15's</u>	<u>The Mean of the 3 Samples Must be Within</u>	<u>The Measured Values Must be Within the Mean</u>
2 lb/min.	0.5 lb	± 0.15 lb	± 0.13 lb
4 lb/min.	1.0 lb	± 0.15 lb	± 0.13 lb

3.1.5 Air Flow

Air flow velocity over the mold surface will be controlled by the auxiliary blower and duct system, which is configured to extract air from within the test enclosure and return the flow through ducts and outlets directed to provide an uniform air flow across the mold surface. The air flow over the mold surface has been measured in three (3) specific locations (the center of each corner adjoining panels of the mold) using a hot wire anemometer (Cole-Parmer Trisense Model No. 37000-00). The dampers in the ducts have been adjusted to specified settings to provide a low air velocity of 50 fpm and a high air velocity of 100 fpm at 2 inches from the center of each corner adjoining panels. The flow rate shall be verified prior to the start of the individual studies.

The verification of the air flow measurement procedure is documented in the draft report "Preliminary Emissions testing at Dow Chemical on January 4-5, 1995," dated Jan. 30, 1995, RTI Project No. 5171-016.

3.1.6 Mass Balance Styrene Recovery Check

A mass balance calibration will be conducted prior to each of the three experimental group runs. The THA and GC will be calibrated according to previously described procedures. Styrene will be evaporated from a shallow pan having an absorbent media hanging over the pan and extending down into the liquid styrene. An auxillary fan may be used to

enhance evaporation. The input weight of the styrene will be compared to the calculated weight based on the average ppm recorded by the THA and the GC.

3.1.7 Resin/Gel Coat Weight

Resin/gel coat weight will be recorded immediately before resin/gel coat application and upon completion of application to the mold. The weight will be measured with a calibrated balance with the calibration documentation available. The precision of the balance is ± 0.002 lbs. with a capacity greater than 100 pounds.

Table 3.1
Quality Assurance Objectives for
Critical and Non-Critical Measurements

Measurement	Measurement Designation	Measurement Frequency	Precision Range	Required Accuracy	Completeness
Styrene Emissions (THA)	Stack - EPA Method 25A	Continuous (2 second interval data points)	±2 ppm	± 10%	>1200 data points per run and when measurement reaches original baseline
Styrene Emissions (GC)	Stack - GC Measurement	120 Second Interval	±2 ppm	± 10%	>30 data points per run and when measurement reaches original baseline
Wet Laminate Thickness	Wet Mil Gauge	Each Experiment	±0.010"	±0.012"	3 measurements per run
Wet Film Thickness	Wet Mil Gauge	Each Experiment	±0.002"	± 10% Specified Thickness	3 measurements per run
Styrene Content	Dow Work Instructions	Each Resin/Gel Coat Batch	±0.34% w/w at 95% confidence level	± 1.5% Specified Styrene Content	2 measurements of each resin prior to a study
Gel Time	Dow Work Instructions	Each Resin/Gel Coat Batch	±4% absolute deviation from mean	± 1.5 min. Specified Gel Time	2 measurements of each resin prior to a study
Resin Flow Rate	Spray Gun Calibration	Each Experimental Run	±.3 lb/min.	±.3 lb/min. Specified Flow Rate	2 measurements per run
Air Flow	Velocity at Mold Surface	Prior to Each Experimental Study	± 20 %	± 20% Specified Air Flow	Six Readings per minute for three minutes
Temperature	Within Enclosure	During Each Experiment	±2°F	75±4° F	> 1200 data points per run
Air Flow Through TTE	Vent Stack Air Flow	Continuous (1 second interval data points)	± 25 cfm	± 100 cfm	> 1200 data points per run
Mass Balance - Styrene Recovery Check	EPA Method 25A/Weight	Before Each Emission Study	± 4%	± 10%	Two measurements prior to each study
Resin/Gel Coat Weights	Precision Balance	During Each Experiment	± 0.002 lb	± 0.004 lb	Two Measurements per run

3.2 Method Detection Limit.

Method detection limit for styrene emissions is critical. Pre-trial experiments and calibration procedures have shown the method detection limit for the THA and the GC measurement equipment to be <2 ppm.

3.3 Mass Balance Styrene Recovery Check

The accuracy of the experiment is expressed as the mass balance styrene recovery check of the experimental set-up and the evaluation is summarized in Table 3.2. The capture efficiency between the analytical equipment and the atmosphere in the TTE has been shown to be 94.7%. This was determined through three(3) styrene evaporation experiments:

Table 3.2
Mass Balance Styrene Recovery Check of Analytical Equipment¹

Date	Minutes	Average Emission (ppm)	Initial Weight (g)	Final Weight (g)	% Recovery
6-1-95	104	9.233	189.67	181.20	95.5
6-1-95	99	9.512	188.14	177.68	94.4
6-2-95	210	9.901	418.35	393.92	94.2
Overall Styrene Recovery Check					94.7

¹Based on THA measurements in ppm converted to weight

Calculation for Total Styrene Emissions:

Total Styrene Emissions, lbs. =

$$\frac{\text{TWA styrene emissions in cc/m}^3 \text{ (ppm)} \times \text{Air flow in m}^3/\text{min.} \times \text{Time in min.} \times 104\text{g/mole}}{24.45 \text{ l/mole} \times 1000 \text{ cc/l} \times 454 \text{ g/lb}}$$

3.4 Precision

The precision objectives for this experiment are the variation in measurement methods. The precision between the THA and the GC is anticipated to be within 18%.

3.5 What If QA Objectives Are Not Met?

If one or more of the QA objectives are not met, specific experiments will be repeated and/or follow-up studies will be designed to examine the parameters relating to the QA objectives. QA objectives not met will be so noted and discussed in the final report.

Section 4.0 SITE AND SAMPLING PROCEDURES

4.1 Sampling Site

The sampling site will be located in the stack of the Temporary Total Enclosure (TTE) exhaust hood. (See Figure 1.6.1). The sampling probes were installed in the exhaust stack as prescribed by Environmental Protection Agency (EPA) Method 40 CFR Ch.1. The air flow through the exhaust ducting is monitored and maintained by electronic air traverse probe utilizing a VorTek™ velocity sensing system and Camille® Data Collection System. The velocity sensor in the duct is consistent with EPA 40 CFR Ch. 1, Method 1 criteria. The method used for determining the air flow for calibration needs is similar to that described in EPA 40 CFR Ch. 1, Method 1. A manometer attached to a S type pitot tube installed in the exhaust ducting will be used as a back-up monitor for any change in set flow.

Sample probes will be linked to both the Total Hydrocarbon Analyzer (THA) and the Gas Chromatograph (GC).

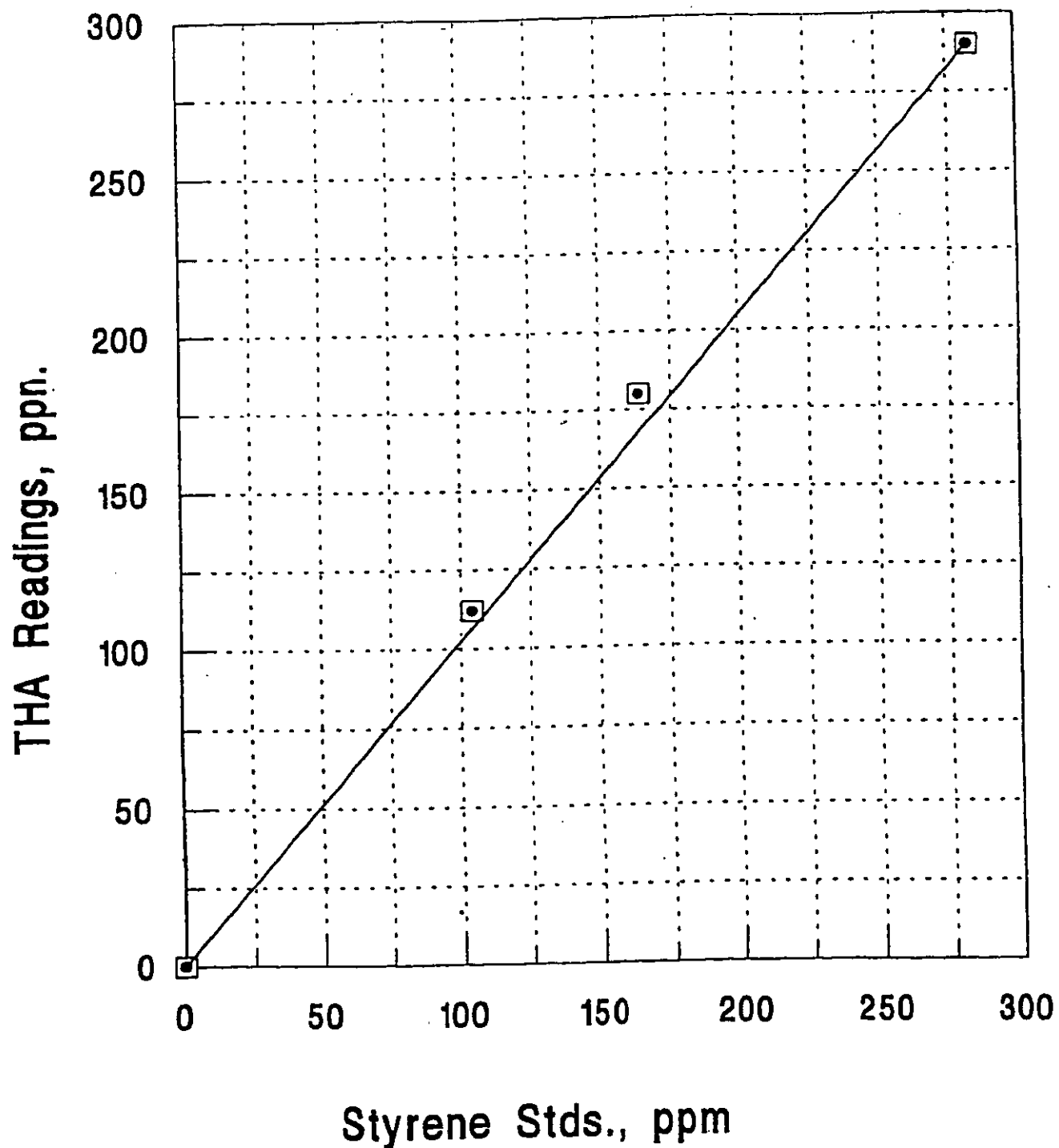
4.2 THA Sampling Procedure

The THA sampling procedure is consistent with EPA Method 25A - Determination of Total Gaseous Organic Concentrations Using a Flame Ionization Analyzer. The following changes will be made to Method 25A:

1. The acceptable accuracy for checking calibration with the 80% span gas standard will be $\pm 10\%$ from the predicted response. See Figure 4.2.1 for an example calibration check of the THA.
2. There will be no checks on the THA accuracy during actual data collection.
3. The calibration of the THA will be verified using the low span, mid-span and the 80% span gas before the first run of the day. The calibration will be checked before the second run of the day using the mid-span calibration gas. The THA will be recalibrated, if necessary for the second run; however, the previous test may not be invalidated, depending on the values obtained by secondary measurements.
4. Only one detection range will be used during the study. The detection range is spanned to cover styrene emissions from 0-350 ppm. The detection range will be spanned to cover higher styrene emissions should the need arise.
5. 100% Hydrogen will be used as a fuel gas.

Figure 4.2.1

Calibration Check for the Total Hydrocarbon Analyzer, 80% of Span



4.3.1 GC Sampling Procedure

A Varian 3700 gas chromatograph equipped with a flame ionization detector will be used. The gas chromatograph sampling valves are controlled by a Camille® software system, and data are output to a Hewlett Packard 3392A integrator.

The GC conditions are as follows:

Gas Chromatograph Set-Up:

Oven Temperature = 90°C

Detector Temperature = 250°C

Sample Valve Injector = 90°C (located in gas chromatograph oven)

Gas Pressures:

Flame Ionization Detector:

Low pressure side of gas regulators

Air = 40 psig

Hydrogen = 40 psig

Column:

Helium = 40 psig

Column Identification:

10 m X 0.53 mm Bonded FSOT RSI-300

1.2 um Polyphenyl Methysiloxane

(Megabore capillary column - 0.53 mm ID)

Column Gas Flow:

Helium = 4 ml/min. (no split)

Gas Standards (may use one or all of the following):

Approximate Styrene Concentration = 20 ppm $\pm$ 1% REL

Approximate Styrene Concentration = 50 ppm $\pm$ 1% REL

Approximate Styrene Concentration = 105 ppm $\pm$ 1% REL

See Figure 4.3.1.1 for a simplified diagram of the piping system. Figure 4.3.1.2 shows the GC system in the total piping system.

