American National Standard

ACMA UEF-1-2011a

Estimating Emission Factors from Open Molding and Other Composite Processes

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American National Standard for Estimating Emission Factors from Open Molding Composite Processes and Other Composite Processes

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Approved: August 20, 2004
Revisions: May 21, 2010
January 26, 2011
October 05, 2011

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Foreword

(This Foreword is included as background information only. It is not part of the official American National Standard ANSI/