Figure 4.3.1.1
Simplified Piping Design for Calibration of GC and Sampling

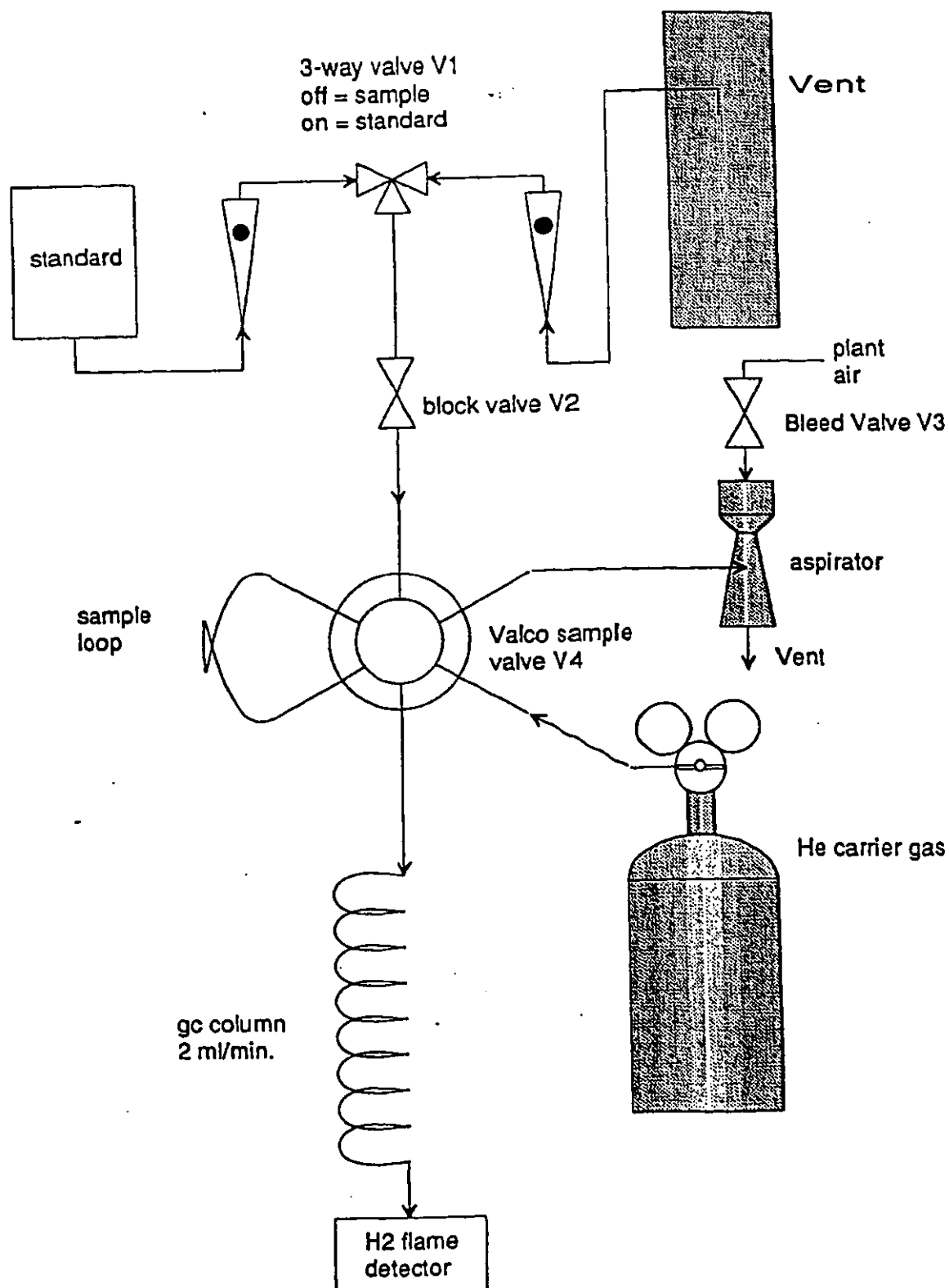
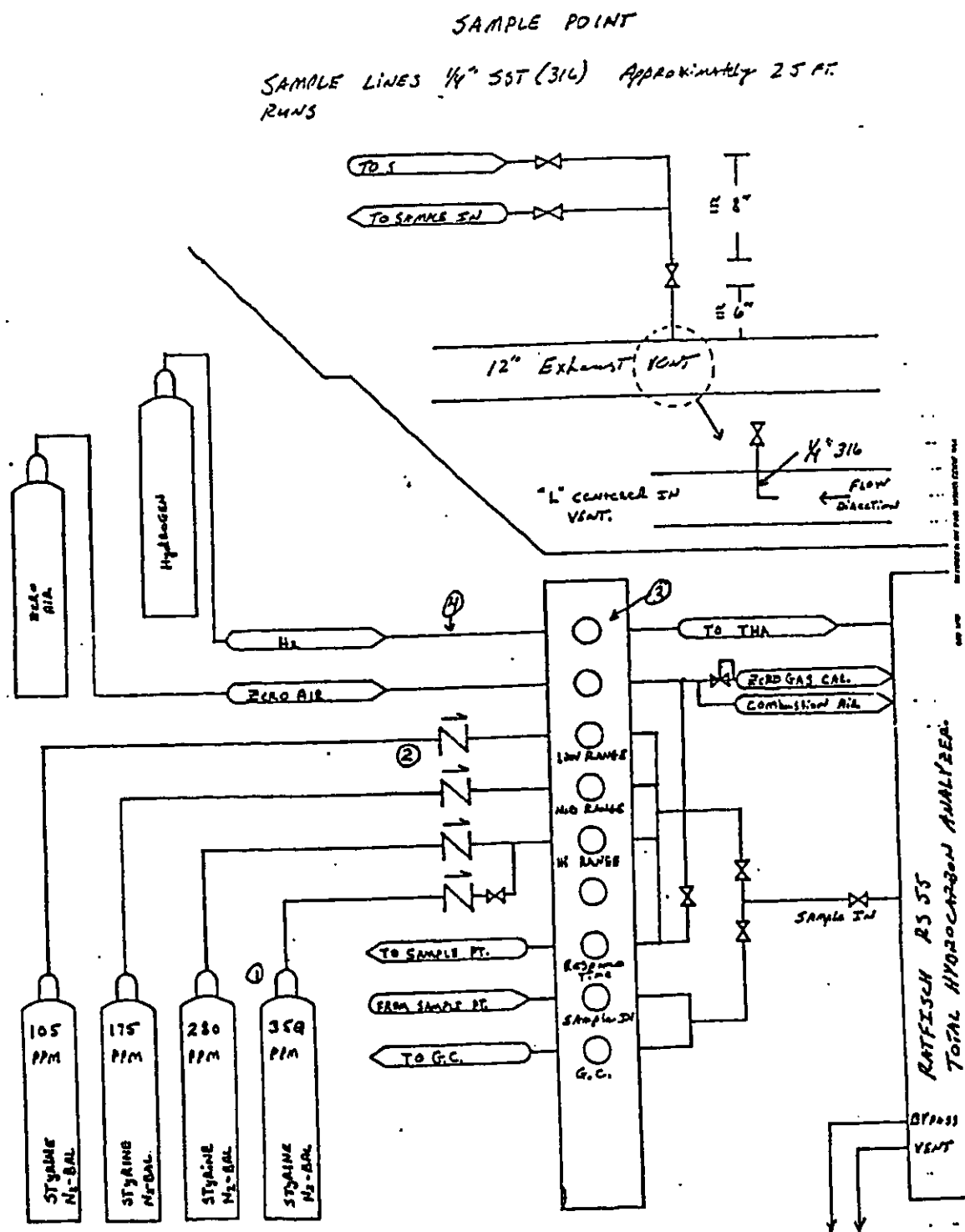


Figure 4.3.1.2
Piping Design for Calibration and Sampling



ACTUAL VALUES MAY VARY depending
ON ACCURACY OF MIXTURE.

- ① Regulators SET AT ≈ 25 PSIG.
- ② 10 lbs. CHECK VALVES
- ③ 1/4 TURN BALL VALVES
- ④ H₂ LINE 1/2" 316L SST ALL OTHERS 1/4" 316L

4.3.2 Gas Chromatograph Standardization

- (1) An appropriate styrene gas standard will be run until the area response for the styrene peak is consistent. A styrene gas standard for the THA will be used to check data consistency between the GC and THA.
- (2) The Hewlett Packard Integrator is then re-calibrated to this response factor for styrene. Another standard analysis is run to assure consistent measurements.

4.3.3 Gas Chromatograph Sample Analysis

- (1) The GC will be standardized at the beginning of each day with calibrated gas sample(s).
- (2) The analysis system is put into the sampling mode prior to resin being introduced into the test chamber. An ambient baseline of styrene concentration will be established at this point. Typical baseline readings will be <2.0 ppm.
- (3) The analysis system takes a sample of air from the TTE exhaust stack ducting every two (2) minutes for gas chromatographic analysis. The gas sample is moved to the sample valve by a vacuum air aspirator.
- (4) The analysis system continues to take air samples throughout the experiment until styrene levels drop to the original baseline level, at which time the sample sequence is stopped.
- (5) The analysis system is then standardized to determine if calibration was valid during sampling period.

4.4 Leak Checks for Sample Lines

Leak checks will be performed at the beginning of each week of testing. All fittings, valves and connections of the THA and GC will be examined. A valve just down stream from each sample port will be closed off while a sample is being drawn to a detector. The ball in a in-line flow meter will drop to zero if no leaks are in the sample line.

4.5 Spray Procedure

The spray application will be conducted so as to produce overspray consistent with observed common shop practices. It has been determined that on average spray stroke will extend approximately 6 inches off the edge of the mold. (A detailed description of this methodology is found in Section 1.1.) The operator will carry the spray stroke off the edge of the mold surface to produce a spray pattern and area deemed common place in the industry.

Section 5.0 SAMPLE AND DATA CUSTODY

Procedures will be used to track all data and information generated during this project. A worksheet will document each experimental run (see Section 8.0). A data ID designation will be assigned prior to commencing each run. This designation will include: the Block No., Run No., and Date. A separate data diskette will be used for each experimental run. The ID number will be recorded on the data diskette prior to the experimental run. Calibration data will be on each data diskette, either, 80% of span calibration or mid-range standard check.

An example of ID designation is: Study (Resin Spray = RS, Gel Coat= GC, Hand Lay-up= HL), Block No., and Run No. The computer file would be designated for example as RS-1-1 (Resin Spray study-Block 1-Run 1).

Physical samples, such as those used in determining non-volatile content, will be assigned a unique sample number, which includes the resin/gel coat batch number, date and experiment for which test is being conducted. Records of the test sampling will be delivered to T. Cowley at the end of the day analyses are performed.

Copies of data diskette will be made and maintained in a separate location.

Section 6.0 CALIBRATION PROCEDURES AND FREQUENCY

6.1 Total Hydrocarbon Analyzer Calibration Procedure

The THA standardization procedure is consistent with EPA Method 25A - Determination of Total Gaseous Organic Concentrations Using a Flame Ionization Analyzer, with noted exceptions. The following changes will be made to Method 25A:

1. The acceptable accuracy for checking calibration with the 80% span gas standard will be $\pm 10\%$ from the predicted response. See Figure 4.2.1 for an example calibration check of the THA.
2. There will be no checks on the THA accuracy during actual data collection.
3. The calibration of the THA will be verified using the low span, mid-span and the 80% span gas before the first run of the day. The calibration will be checked before the second run of the day using the mid-span calibration gas. The post-test calibration drift will be recorded before any re-calibration takes place. (Criteria used to decide when to re-calibrate will be "readings outside $\pm 10\%$ of the mid-span standard value".)

The THA will be recalibrated, if necessary for the second run; however, the previous test may not be invalidated, if the total styrene emission value obtained by the secondary GC measurement is within 18% of the total styrene value obtained by the THA.

4. Only one detection range will be used during the study. The detection range is spanned to cover styrene emissions from 0-350 ppm. The detection range will be spanned to cover higher styrene emissions should the need arise.

The THA has a separate RS-232 port for DOS type hook-up to the Camille® Data Collection System. If the styrene emission concentration exceeds the THA scale of 500 ppm, the separate data system will still record the actual emission data. A reading from the RS-232 is received and recorded by the Camille® Data Collection System approximately every 5 seconds.

5. 100% Hydrogen will be used as a fuel gas.

Gas Standards (may use some or all of the following):

Approximate Styrene Concentration = 50 ppm $\pm 1\%$ REL

Approximate Styrene Concentration = 105 ppm $\pm 1\%$ REL

Approximate Styrene Concentration = 174 ppm $\pm$ 1% REL
Approximate Styrene Concentration = 280 ppm $\pm$ 1% REL
Approximate Styrene Concentration = 350 ppm $\pm$ 1% REL

Styrene Gas Standards

All styrene gas standards are in air with a shelf-life of at least six months. Certificates of analysis are received with each gas standard. Copies of certificates of analysis are shown in the Appendix.

6.2 Gas Chromatograph Calibration Procedure

- (1) An appropriate styrene gas standard will be run until the area response for the styrene peak is consistent. A styrene gas standard for the THA will be used to check data consistency between the GC and THA.

Gas Standards (may use one or all of the following):

Approximate Styrene Concentration = 20 ppm $\pm$ 1% REL
Approximate Styrene Concentration = 50 ppm $\pm$ 1% REL
Approximate Styrene Concentration = 105 ppm $\pm$ 1% REL

Styrene Gas Standards

All styrene gas standards are in air with a shelf-life of at least six months. Certificates of analysis are received with each gas standard. Copies of certificates of analysis are shown in the Appendix.

- (2) The Hewlett Packard Integrator is then re-calibrated to this response factor for styrene. Another standard analysis is run to assure consistent measurements.

6.3 Air Flow Through the TTE Calibration

The air flow calibration will be performed by the distributor of the VorTek™ air flow sensing system prior to the start of the study. A hot-wire anemometer will be used by the distributor of the VorTek™ sensing system to determine the air flow through the TTE in order to calibrate the air flow sensing system. The method used to determine the air flow through the TTE is similar to that described in EPA 40 CFR Method 1, Ch. 1, except a hot-wire anemometer is used instead of a pitot tube. The Camille® data collection system will be adjusted by trained Dow personnel to output the air flow as determined by the VorTek™ velocity sensing system. Qualified Dow personnel can check the air flow through the TTE with a pitot tube following the Method 1 procedure to verify the output of the data collection system.

The air flow will be re-calibrated as deemed necessary, such as but not inclusive, in the case of related equipment failure and/or modification. The manometer reading will be recorded at the beginning and end of each test run. If a change of ± 0.05 inches of water is noted from the reading (0.13 inches of water) obtained at the time of initial air flow calibration, the air flow through the TTE will be re-calibrated.

6.4 Spray Equipment Calibration

The spray equipment will be calibrated before each test run.

The spray equipment flow rate will be calibrated to provide a specific resin and gel coat output as required by the experimental design. In the case of the spray-up application, the glass content will be adjusted to the required resin flow rate. The flow rate calibration will consist of spraying resin into a pre-weighed container for 15 seconds and recording the material weight in lbs/min. The resin pump pressure will be adjusted and spray tip sizes will be changed to achieve the specified flow rate.

For the spray-up experiments the calibration will consist of capturing both resin and chopped glass for 15 seconds, in separate containers, and weighing individually to determine the resin to glass ratio. Once the flow rate is established, the chopper speed will be adjusted to provide the proper glass ratio.

Resin/gel coat to catalyst ratio will be calibrated by means of catalyst volume measurement compared to flow rate. The catalyst ratio will be adjusted by the slave pump setting.

6.4.1 Spray Gun's Flow Rate Calibration

- 1.) Spray tip is selected with specific orifice size and fan angle.
- 2.) Catalyst pump is disconnected.
- 3.) Atomizing air is shut off.
- 4.) Spray unit is charged with a specific resin or gel coat. Air is purged from system and material flow is checked to verify cleaning solvent is fully purged from fluid lines.
- 5.) Pump pressure is set to anticipated pressure.
- 6.) Analytical balance is tared.
- 7.) Container tare weight is recorded.
- 8.) Resin/gel coat is sprayed into container for a timed 15 seconds.
- 9.) Resin/gel coat weight and pressure setting are recorded.
- 10.) Pump pressure is adjusted to modify flow rate, if needed.
- 11.) Steps 8 -10 are repeated to produce the required flow rate with ± 0.3 lb/min.
- 12.) Two flow rate checks will be made once final adjustments are made.

6.4.2 Catalyst Flow Rate Calibration

- 1.) Spray unit is charged and resin/gel coat flow rate calibration is completed as described in 6.4.1.
- 2.) The 250-ml graduated cylinder serving as the catalyst reservoir is filled with the catalyst to specified volume.
- 3.) The catalyst pump is positioned to the appropriate setting.
- 4.) The separator tip is mounted on the spray gun.
- 5.) The spray gun is activated for 15 seconds.
- 6.) The reduction in catalyst volume in the graduated cylinder is recorded.
- 7.) The catalyst pump setting is adjusted to modify flow rate.
- 8.) Steps 5-7 are repeated to produce the required flow rate yielding the specific gel time.
- 9.) The specific gravity of the catalyst will be used to convert volume to mass. The specific gravity will be obtained from the catalyst supplier specifications.

6.4.3 Chopper Gun Calibration - Resin:Glass Ratio

- 1.) Spray gun rate calibration and catalyst calibration are completed.
- 2.) Continuous strand roving is fed to the chopper and unit is initialized.
- 3.) Chopper unit air pressure is set to anticipated level.
- 4.) A pre-weighed plastic bag is placed over the chopper chute and another pre-weighed plastic bag is placed over the spray tip.
- 5.) The spray gun is activated for 15 seconds.
- 6.) The bag containing dry chopped glass and the bag containing sprayed resin are separately weighed and recorded.
- 7.) The chopper unit air pressure is adjusted to modify chopped glass output in relation to resin.
- 8.) Steps 5 - 7 are repeated to produce the specified resin to glass ratio.

6.6 Balances Calibration Check

6.6.1 Lab Balance for Resin/Gel Coat % Solids

- 1.) The balance will be calibrated semi-annually by an approved outside vendor utilizing NIST traceable standards and documented procedures.
- 2.) Internal adjustments will only be made by a qualified repair technician.
- 3.) The vendor responsible for checking the balance's calibration is the Aldinger Company, Dallas, TX.

6.6.2 Balance for Resin Weight During Spray-Up and Hand Lay-Up

- 1.) A Sartorius balance model F61S will be used.
- 2.) The balance upon arrival at the test site will be calibrated by an approved outside vendor utilizing NIST traceable standards and documented procedures.
- 3.) Internal adjustments will only be made by a qualified repair technician.

- 4.) The vendor responsible for checking the balance's calibration is the Aldinger Company, Dallas, TX.
- 5.) The balance will be calibrated semi-annually by an approved outside vendor utilizing NIST traceable standards and documented procedures.

6.7 Gel Timer Calibration Check

Calibration check procedure for the Sunshine Gel Timer is as follows:

- 1.) Obtain a NIST traceable stopwatch.
- 2.) Press the "ON" button to the NIST stopwatch and Gel Timer simultaneously.
- 3.) Let the NIST traceable stopwatch and gel timer run for 15 minutes $\pm$ 5 seconds.
- 4.) When the time is up, simultaneously stop the NIST traceable stopwatch and the gel timer.
- 5.) Record the time displayed by the gel timer.
- 6.) The time displayed by the gel timer must be 15 minutes $\pm$ 15 seconds in order to meet acceptance criteria.
- 7.) The frequency of calibration check is "at the time of use or monthly, whichever is greater."

6.8 Thermocouple in TTE Calibration Check

The temperature reported by the Camille® Data System will be checked against a NIST traceable thermometer on a weekly basis. A type J thermocouple is located approximately three feet above the floor level.

6.9 Thermometer for Constant Temperature Water Bath Calibration Check

- 1.) Immerse the probe of a NIST digital thermometer to the same depth as the probe of the thermometer for the constant temperature water bath.
- 2.) Wait one minute for temperature readings to stabilize.
- 3.) Compare the temperature readings of both thermometers.
- 4.) Acceptance criteria is a difference in temperature from the NIST thermometer of no greater than ± 5 °F.
- 5.) Frequency of calibration check is "At time of use or monthly, whichever is greater".

Section 7.0 ANALYTICAL PROCEDURES

7.1 % Resin Solids Determination Procedure (Styrene Content)

- 1.) Bring oven to temperature of $125 \pm 2^{\circ}\text{C}$ with a calibrated thermocouple.
- 2.) Zero the analytical balance, place an aluminum dish on the scale and record the weight.
- 3.) Tare the scale, weight out 0.42 ± 0.02 grams of resin sample with a transfer pipet and immediately record the weight.

Note: It may be useful to spot individual droplets around the base of the weighing dish to help the resin spread and dissolve more easily.

- 4.) Repeat steps 1 and 2 for a replicate sample as this procedure requires duplicates.
- 5.) Dispense 2 milliliters of acetone into each dish and carefully swirl the solution around to dissolve all of the resin.
- 6.) Place both dishes into the catch pan and place them into a forced air heated oven.
- 7.) Set a alarm timer to 45 minutes and remove dishes at 45 ± 2 minutes after placement in the oven.
- 8.) Remove the samples from the catch pan and place on a paper towel to cool for at least 5 minutes.

Note: It is extremely important that the sample be removed at 45 minutes, otherwise the accuracy of the test may be significantly altered.

- 9.) Zero the analytical balance, place dish on the scale and record this weight.
- 10.) Calculate the % solids content as follows:

$$\% \text{ Solids} = \frac{M_{S2} - M_d}{M_{S1} - M_d} \times 100$$

Where,

M_{S1} , is the combined mass of the sample and dish before heating,

M_{S2} , is the combined mass of the sample and dish after heating, and;

M_d , is the tare weight of the dish.

7.2 Gel Time Procedure

- 1.) The promoted resin should be brought to $77 \pm 2^{\circ}\text{F}$ by use of a constant temperature water bath.
- 2.) Weigh 100 ± 1.00 grams of the promoted resin into a tared 4 oz. wide mouth bottle.

- 3.) Catalyze the promoted resin with the prescribed amount of catalyst. Cap the bottle tightly, turn the Power switch "ON", and shake the bottle for 45 seconds.
- 4.) Immediately uncap the bottle, place the bottle in a foam holder, and position the bottle under the gel timer.
Attach the glass rod spindle to the gel timer, while centering the glass rod in the 4 oz. glass bottle. Gel times are performed at ambient temperature.
- 5.) Turn the Test switch to the "ON" position to activate the gel time alarm.
- 6.) When the alarm sounds, immediately turn both the Power and Test switches "OFF". Record the gel time.

Section 8.0 DATA REDUCTION, VALIDATION, AND REPORTING

8.1.1 Data Reduction

Data reduction responsibilities will be assigned to P.L. Wykowski, Project Leader, Dow Chemical Company. Preliminary data reduction is described in Section 1.2 - Experimental Design. Calculations for the data reduction and statistical evaluation will be performed on a computer using the program JMP 3.0 (SAS Institute Inc., SAS Campus Drive, Cary, NC 27513) (1).

The total styrene emissions for each test run will be calculated by using the equation shown in Section 3.3.

8.1.2 Calculation of Effects

Each of the effect levels will be defined by the coefficient from -1 to 1 as shown in the table below.

Table 8.1
Coefficient Designations for Factor Levels

		Factor Levels							
		(-1)				(+1)			
Factors	Units	Level	Spray	Gel	Batch	Level	Spray	Gel	Batch
Thickness	in.	Thin	0.040	0.018	0.041	Thick	0.080	0.024	0.088
Styrene %	%wt.	Low	35	35	35	High	42	42	42
Gel Time	min.	Slow	30	30	30	Fast	15	15	15
Resin Flow	lb/min	Slow	2	2	---	Fast	4	4	---
Air Flow	fpm	Slow	50	50	50	Fast	100	100	100

The estimate of the contrast for k subgroups of X_n with the response y (2):

$$\hat{C}_n = \sum_{j=1}^k c_j y_j$$

The effect of a factor is the change in response produced by a change in the factor level

(2, 3):

$$\hat{\beta}_n = \frac{\hat{C}_n}{\frac{1}{2} \sum_{j=1}^k |c_j|}$$

In the case of a 2^k factorial experiment, the coefficients of the linear model β_n can be expressed as (3, 4):

$$\beta_n = \frac{\hat{\beta}_n}{2}$$

The terms of the parameter estimates for the model as generated by the software will be given as follows:

Table 8.2

Designation	Symbol	Explanation
Term	X_n	This is the name for the factor in the model.
Estimate	β_n	The coefficient for the linear model.
Standard Error	Std Error	The standard error is an estimate of the standard deviation about the parameter estimate and is used to determine the t-Ratio.
t-Ratio		A test statistic for the null hypothesis that each parameter estimate is zero. This value is calculated for the estimate divided by the standard error.
Prob > t		The probability that the magnitude of the coefficient is due to a random event. Typically, the estimate is accepted at values less than 0.05.

Further details on the above effect terms and their evaluation may be found in reference 1.

8.1.3.1 Evaluation of the Model: Effects Table

The effects table is an ANOVA which summarizes the statistical significance of the effect terms.

Table 8.3
Explanation of Analysis of Variance Table for Effect Terms

Designation	Symbol	Explanation
Term	X_n	This is the name for the effect in the model.
Degrees of Freedom	D_f	$D_f = 1$ for each effect as one degree of freedom is defined for each parameter in the model.
Sum of Squares	SS	The sum of the squares is calculated from the Type III method for sum of squares. The explicit calculation method is too complicated to be given here. However, further details may be found in references 5 and 6.
F-Ratio	F_0	A test statistic for the hypothesis that each parameter estimate is zero.
Prob > F		The probability that the magnitude of the parameter estimate is due to a random event if the hypothesis that the parameter estimate = 0. Typically, the estimate is accepted at values less than 0.05.

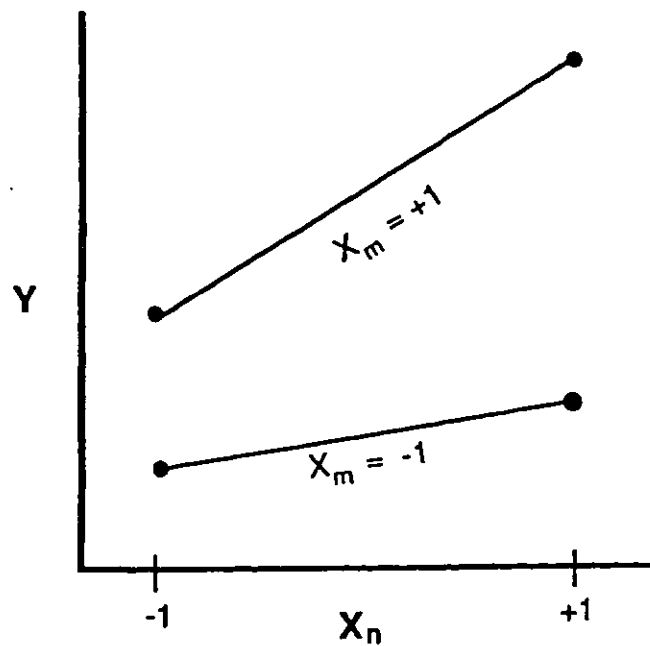
8.1.3.2 Evaluation of the Model: Effects of Blocking

The use of blocking as a means of accounting for any uncontrolled variation that may occur during the course of the testing (7). In this study the blocking is taken to be a day-to-day variation due to possible changes in environmental conditions, variability by the operator, and other unaccounted for effects. Use of blocking consists of confounding the block effects with two-factor interactions and leaving the main effects clear of each other. This process is accomplished through the use of fold-over pairs in each of the blocks (8). A fold-over pair consists of runs with complementing coefficients paired with each other (e.g. -- with ++)

8.1.3.3 Evaluation of the Model: Prediction and Interaction Profiles

The use of prediction and interaction profiles is a visual means of evaluating the data. Figure 8.1 is an illustration of an intersection of $X_n X_m$ with response Y which shows that the response is more sensitive to changes in X_n at high levels of X_m .

Figure 8.1
Example of an Interaction Profile



8.1.3.4 Evaluation of the Model: Lack of Fit Testing

The lack-of-fit test is used to evaluate the effects of variation upon the fit of the model. The replicate values of the experiments are run on days 2, 4, 7, and 9 with block number 4 being a replicated of 2 and block 9 is a replicate of 7. Spacing of these replicates was based on evaluating the possible variation near the beginning and the end of the week. The lack-of-fit test is designed to determine if the lack-of-fit is from either the model fits the data adequately or the pure experimental error. This is based on a partitioning of the sum of the squares of error (SS_E) into: $SS_E = SS_{PE} + SS_{LOF}$ (7).

Table 8.4
ANOVA Table for Lack-of-Fit

Effect	Degrees of Freedom D_f	Sum of Squares SS	Mean Square MS	F-Ratio F_0
Lack-of-Fit (LOF)	$f - p$	$SS_E - SS_{PE}$	$\frac{SS_{LOF}}{f - p}$	$\frac{MS_{LOF}}{MS_{PE}}$
Pure Error (PE)	$n - f$	$\sum_{i=1}^f \sum_{u=1}^v (y_{iu} - \bar{y}_i)^2$	$\frac{SS_{PE}}{n - f}$	
TOTAL (E)	$n - p$	$\sum_{i=1}^n (y_i - \hat{y}_i)^2$		

Where:

- f = number of experiments (runs) at distinct levels of X_n
- n = number of total experiments
- p = number of parameters used in the model
- v = number of replicates for a given experiment
- y_{iu} = value of response for a given run number i at a replicate number u
- $\hat{y}_i$ = predicted value of response at given run number i

$\bar{y}_i$ = mean value of response at a given run number i (mean value will be set equal to the measured response where no replicates are measured)

The proposed model is said to provide a reasonable fit if the value $F_0 < F_{0.05, m-2, n-m}$. If there is a significant lack-of-fit, then $F_0 > F_{crit}$. This may indicate that either curvature exists which requires higher order terms, or that the response may have to be transformed into another form such as a logarithmic or exponential form.

8.1.3.5 Evaluation of the Model: Other Tests

The above mentioned methods of evaluating the data will be the primary means of evaluation of the data and model. However, other techniques such as the coefficient of determination (R^2), adjusted coefficient of determination, and examination of residuals among others may also be included in evaluation of the model.

8.2 Data Validation

Terry W. Cowley and Paul L. Wykowski will be responsible for the data validation during the data reduction process.

Outliers will be flagged by the use of studentized residual values plotted against the run number, and as normal probability plots. Once the outlier has been identified, the model will be examined to determine if either the outlier point may be removed from the model and reevaluate the model or if the model terms may need to be modified. If the model needs to be modified, then the direction of a future study would be recommended.

8.3 Data Reporting

Examples of the sheets used in the data reporting process are attached to the end of this section.

G. Webster will report styrene emission results and deliver records to T. Cowley on a daily basis. This data will be distributed to P. Wykowski, L. Craigie and B. Lacovara. P. Wykowski will be responsible for data reduction. Final report will be written by T. Cowley, P. Wykowski, L. Craigie and B. Lacovara: refer to Section 2.0. The final report will be delivered to the CFA Board of Directors, CAMP organizations and signers of this QA plan.

SAMPLE WORKSHEET

Resin Spray Application Experiment Work Order / Process Data Sheet

Block (Day)	Date	Run No.	Thickness (in.)	Resin Batch Designation	Spray Gun Flow Rate (lbs/min)	Air Flow Rate (fpm)
1 (am)		1	.040	C	4	100

Data ID Code:	

Equipment Set-up

Spray Tip Size:		Air Assist Pressure:	
Spray Tip Angle:		Catalyst Pump Setting:	
Pump Pressure:		Flow Rate:	
Chopper Pressure:			

Resin / Gel Coat Data

Adjusted Gel Time:		@ Catalyst %	

Temperature

Ambient Temp. Start Run:		Ambient Temp. End Run:	

Process Times

Data Recording Start:		Batch Start Time:	
Data recording End:		Batch End Time:	
Total Experiment Time:		Total Batch Time:	
Spray Start Time:		Laminating Start Time:	
Spray End Time:		Laminating End Time:	
Total Spray Time:		Total Laminating Time:	

Resin/Gel Coat Weight

Initial Weights:		Final Weights:	
Total Resin/Gel Coat Weight			

Section 9.0 INTERNAL QUALITY CONTROL CHECKS

9.1 Types Of QC Checks

Following are examples of the quality control checks which will be made during the course of the experiments:

9.1.1 Materials

Each batch of polyester resin and gel coat will be adjusted to the specified gel time by adjusting the level of initiator to produce the required gel time. Gel times will be tested using a Sunshine Gel Timer and Dow Gel Time Determination Work Instructions.

9.1.2 Temperature

The ambient air temperature will be monitored and recorded during the testing by the Camille® Data System linked to a thermocouple in the TTE.

9.1.3 Replicate Experiments

Each emission study contains four replicate runs for a total of eight runs per study to check the reproducibility of test runs.

9.1.4 Air Flow Over Mold Surface

Air flow volume has been measured and fixed during the pre-trial testing. Prior to each emission study, the air flow over the surface of the mold will be checked to verify that no changes have occurred.

9.1.5 Measurement Equipment

Equipment calibration procedures and work instructions are part of the quality management system, which is certified to ISO 9001.

This equipment includes:

- balances
- Sunshine Gel Timer
- ovens.

The following work instructions to be used are

- Determination of Resins' Gel Times
- Determination of Resins' Solid Content.

9.1.6 Air Flow Through the TTE

The manometer located in the vent hood stack is used to monitor for changes in air flow through the TTE. The vacuum in inches of water determined at the initial calibration of the air flow will be recorded and daily vacuum readings checked against it.

9.1.7 Blank Readings

Emission blank readings will be obtained by the THA and GC prior to each test run to ensure that extraneous styrene vapors are not present. Blank readings should be less than 2 ppm.

9.1.8 Data Validation

Data will be examined for precision, accuracy and completeness according to Section 8, Data Reduction, Validation, and Reporting.

Section 10.0

AUDITS

Mr. Bill Davis, the QA Coordinator for this project, will conduct one internal systems audit during the course of this project. Mr. Davis is not associated with the project on a day-to-day basis.

It is currently expected that this audit will be performed after the first set of experiments. The audit will cover sampling, analysis, and data handling procedures. Mr. Davis will prepare a written report summarizing the audit objectives, procedures, and findings and submit it to Mr. Larry Craigie and Mr. Robert Lacovara within 30 days of completion of the audit. In addition, Mr. Davis will conduct a formal review of the project at the end of the project, but before the report is finalized.

Section 11.0 DATA QUALITY INDICATORS

11.1. Precision

Calculated from duplicate measurements, the relative percent difference is the measure of precision:

$$RPD = \frac{|C_2 - C_1|}{m} (100\%)$$

Where: RPD = relative percent difference

C_1, C_2 = observed values

m = mean of the two values

Standard deviation will be calculated for multiple duplicate measurements.

11.2 Completeness

Completeness is as follows for all measurements:

$$\%C = \frac{V}{N} (100\%)$$

Where: %C = percent completeness

V = number of measurements executed

N = total number of measurements planned

11.3. Accuracy

Accuracy is expressed as the relative error from a value from a known standard:

$$\%RE = \frac{\mu - S}{S} (100\%)$$

Where: %RE = percent relative error

μ = measured value

S = standard value

Section 12.0

CORRECTIVE ACTION

The need for corrective action will be assessed on the basis of data audits conducted by the Quality Assurance Manager and technical systems audits conducted by the Project Managers. If corrective action is deemed necessary, the experiment will be delayed until appropriate action can be taken. If any data collected is considered invalid, due to a problem during an experiment, remedial action will be taken to determine the statistical significance of the experimental run in question or to repeat the run after corrective action is taken.

Section 13.0
REFERENCES

- 1) JMP User's Guide, Version 2 of JMP, SAS Institute Inc., Cary, NC, 1989. Chapter 14,15.
- 2) Wheeler, Donald J., Understanding Industrial Experimentation, Statistical Process Controls, Inc., Knoxville, TN, 1988.
- 3) Montgomery, Douglas C., Design and Analysis of Experiments, Wiley & Sons, 3rd edition, New York, 1991. pg. 69
- 4) Montgomery, op. Cit., pg. 197ff.
- 5) SAS User's Guide: Statistics, Version 5 edition, SAS Institute inc., Cary, NC, 1985. pg. 464-7.
- 6) Milliken, G.A., Johnson, D.E., Analysis of Messy Data, vol I: Designed Experiments, Van-Nostrand-Reinhold, New York, 1984.
- 7) Montgomery, op. Cit., pg. 134.
- 8) Box, E.P., William G. Hunter, J. Stuart Hunter, Statistics for Experimenters, An Introduction to Design, Data Analysis, and Model Building, John Wiley & Sons, New York, 1978. pg. 340.
- 9) Deming, Stanley N., and Stephen L. Morgan, Experimental Design for Quality and Productivity in Research, Development, and Manufacturing, Statical Designs, Houston, Texas, 1992. pg. 105ff

Section 14
Appendix

MODEL 51

HEATED
TOTAL HYDROCARBON ANALYZER

INSTRUCTION MANUAL



Thermo Environmental Instruments Inc.

SECTION 3

SPECIFICATIONS

MODEL 51 TOTAL HYDROCARBON ANALYZER

Detector

Type	Flame Ionization
Minimum Detectable	0.1 PPM (independent of gas)
Auto Igniter	Electronic, processor controlled
Flame Out Safety	Solenoid shuts off hydrogen fuel on flame out and alarms
Noise	Less than 1% F.S.
Drift	Less than 1% in 24 hours
Repeatability	2% of reading $\pm$ 0.1 ppm
Accuracy	2% of reading plus span gas accuracy $\pm$ 0.1 ppm
Range	0.1 ppm to 10,000 ppm (for propane)
Auto Ranging	Covers total instrument operating ranges automatically
Temperature	200 degrees C. Controlled by microprocessor with readout on screen

Sample

Sampling Rate	Approximately 2.5 L/min
Detector Flow Rate	Approximately 30 mL/min
Response Factor	Front panel settable to report same as span gas or different compound
Response Time	90% within 5 seconds (on each range)

Outputs

Vacuum Fluorescent Display	Alpha numeric 20 character length 4 lines
Analog	0-10 volts (0 - 5V & 0 - 1V options available) with 7 adjust- able ranges 4-20 mA output available as Option 5.
Serial Port RS-232	Port for sending all reports to external printer for archival purposes, or to a computer for two way communication.

Reports

Analysis Reports	High, low, and average concen- tration for each period scrolled on display and made available to RS-232C port.
Report Frequency	Settable from 1 to 99 minutes
Alarm	Concentration alarm with time written to alarm report in UTILITY. Notice also appears on the display any time there is a concentration exceedance.

Calibration

External	The standard calibration procedure permits the introduction of the zero and span gases into the Model 51 through the sample port.
Internal Span Gas (optional)	Standard span value entered via key pad
Frequency	Completely automatic zero and span on a settable cycle from 1 to 99 hours The most recent good calibration data retained in EEPROM's not overwritten by erroneous calibration.

Sample Stream Selection

Stream Sequence	Settable in any order to 10 digits

Time Between Stream Changes (also time of analysis reports)	Settable in minutes 1 to 99
Manual	Front panel controls, through Utility Menu, to hold the present stream or to advance to the next stream.
Alarm	
Concentration	Individually settable over total range for each sample stream.
System	Denotes problem with analyzer.
Internal	Audible 80 db alarm for both alarms
External	Both alarms activate 3A AC/DC contact closure for external alarms
Alarm Condition	Reported to screen, RS-232C and alarm status memory in unit.
Gases	
Combustion Air	150 mL/min at 30 psig required.



43 Beaver Brook Rd., Danbury, CT 06810 (203) 791-1400
FAX: (203) 798-6534

VorTek-SD
Airflow Transmitter
for Smaller Ducts

INSTALLATION, OPERATING,
and MAINTENANCE
MANUAL

Rev 1, 8/91

Protected by US Patent 4,770,035

TABLE OF CONTENTS

1.0	OPERATION	
1.1	General Description.....	1
1.2	Specifications.....	2
1.3	Operation of VorTek Sensors.....	3
1.4	Transmitter Operation.....	4
2.0	INSTALLATION	
2.1	Probe Mounting and Location.....	4-5
2.2	Transmitter Mounting.....	6
2.3	Transmitter Wiring.....	7
3.0	CALIBRATION & MAINTENANCE	
3.1	Field Calibration.....	8
3.2	Bench Calibration.....	8-9
3.3	Troubleshooting.....	10-11
4.0	APPENDIX	
4.1	Possible Wiring Examples.....	12

1.0 OPERATION

1.1 General Description

The Tek-Air VorTek_{tm} airflow measurement system consists of one or more duct insertion probes and an electronic transmitter. The VorTek measurement system is capable of measuring airflow volume in ducts of all sizes and shapes.

VorTek insertion probes have multiple velocity sensors located along their length. Each sensor measures airflow velocity using a unique, patented (4,770,035) application of the digital velocity sensing technique called vortex shedding.

Vortex shedding is the generation of eddy currents by an obstruction in an air stream. Airflow through each VorTek sensor creates a succession of eddy currents which are then sensed as pressure pulses. The frequency at which these pulses are generated is directly proportional to the velocity of airflow around the sensor.

In large ducts, the profile of the air velocity across a duct is often uneven due to the bends and transitions in the ductwork. In-line devices such as dampers, elbows, and transitions also create disturbances in the flow profile. To compensate for these varying velocity profiles, multiple VorTek sensors are utilized within a duct. The frequency outputs of individual sensors are flow averaged to obtain the average duct velocity.

The VorTek transmitter totalizes the frequency signals from the individual sensors to perform true velocity averaging. From this average, an electronic signal (4-20ma) is generated for direct input to a customer's control system.

The VorTek-SD transmitter is specifically designed for application in smaller ducts where one to four sensors are adequate for measurement of the air volume. This manual will cover the operation, installation, startup, and calibration of the VorTek-SD probes and transmitter.

1.2 Specifications-

Sensors and Probes

Sensor Type: Vortex shedding

Velocity Range: 350 to 7500 FPM

Probe Length: 8" to 24"

Probe Configuration: Rectangular, Round, Oval

Materials of Construction; Standard:

Mounting Plate: Galvanized Steel or Aluminum

Probe Bar: Extruded Aluminum

Sensor Assembly: Aluminum, ABS, and Polypropylene

Miscellaneous: EPDM Finishing Strip

Materials of Construction; Fume Hood:

Mounting Plate: Stainless Steel or CPVC

Probe Bar: CPVC

Sensor Assembly: CPVC and ABS

Probe Support Mounting: Flange Plate and Threaded Rod

Sensors Per Probe: 1 to 4 per Bar

Number of Bars per Transmitter: 1 to 2

Operational Temperature: -20 to 200 degrees F

Weight: Function of probe configuration

Transmitter Electronics

Input: One to four sensor inputs

Output: 4-20ma, isolated

Load Capability: 650 ohms

Voltage: 15-35Vdc

Power: 50 milliamperes at 24 Vdc

Calibration: Adjustable from 0-1000 to 0-4000 FPM;

Optional to 8000 FPM

Operational Temperature: 40 to 130 deg F

Frequency Conversion Error: less than $\pm 0.25\%$ FS (4 sensors)

Temperature Error: less than $\pm 0.5\%$ over 25 to 125 deg. F

Low Frequency Cutout: 350 FPM (adjustable)

Time Constant: 0.67 seconds, fixed

Housing: NEMA 1 type, use indoors only

Dimensions: 6" x 6" x 2" (WxHxD)

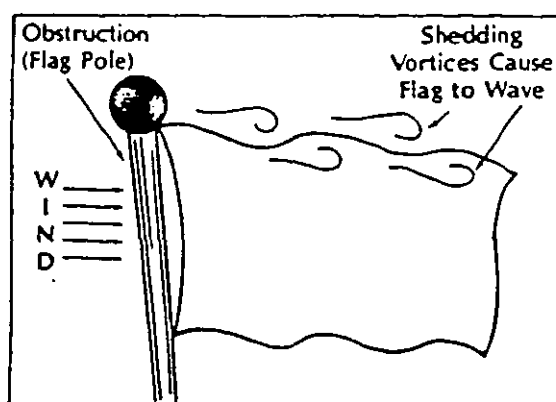
Weight: 5 lbs with probes

Mounting: Standard; integral to probe assembly

Optional; 24 inch umbilical

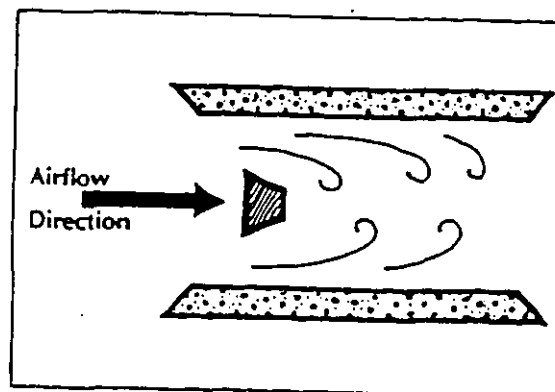
1.3 Operation of VorTektm Sensors

The VorTek Sensing system measures air velocity by a physical principle called vortex shedding. The vortex shedding phenomena can be witnessed all around us in everyday life. Swirling vortices, or eddy currents, are generated whenever air or liquids flow around an obstruction in their flow path. Common examples are the eddy currents which develop behind rocks in a stream, and in the fluttering of a flag behind a flag pole. The flag and the flag pole provide the most visual example of how vortex shedding works.



The flag pole presents an obstruction in the path of the airflow, which is the wind. As the wind passes around the flag pole, vortices (eddies) are created in the wake of the pole. These vortices, in accordance with the laws of nature, are developed and shed in an alternating manner, from one side of the flag pole to the other. The evidence of the shedding of vortices is in the waving of the flag itself.

Tek-Air's unique VorTek flow sensors use a trapezoidal shaped obstruction placed in a small tube section to generate stable vortices over a wide range of low velocities. Pressure sensors sense the passing of individual eddies. Multiple VorTek sensors are mounted on probe supports to provide ample coverage of the duct cross section.



1.4 Transmitter Operation

The VorTek-SD Transmitter is integrally mounted on the end of one duct insertion probe. If there are two probes, the second probe is integrally connected to the electronics by an umbilical cord.

The VorTek-SD transmitter is capable of accepting inputs from one to a maximum of four VorTek sensors. These can be located on one or two probe bars.

In the simplest sense, the transmitter electronics can be considered a pulse to analog convertor. The transmitter receives electronic pulses from each of the VorTek sensors. As every pulse represents the same increment of velocity, the pulses need only be summed together and integrated over time to determine velocity. Additional circuitry converts the total pulses per second into an analog, 4-20ma signal which is proportional to either CFM or FPM.

The VorTek transmitter performs two functions electronically. The amplifier section performs the required signal conditioning on up to four VorTek sensor inputs. The summing section accepts the conditioned pulses from the amplifier section, sums them, integrates them, and converts them into a 4-20ma output signal. The summing section also provides the power supply and calibration adjustments.

Because airflow is inherently turbulent, it tends to produce fluctuating electronic output signals if not dampened when high turbulence is present. Also, some commercial DDC systems update control outputs only on large changes in input signals. The rapid input changes caused by airflow turbulence can cause these types of systems to effectively overload and crash. To eliminate this problem, the transmitter includes a time constant of 0.67 seconds.

2.0 INSTALLATION

The VorTek-SD measurement system consists of two basic elements which are connected together, the probes and the transmitter. The VorTek sensing probes are inserted into the duct and measure the velocity of the air moving through the duct. The VorTek transmitter which is connected to the probes, converts the electronic pulses

generated by the sensors into an electronic signal compatible with most DDC control systems.

The following details are provided on the mounting and installation of the VorTek transmitter and flow probes. Please read this data carefully and install the equipment in strict accordance with the instructions provided. Should you have any questions, contact Tek-Air directly.

2.1 Probe Mounting and Location

General - VorTek probes are designed for installation in ducts, regardless of the duct size. Usually, the larger the duct, the more sensing points are required to provide an accurate measurement of airflow volume. In a typical application, multiple probe support bars are directly inserted in the duct. Each probe bar has multiple VorTek sensors for measurement of the air velocity in the area of the duct it serves.

Turbulent Airflow - Probe design allows for installation in ductwork without the requirement for special air straighteners. However, care should be taken to avoid installation within close proximity to:

- o Balancing dampers
- o Modulating opposed blade dampers
- o Non-airfoil type, normally open dampers
- o Elbows without Turning Vanes
- o Expanding transitions
- o Humidifiers
- o Coils

Refer to the drawing "Minimum Recommended Installation Requirements" for the minimum acceptable installation criteria for specific applications. If more space is available probes should be located so that they have two thirds of the straight duct length upstream of the probe. Keep in mind that locations other than those specified as minimums often have areas with very high turbulence and reverse flow. Accurate airflow measurement is impractical in these locations.

Direction of Flow - VorTek airflow probes must be mounted so airflow direction corresponds to the direction indicated by the flow arrow on the duct mounting flange. Failure to mount the units properly will result in a "no flow" output. Probes can be mounted in any plane, vertical or horizontal, without effecting the measurement quality.

Temperature - VorTek probes are designed for use in normal HVAC applications. Continuous operation with temperatures over 200 degrees with standard materials of construction is not recommended. Fume hood exhaust sensors with CPVC construction have a limit of 175 degrees. Close proximity to steam humidifiers and coils is not recommended. Should a steam valve leak when air is not flowing, temperatures in excess of the recommended maximum can occur.

Airborne Contaminants - Normal dirt and dust associated with air conditioning and fume hood applications will not effect probe performance. The presence of agglomerating or sticky particles can cause performance problems and should be avoided. Should this occur, however, the probes can be cleaned with soapy water.

Inspection - Carefully unpack and inspect the probes. If probes have been bent or broken in shipment, advise Tek-Air immediately.

Installation - Probes are mounted across the duct and attach to the duct on both sides. A 3.5" diameter hole should be located on the side of the duct where the probe will be inserted. On probes longer than 12 inches a 5/16" diameter hole is required in the duct wall on the opposite side of the duct.

The sensor flange plate is provided with a neoprene gasket and does not require the application of special sealants. The flange plate should also not be insulated to allow for easy removal if ever desired.

2.2 Transmitter Mounting and Location

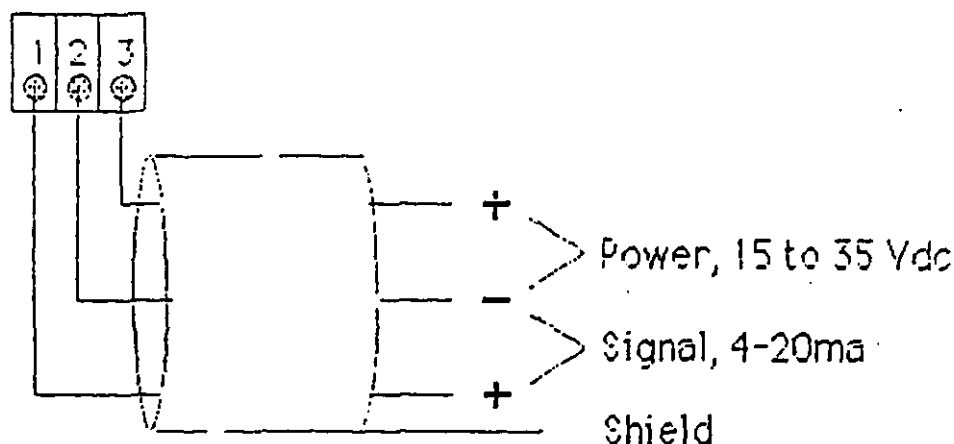
General - The transmitter is typically located on one of the duct insertion probes and transmits a 4-20ma signal over long distances to the customers control system.

Transmitter Location - The VorTek transmitter is small and is designed for mounting on the probe at the point of measurement. The transmitter housing is a general purpose enclosure and is therefore not designed for mounting outdoors or in areas requiring explosion-proof classification. Areas where the temperatures are expected to exceed 130 degrees F for extended periods of time are to be avoided.

2.3 Transmitter Wiring

Terminations - Inside the transmitter enclosure, in the center of the electronics board, are three removable termination points. These are for the termination of power and signal wiring as follows (other typical configurations are attached in the appendix):

Transmitter



Transmitter Power and Signal Wiring
Figure 1

Signal and power wiring should be run in a common shielded cable. Shields should be terminated at only one end and taped back on the other. Shields should be terminated at the controller in accordance with the controller manufacturers instructions.

Output Signal - Transmitter output is 4-20ma and is capable of driving up to 600 ohms of load. Control equipment which accepts voltage inputs will require the installation of an appropriate dropping resistor at the controller input terminals. A 500 ohm resistor will provide a 2-10 Volt signal; a 250 ohm resistor will provide a 1-5 volt signal.

3.0 CALIBRATION & MAINTENANCE

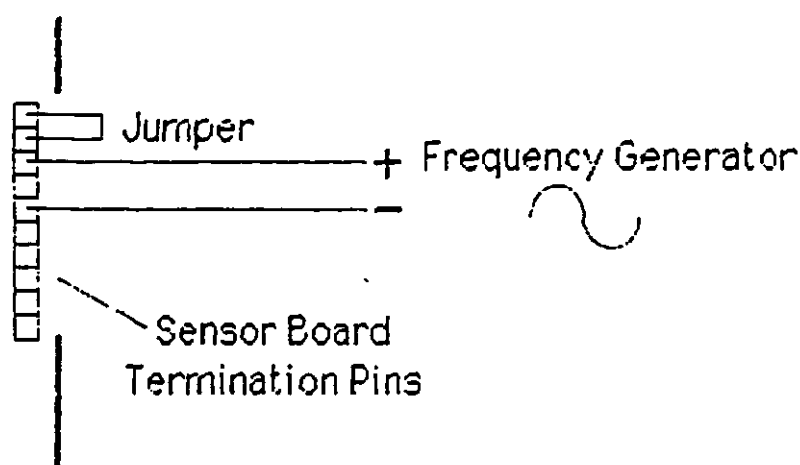
3.1 Field Calibration

The VorTek-SD Transmitter comes calibrated for the CFM or FPM specified by the user. The calibration factor is established as a function of the type of VorTek sensor utilized in the construction of the probe bars. These calibration factors are established by test and represent flow conditions expected when normal minimum up- and downstream dimensions are observed.

When these conditions are not present and duct turbulence is a problem, corrections may be required to match flow transmitter output to readings observed by traverse. In these cases, either software constants or transmitter span can be adjusted to read the desired output. Adjustment of span will not effect transmitter zero.

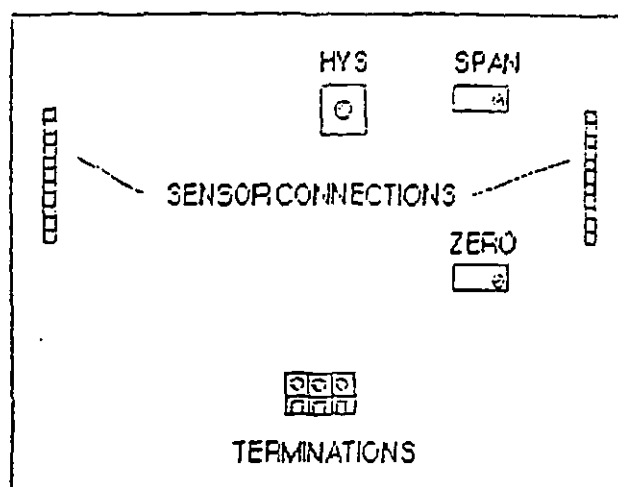
3.2 Bench Calibration

The transmitter is normally calibrated at a bench although it is possible to bring the bench calibration instruments to the transmitter in the field. Connect a power supply and digital voltmeter in the milliamp mode to the transmitter as shown in figure 1. With the sensor boards unplugged, connect a jumper wire and frequency generator as shown in figure 2. The frequency generator must be set to an output voltage of less than 250 millivolts. The frequency generator can be used in conjunction with a frequency counter the best accuracy. The full procedure is as follows:



Frequency Calibration Connections

Figure 2



VorTek-SD Board Layout
Figure 3

Set Zero - With the jumper installed and the frequency generator disconnected, adjust the "ZERO" potentiometer until 4.00 ma is read at the digital voltmeter.

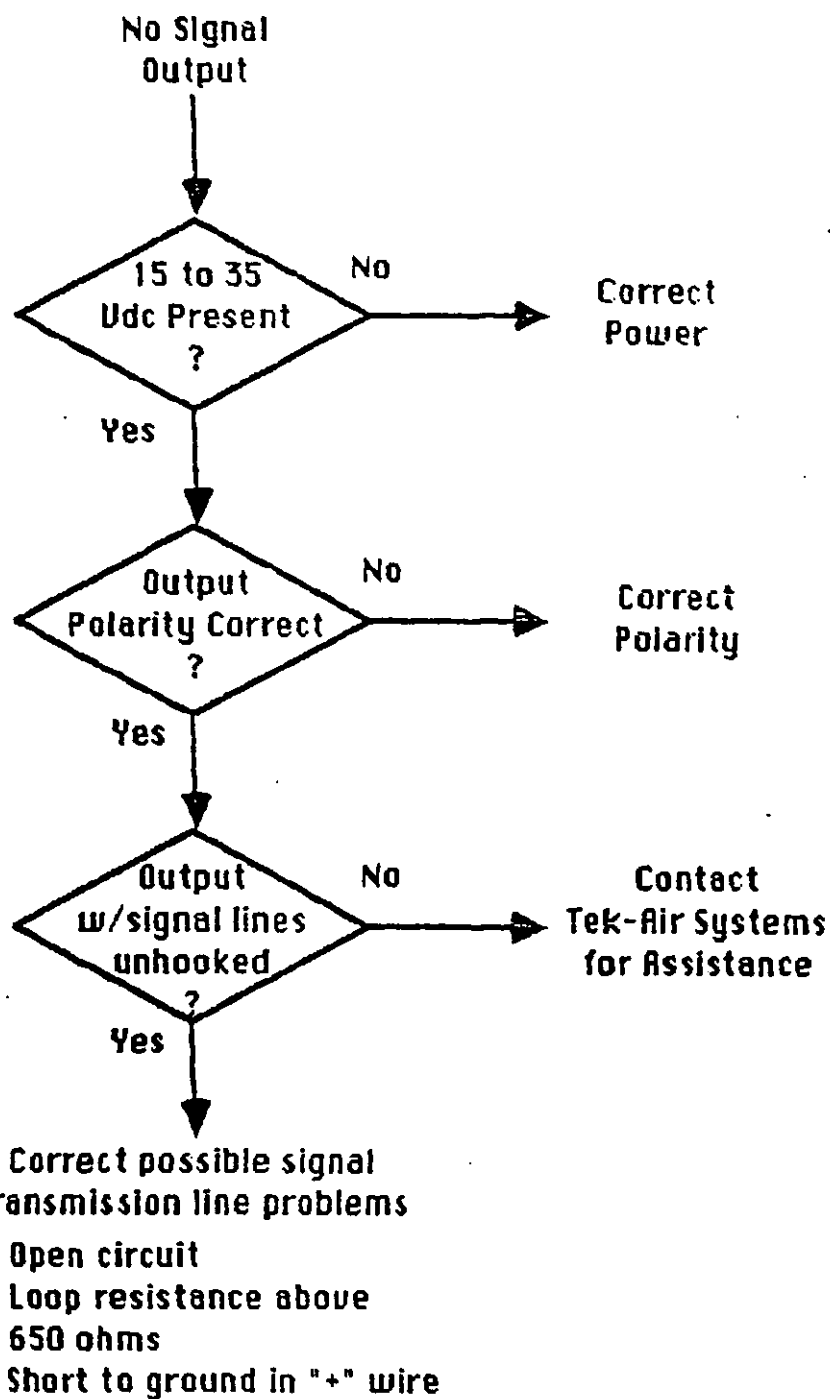
Set Full Scale - Connect the negative lead of a frequency generator to one of the two center pins on one of the sensor board connectors. Connect the positive lead to the third pin from either end (refer to figure 2). Set the frequency generator to the full scale Hz indicated on the transmitter nameplate. Set the frequency generator to sinusoidal wave and the output voltage to the minimum level. Adjust the "SPAN" potentiometer to achieve a 20.0 ma output.

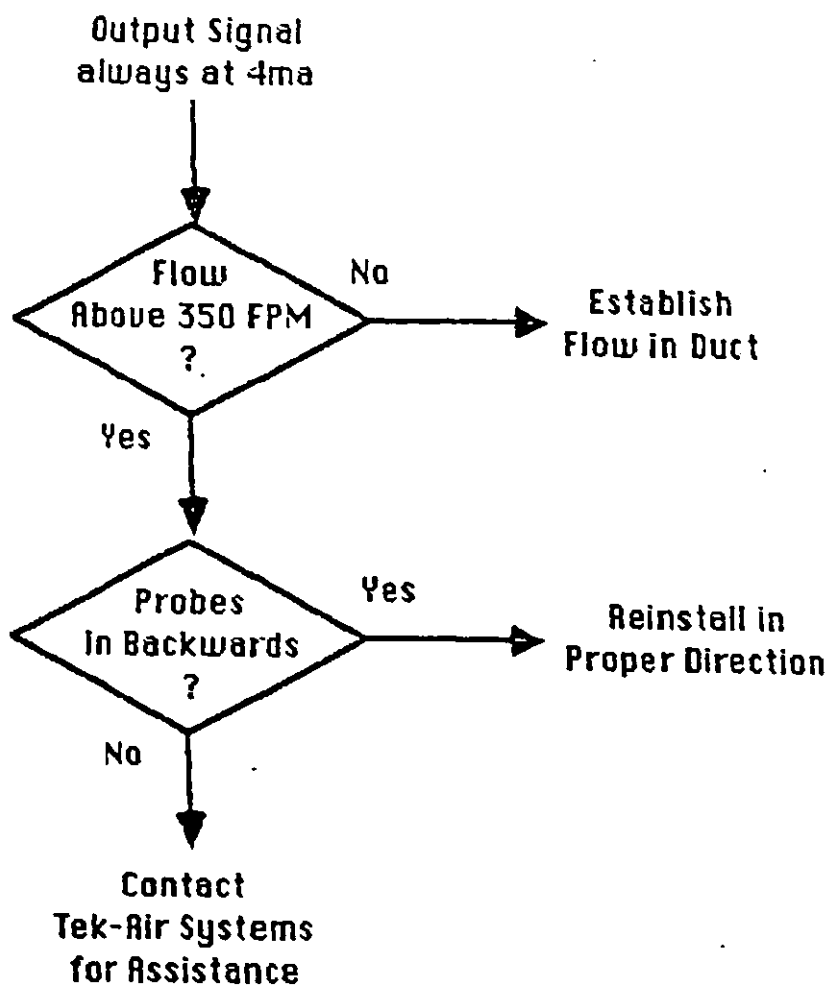
Threshold Operation - The sensing threshold cutoff is provided to eliminate a "false" flow reading when flow is not present. The threshold level is set at approximately 350 FPM but it can be adjusted. To calibrate perform the following steps.

With the above connections and settings in place from the previous step, set the frequency generator to approximately 50 Hz. Slowly turn the "HYS" adjustment counter clockwise until the transmitter output switches to 4 ma. Then, slowly turn the "HYS" adjustment clockwise until the output switches to a milliamp reading corresponding to 50Hz/F.S Hz. Formula is $ma = (16 \times 50 / FS \text{ Hz}) + 4$

3.3 Trouble Shooting

The following flow charts are designed to aid in trouble shooting the transmitter and flow sensors should problems be experienced in commissioning the airflow measurement system.

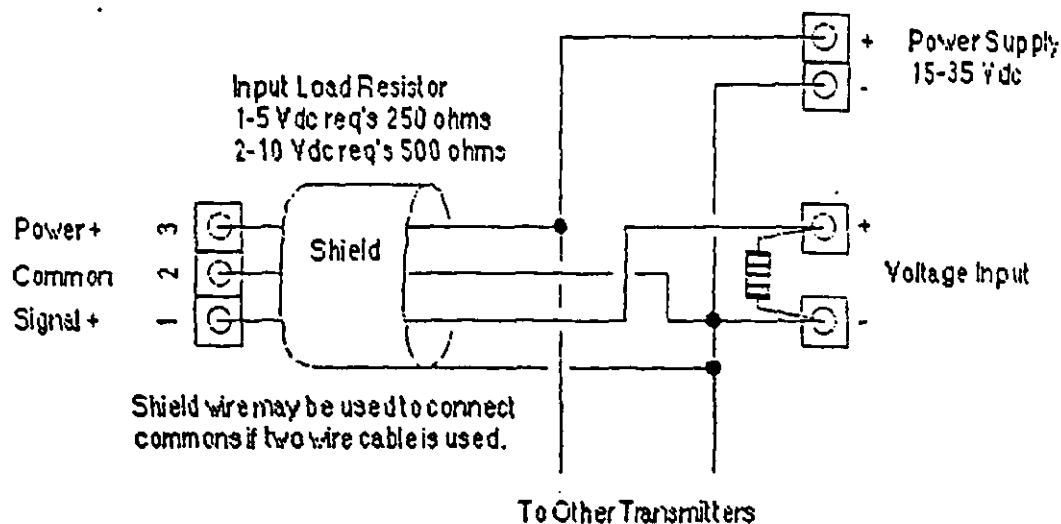




4.0 Appendix

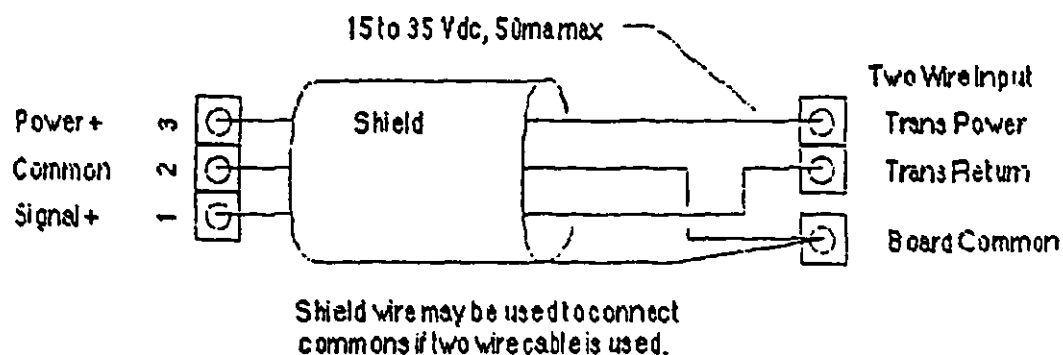
4.1 Sample Terminations

The following wiring configuration can be used for multiple transmitters, powered from a common supply, inputting to a voltage type input channel. Do not provide resistor if input is 4-20ma type.



Voltage Input, Common Power Supply
Figure 4

The following wiring configuration can be used where system incorporates two wire transmitter power which fused for current greater than 50ma.



Current Input with Integral
Loop Power Supply
Figure 5

IWECO, INC.

TO: DOW CHEMICAL
FREEPORT, TEXAS

DATE: 06/08/95
IWECO ORDER NO: L0608.JUN-10
CUSTOMER P.O.: BR-1316

DEAR SIR:

THIS IS YOUR CERTIFICATE OF ANALYSIS FOR: PRIMARY STANDARD MIXTURE(S)

<u>CYLINDER NUMBER</u>	<u>MIXTURE COMPONENTS</u>	<u>REQUESTED COMPOSITION</u>	<u>CERTIFIED COMPOSITION</u>	<u>CERTIFICATION ACCURACY</u>
CC-16247	STYRENE AIR	105 PPM BALANCE	104 PPM BALANCE	+/-1% REL

MIXTURE SHELF LIFE IS 12 MONTHS.
EXPIRATION DATE IS 06/07/96.

COA6MP


QUALITY CONTROL SUPERVISOR

COMPOSITION IS IN MOLE %.

IWECO, INC.

TO: DOW CHEMICAL
FREEPORT, TEXAS

DATE: 06/08/95
IWECO ORDER NO: L0608.JUN-11
CUSTOMER P.O.: BR-1316

DEAR SIR:

THIS IS YOUR CERTIFICATE OF ANALYSIS FOR: PRIMARY STANDARD MIXTURE(S)

<u>CYLINDER NUMBER</u>	<u>MIXTURE COMPONENTS</u>	<u>REQUESTED COMPOSITION</u>	<u>CERTIFIED COMPOSITION</u>	<u>CERTIFICATION ACCURACY</u>
CC-45991	STYRENE AIR	175 PPM BALANCE	175 PPM BALANCE	+/-1% REL

MIXTURE SHELF LIFE IS 12 MONTHS.
EXPIRATION DATE IS 06/07/96.

COA6MP

COMPOSITION IS IN MOLE %.


QUALITY CONTROL SUPERVISOR

IWECO, INC.

TO: DOW CHEMICAL
FREEPORT, TEXAS

DATE: 06/08/95
IWECO ORDER NO: L0608.JUN-9
CUSTOMER P.O.: BR-1316

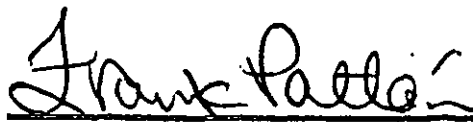
DEAR SIR:

THIS IS YOUR CERTIFICATE OF ANALYSIS FOR: PRIMARY STANDARD MIXTURE(S)

<u>CYLINDER NUMBER</u>	<u>MIXTURE COMPONENTS</u>	<u>REQUESTED COMPOSITION</u>	<u>CERTIFIED COMPOSITION</u>	<u>CERTIFICATION ACCURACY</u>
CC-116818	STYRENE AIR	280 PPM BALANCE	281 PPM BALANCE	+/-1% REL

MIXTURE SHELF LIFE IS 12 MONTHS.
EXPIRATION DATE IS 06/07/96.

COA6MP


QUALITY CONTROL SUPERVISOR

COMPOSITION IS IN MOLE %.

14.4.1

REICHOLD CHEMICALS

JACKSONVILLE PILOT PLANT

Certificate of Analysis

FROM: Reichhold Chemicals Inc.
54 Wamsley Road
Jacksonville, FL 32254

TO: Dow USA-Texas Operations
2301 N. Brazosport Blvd.
Freeport, TX 77541-3264

Product Code Number RP-1091 Batch Number 314-045-0202

VISCOSITY DATA

Brookfield Viscosity (in cps)	920
Viscometer Type	LVF
Spindle Number	3
Viscometer Speed	60

GEL TIME DATA

Gel Time (in minutes)	13.3
Interval (in minutes)	21.5
Total Time (in minutes)	34.8
Peak Exotherm (in F)	282
Catalyst Level	1.25cc DDM-9

OTHER PHYSICAL PROPERTIES

Specific Gravity	1.13
Acid Number	25.1
Percent Non-volatiles	65.06

Thank you for choosing Reichhold Chemicals.

Mike Weaver
Pilot Plant Operator

Jim Eisenhutt
Pilot Plant Supervisor

April 28, 1995

REICHOLD CHEMICALS

JACKSONVILLE PILOT PLANT

14.4.2

Certificate of Analysis

FROM: Reichhold Chemicals Inc.
54 Wamsley Road
Jacksonville, FL 32254

TO: Dow USA-Texas Operations
2301 N. Brazosport Blvd.
Freeport, TX 77541-3264

Product Code Number RP-1092 Batch Number 314-045-0203

VISCOSITY DATA

Brookfield Viscosity (in cps)	1004
Viscometer Type	LVF
Spindle Number	3
Viscometer Speed	60

GEL TIME DATA

Gel Time (in minutes)	28.9
Interval (in minutes)	9.9
Total Time (in minutes)	38.8
Peak Exotherm (in F)	278
Catalyst Level	1.25cc DDM-9

OTHER PHYSICAL PROPERTIES

Specific Gravity	1.13
Acid Number	24.2
Percent Non-volatiles	64.95

Thank you for choosing Reichhold Chemicals.

Mike Weaver
Pilot Plant Operator

Jim Eisenhutt
Pilot Plant Supervisor

April 28, 1995

REICHOLD CHEMICALS

JACKSONVILLE PILOT PLANT

Certificate of Analysis

FROM: Reichhold Chemicals Inc.
54 Wamsley Road
Jacksonville, FL 32254

TO: Dow Chemical Company
2301 N. Brazosport Blvd.
Freeport, TX 77541

Product Code Number 2985-09B

Batch Number 314-104-0683

VISCOSITY DATA

Brookfield Viscosity (in cps)	448
Viscometer Type	LVF
Spindle Number	3
Viscometer Speed	60
Thixotropic Index	2.46
Viscometer Speed	6

GEL TIME DATA

Gel Time (in minutes)	15.3
Interval (in minutes)	11.0
Total Time To Peak (in minutes)	26.3
Peak Exotherm (in F)	323
Catalyst Level	1.25cc DDM-9/100grms
Promotion Level	

OTHER PHYSICAL PROPERTIES

Specific Gravity	1.10
Acid Number	25.9
Percent Non-volatiles	57.4

Thank you for choosing Reichhold Chemicals.

Paul Ridgely
Pilot Plant Operator

Jim Eisenhutt
Pilot Plant Supervisor

REICHOLD CHEMICALS

JACKSONVILLE PILOT PLANT

Certificate of Analysis

FROM: Reichhold Chemicals Inc.
54 Wamsley Road
Jacksonville, FL 32254

TO: Dow Chemical Company
2301 N. Brazosport Blvd.
Freeport, TX 77541

Product Code Number 2985-09A

Batch Number 314-104-0677

VISCOSITY DATA

Brookfield Viscosity (in cps)	500
Viscometer Type	LVF
Spindle Number	3
Viscometer Speed	60
Thixotropic Index	2.0
Viscometer Speed	6

GEL TIME DATA

Gel Time (in minutes)	29.2
Interval (in minutes)	11.8
Total Time To Peak (in minutes)	41.0
Peak Exotherm (in F)	294
Catalyst Level	1.25cc DDM-9/100grms
Promotion Level	

OTHER PHYSICAL PROPERTIES

Specific Gravity	1.11
Acid Number	27.1
Percent Non-volatiles	59.1

Thank you for choosing Reichhold Chemicals.

Mike Weaver
Pilot Plant Operator

Jim Eisenhutt
Pilot Plant Supervisor

COOK COMPOSITES AND POLYMERS CO.
P. O. BOX 419389
KANSAS CITY MO 64141-6389
PACKING LIST NO. 121353

PAGE: 1

ORDER NO: 165326
BOL DOC NO: 165326 CUST: 889531 ALT STAGING LOC:

OLD TO: DOW CHEMICAL
B-1605

SHIP TO: DOW CHEMICAL
ATTENTION: MR CRAIGE
BLDG B, 2009

FREEPORT

TX 77541

FREEPORT

TX 77541

CARRIER: AMERICAN FRTWYS FREIGHT: PREPAID FOB: ORG TERR: 148373
CUST PO # : LARRY CHIRPICH ORDER DT: 11/03/94 SHIP FROM: 70
SCHLD DEL DATE: PHONE: () -

PRODUCT CODE: 944WJ025 UM: LB UNIT: 5 GAL (10) BOL: F2199
DESCRIPTION: WHITE
CUST PART NO: 9-12 min. 65% Solids [Fast-Low Styrene] 35%

QTY TO SHIP	QTY SHIPPED	PIECES	GROSS WT	TARE WT	NET WT	BATCH NUMBER
5	5	5	280	15	265	701994110118

PRODUCT CODE: 944WJ027 UM: LB UNIT: 5 GAL (10) BOL: F2199
DESCRIPTION: WHITE
CUST PART NO: 20-24 65% Solids [Slow-Low Styrene] 35%

QTY TO SHIP	QTY SHIPPED	PIECES	GROSS WT	TARE WT	NET WT	BATCH NUMBER
5	4	4	212	12	200	701994110125
	1	1	27	3	24	701994110125

PRODUCT CODE: 944BJ009 UM: LB UNIT: 5 GAL (10) BOL: F2199
DESCRIPTION: BLACK
CUST PART NO: 9-12 min 58% Solids [Fast-High Styrene] 42%

QTY TO SHIP	QTY SHIPPED	PIECES	GROSS WT	TARE WT	NET WT	BATCH NUMBER
5	5	5	265	15	250	701994110119

PRODUCT CODE: 944BJ010 UM: LB UNIT: 5 GAL (10) BOL: F2199
DESCRIPTION: BLACK
CUST PART NO: 20-24 min. 58% Solids [Slow-High Styrene] 42%

QTY TO SHIP	QTY SHIPPED	PIECES	GROSS WT	TARE WT	NET WT	BATCH NUMBER
5	5	5	265	15	250	701994110126
	1	1	37	3	34	701994110126



FORM 2506 (05/91)

**POLYCOR / STYPOL****POLYESTER
PRODUCTS**

Cook Composites and Polymers

**POLYESTER GEL COAT
BATCH TEST VALUES**

Customer Dev Chemical Location _____ Date _____
 Attention _____
 Product Code 944-W5-027 Color Name _____
 Batch # 20199411025 Batch Date 4-3-94 Batch Size 224

Test Name	Typical Range	Method	Batch Value
Viscosity	<u>16500 - 19500</u>	<u>RUF 424</u>	<u>17000</u>
Thix Index	<u>6.0 - 7.0</u>		<u>6.0</u>
Gel Time	<u>20-24</u>	<u>1.5% HP-90</u>	<u>23.5</u>
Hide			
Weight/Gallon			
Solids			<u>64.29</u>

Prepared by AK Date 11-14-94
 Location KE

FORM 2506f (05/91)


POLYCOR / STYPOL **POLYESTER PRODUCTS**
**POLYESTER GEL COAT
BATCH TEST VALUES**

Customer Dow Chemical Location _____
 Attention _____ Date 11-14-94
 Product Code 944-BJ-W9 Color Name Black
 Batch # 701994110119 Batch Date 4-3-95 Batch Size 491

<u>Test Name</u>	<u>Typical Range</u>	<u>Method</u>	<u>Batch Value</u>
Viscosity	<u>12000 - 15000</u>	<u>RUE 48V</u>	<u>13000</u>
Thix Index	<u>6.0 - 7.0</u>		<u>6.9</u>
Gel Time	<u>9-12</u>	<u>1.5% HP-90</u>	<u>9.0</u>
Hide			
Weight/Gallon			
Solids			<u>59.50</u>

Prepared by MT Date 11-14-94
 Location KE


POLYCOR / STYPOL POLYESTER PRODUCTS
**POLYESTER GEL COAT
BATCH TEST VALUES**

Customer Dow Chemical Location _____
 Attention _____ Date 11-14-94
 Product Code 944-BJ-010 Color Name Black
 Batch # 701994110126 Batch Dat 4-318 Batch Size 284

Test Name	Typical Range	Method	Batch Value
Viscosity	<u>12000-15000</u>	<u>RUF 424</u>	<u>14300</u>
Thix Index	<u>6.0-7.0</u>		<u>6.4</u>
Gel Time	<u>20-24</u>	<u>1.5% HP-90</u>	<u>20.0</u>
Hide			
Weight/Gallon			
<u>Solid</u>			<u>59.50</u>

Prepared by HZ Date 11-14-94
 Location KC

FORM 2506f (05/91)


POLYCOR / STYPOL POLYESTER PRODUCTS
**POLYESTER GEL COAT
BATCH TEST VALUES**

Customer Dow Chemical Location _____
 Attention _____ Date 11-14-94
 Product Code 944-W5-976 Color Name White
 Batch # 201994110118 Batch Date 4-321 Batch Size 26.1

Test Name	Typical Range	Method	Batch Value
Viscosity	<u>16500 - 19500</u>	<u>RULE 424</u>	<u>16750</u>
Thix Index	<u>6.0 - 7.0</u>		<u>6.1</u>
Gel Time	<u>9-12</u>	<u>1.8% 1H²-90</u>	<u>10.0</u>
Hide			
Weight/Gallon			

Solids

64.12

Post-It® brand fax transmittal memo 7671 # of pages = 4

To	Bob LACAVARA	From	L CHIRPICH
Co	CEA C	Co.	
Dept.		Phone	800 871 3590
Fax	409 738 0789	Fax	

Prepared by MZ Date 11/14/94
 Location K.C.

Test Results - CFA Styrene Emissions Project

Phase I Baseline Study & Optimization Study

Report From The Emissions Project Team:

Bob Lacovara, CFA

Larry Craigie, Dow Chemical

Terry Cowley, Dow Chemical

Paul Wykowski, Dow Chemical

Gary Webster, Dow Chemical

The industries using unsaturated polyester and vinyl ester resins process an estimated 1.4 billion pounds of resin per year. Various industry estimates indicate a range of 40% to 70% of this resin is used in the open molding processing category. A wide and diverse range of products are produced through open molding, including: corrosion control and pollution prevention products; transportation products; marine products; architectural products; sports and leisure products; and custom molded products.

Because of the versatility of composites, including the fact that many companies manufacture composites as a component of other products, it is difficult to ascertain the absolute size and scope of the industry. Recent surveys estimate that between 3,000 and 5,000 companies are engaged in composites production. These operations may range in size from literal "mom and pop" two person operations, to facilities employing nearly 1000 workers. It is estimated that at least 150,000 workers are employed by the U.S. composites industry, and that the industry contributes over \$16 billion annually to the U.S. economy.¹

As a result of the 1990 Clean Air Act Amendment, the USEPA is developing a maximum available control technology (MACT) standard for the open molding composites industry. This standard is focused on styrene emissions from the molding process. Currently EPA's *Compilation of Air Pollutant Emission Factors (AP-42)*² is the primary source of styrene emission factors for both the agency and the industry. A series of unrelated emissions tests conducted by various EPA contractors and other sources have shown a wide range of emission factors. The purpose of the CFA Open Molding Styrene Emissions Test Project is to identify and quantify contributing factors to styrene emissions, and to establish baseline emission levels from the open molding process and quantify emissions reductions from various pollution prevention techniques.

The CFA sponsored *Open Molding Styrene Emissions Test Project* is the most extensive research conducted to date on this subject. The scope, details and data quality produced by this project have provided a foundational understanding of styrene emissions measurement techniques, and the factors contributing to styrene emissions. In addition, the EPA Category II Quality Assurance Project Plan qualification provides a level of recognition and confidence in this work which is unprecedented by any other study or emissions test project.

Phase I of this project is a Baseline Study of the hand lay-up, gel coating, and spray-up (chopping) processes. In the baseline study, no attempt was made to reduce or control emissions. The application practices employed are considered typical for uncontrolled processing. The parameters of the experimental variables (i.e. styrene content, gel time, thickness, air flow and material flow) are again typical of what may be found in the industry. However, the range of these variables does not approximate the range that might be found across the scope of the industry. For example, the mold used for these experiments is a male mold with a surface area of approximately 37 square feet. Molds which are larger or smaller, and in both male and female configuration, can be found throughout the industry. These data represent an accurate picture of styrene emissions within the parameters of this project, and form the foundation for understanding a larger scope of the industry.

The data presented in this Phase I Study indicates emissions levels higher than current EPA AP-42² factors for uncontrolled processing. However, it has been shown that substantial reductions in emissions are available through relatively minor resin/gel coat formulation changes, and straightforward refinements in application techniques. Some of these material formulation changes are explored with the use of high and low styrene content resin/gel coats, or in the fast and slow gel times represented in the experimental design.

The subsequent *Gel Coat Spray-Up Optimization Study* explores modifications to application technique which resulted in substantial and easily attainable reductions in emissions.

*The Open Molding Styrene Emissions Test Project - Phase I Study*³ experimental runs were conducted by the Composites Fabricators Association, at a Dow Chemical applications laboratory facility in Freeport, Texas, between September 19, 1995 and December 14, 1995. A total of 60 valid experimental runs were made during this time period. The follow-up *Gel Coat Spray-Up Optimization Study*⁴ was conducted from February 21, 1996 to March 7, 1996. Phase II of the Project, which is specifically exploring source reduction and pollution prevention methods was initiated in May, 1996 and is expected to be finalized in September, 1996.

An extensive pilot program preceded this study, in which the operation of the temporary total enclosure, exhaust stack air flow, measurement equipment, and experimental procedure was established and refined. The test set-up was then transferred to another building in the Dow complex, where final improvements were incorporated for the "official" experimental runs. The sophisticated data acquisition system incorporated in this study has provided unprecedented data resolution, and correlation of data to operating conditions.

The Baseline experiments were conducted using an orthophthalic polyester resin and a polyester gel coat with styrene as the sole monomer. Hand lay-up laminates were fabricated using chopped strand mat, while the spray-up laminates used continuous strand roving. For gel coating and spray-up, an air-assist airless spray unit was used, which is common throughout the industry.

Statistical analysis of the resulting data has shown a high level of confidence in validity, and the repeatability of replicate experiments has proven to be very accurate. During the course of both the Baseline Study and the Optimization Study, identical experimental runs conducted months apart produced results within a few percent of each other. This indicates the level of accuracy and consistency of the experimental set-up. Resulting emissions data are expressed in a number of forms in the report data tables. These data include emissions by weight of styrene and resin, in addition to emissions by surface area. The test results as discussed in this document are expressed as percent emissions of available styrene (AS). Available Styrene can also be thought of as percent emissions of resin styrene content. Analysis of the data based on each of the various expressions yields a slightly different view of the results. For example, the analysis of surface area emissions vs. emissions based on weight of resin, yields a different ranking of test results. This analytic flexibility allows a better understanding of the emissions mechanism, and will contribute to the construction of more accurate modeling of emissions.

One of the objectives of the project is the development of mathematical modeling of styrene emissions which can be used to predict emissions over a wide range of conditions. The current models, which are derived from the test results are accurate predictors of emissions within the parameters of the test variables. On-going work will expand the boundaries of these models to allow wide spread use across the industry.

Hand Lay-up Summary

The major factors contributing to styrene emissions in the hand lay-up process are: 1) Laminate thickness; 2) Gel time; 3) Styrene content. Air flow over the mold surface, in the range of 50 -100 fpm, is an insignificant factor. An average of 14.1% (AS) emissions were produced for all experimental runs. Emissions ranged from 9.8% to 21.1% (AS). The combination of a thick laminate, low styrene content, fast gel time and low air flow produced the lowest emissions at 9.8% AS. At the high end of the range, a thin laminate, high styrene content, slow gel time and high air flow produced 21.1% (AS) emissions. Approximately 50% of total emissions were produced during the resin application phase of the process (transferring resin from the bucket to the laminate with a paint roller). 25% of total emissions were produced during the laminate roll-out sequence and the remaining 25% emissions were produced in the post roll-out curing stage.

Gel Coat Summary

The major factors contributing to styrene emissions in the gel coat process are: 1) Film thickness; 2) Styrene content. Gel time and air flow over the mold are minor factors, while gel coat flow rate is an insignificant factor. An average of 51.4% (AS) emissions were produced for all experimental runs. Emissions ranged from 43.5% to 61.8% (AS). The combination of thick film, low styrene, fast gel time, high gel coat flow and low air flow produced the lowest emissions at 43.5% (AS). At the high end of the range, a thin film, high styrene, slow gel time, high gel coat flow and low air flow produced 61.8% (AS) emissions. Approximately 50% of total emissions were produced during the spray application and 50% during the curing stage.

Spray-up Summary

The major factors contributing to styrene emissions in the spray-up process are: 1) Styrene content; 2) Resin flow rate. Laminate thickness was a smaller contributor, and a two factor interaction of styrene content + resin flow is a significant factor. Air flow was an insignificant factor. An average of 25.0% (AS) emissions was produced for all experimental runs. Emissions ranged from 17.1% to 38.0% (AS). The combination of thick laminate, low styrene, fast gel time, low resin flow and high air flow produced the lowest emissions at 17.1% (AS). At the high end of the range, a thick laminate, high styrene, slow gel time, low resin flow and high air flow produced 38.0% (AS) emissions. Approximately 50% of total emissions were produced during the spray application, 25% during the laminate roll-out, and 25% during the post roll-out curing stage.

Conclusion of Phase I Baseline Studies

In all three studies, styrene content was consistently a major factor. Laminate or film thickness, gel time and resin flow rate are significant emissions contributors in varying degrees. Air flow over the mold was an insignificant factor in all cases. The combination of styrene content and resin flow, in the spray-up study, was the only significant two factor interaction in all the studies. The combination of thick laminate/film, low styrene content and fast gel time is consistent in producing the lowest emissions in all three studies.

Optimization Study

The objective of the Optimization Study was to explore the effects of optimizing the spraying process for both gel coat and spray-up resin application. Whereas in the Baseline studies no attempt was made to control emissions, this study sought to quantify the effects of changes to the spray gun and application technique. The Optimization Study was carried out under the same rigorous Category II Quality Plan parameters as the Baseline study.

The results of this study indicate that the reduction of overspray, through optimized spray gun set-up and controlled spraying technique, makes major contribution to reduced styrene emissions. Gel coat emissions were reduced by over 40%, and spray-up emissions by over 20% with controlled spraying techniques. Extrapolating these reductions to the range of emissions from the Baseline Studies finds the potential to reduce gel coat emissions to between 25.4% and 36%. While spray-up emissions can be reduced to between 13.4% and 29.8%. This brings the gel coat emissions within the range of current EPA AP-42¹ emissions factors, and spray-up emissions within the upper range of the AP-42 factors.

Optimization Study Conclusions

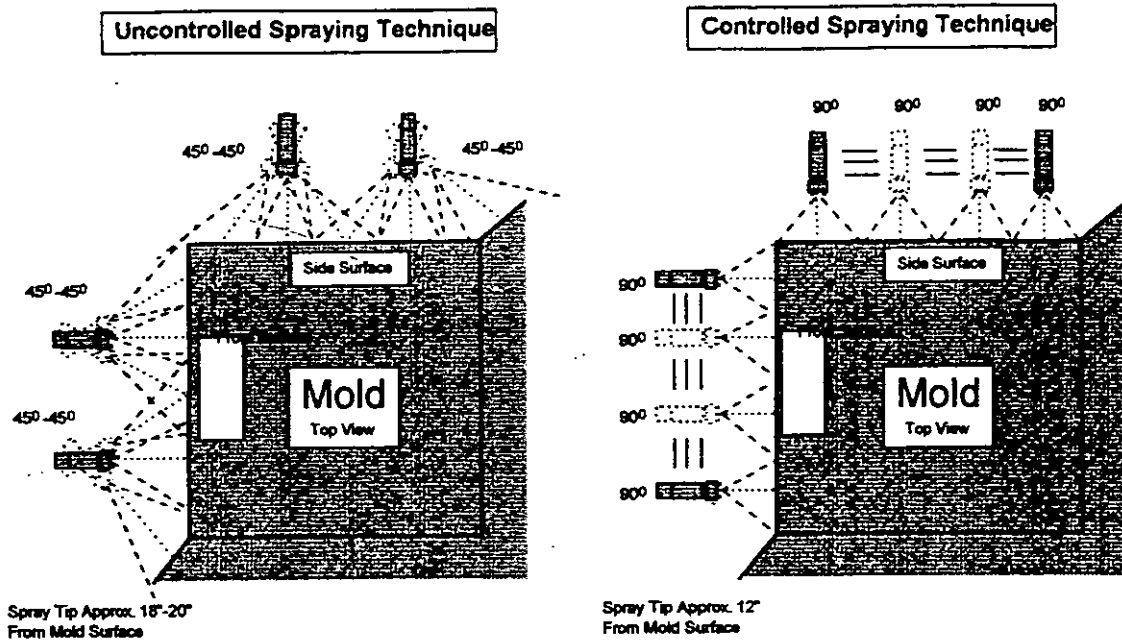
Optimization of spray gun set-up and spraying technique can have a highly significant impact in reducing emissions. The reduction of overspray is a primary factor in lowering emissions from gel coating and resin spraying operations. These methods provide substantial pollution prevention opportunities in the form of source reduction and bring emission factors within, or in proximity to, AP-42 emission factors.

Optimization Recommendations

Optimization of spray gun set-up and spraying technique should be the first line of pollution prevention and source reduction in polyester/vinyl ester resin spraying operations. These methods provide a "win-win" scenario for mitigating styrene emissions while providing cost savings. It is recommended that all spray application equipment be optimized, and spraying techniques aimed at reducing overspray be adopted to achieve these emissions reductions. Following are specific recommendations for spray application optimization:

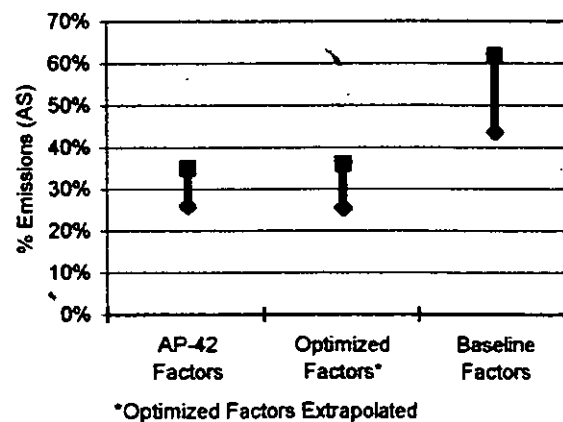
1. *Spray Equipment Set-up*: Spray tips should be sized for a specific application, in order to spray from between 12" - 18" from the surface, or as close as reasonably possible. The primary factor in adjusting material flow rate is the tip orifice size. The fan pattern width is adjusted by selecting the appropriate orifice angle.
2. *Tip Pressure*: The spray gun should be adjusted to the lowest possible pressure that produces an acceptable fan pattern. The procedure for proper spray gun set-up is described in the *Optimization Study Report*.
3. *Spray Operator Training*: Operator training is a critical part of the optimization plan. This training should include: The use of proper spraying techniques; An understanding of the function and proper set-up of spray equipment; And an understanding of the effects of overspray.
4. *Spraying Technique*: Handling of the spray gun is a critical element of optimizing the process. In simple terms, where the gun is "aimed" is very important. These techniques designed to minimize "off-spray" and reduce wet surface area surrounding the mold.
 - a. The spray gun should be held as close to the mold surface as possible, in consideration of the material output, fan pattern size, and size and configuration of the mold.
 - b. The fan pattern intercept angle should be maintained as close to perpendicular to the mold surface as possible.
 - c. The perimeter of the mold should be sprayed as accurately as possible, avoiding spraying off the edge to the greatest extent possible.
5. *Overspray Capture Mold Edge Configuration*: It is a distinct advantage to capture "off-spray" as close to the mold edge as possible. When considering the geometry of spray off the edge of the mold, the total wet surface area increases considerably as the "footprint" of the overspray area increases. It is recommended that a wide flange be incorporated at the mold perimeter, or an arrangement of masking the mold edge be used. The objective is to spray to the useful edge of the part and contain as much overspray as possible with the masking around the mold perimeter.

Fan Pattern Intercept Angles Top View

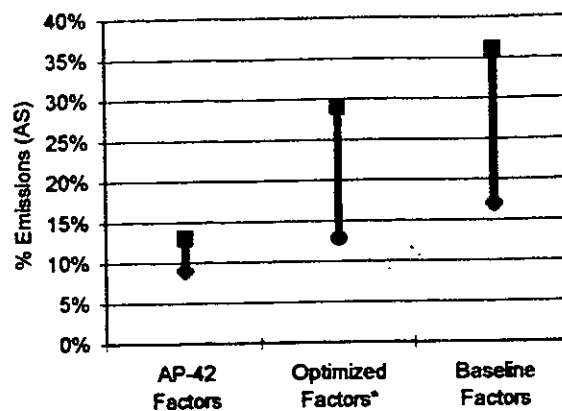


Although the Baseline Study shows emissions higher than most commonly used emissions factors, the Optimization Study demonstrates the feasibility of pollution prevention techniques which are effective and practical. During the Phase II Study, the use of styrene suppressants, filled systems, alternative application methods (pressure fed rollers and flow coaters), and the effects of larger molds and thicker laminates will be explored. Based on the current results, it is anticipated that substantial reductions in emissions will be documented.

Gel Coat Emissions Factor Range



Spray-Up Emissions Factor Range



References:

¹ Composites Fabrication, April 1996, *Developing the Demographics of the Composites Industry*, Joseph McDermott, CFA, Arlington, VA 1996

² AP-42 - U.S. EPA, Office of Air Quality Planning and Standards, *Compilation of Air Pollutant Emission Factors (AP-42)*, Research Triangle Park, NC, September 1988

³ CFA Open Molding Styrene Emissions Test Project - *Phase I Baseline Study, Final Report*, Composites Fabricators Association, McLean, VA 1996

⁴ CFA Open Molding Styrene Emissions Test Project - *Optimization Study, Final Report*, Composites Fabricators Association, McLean, VA 1996

####

word count 2,498

File: projrpt.txt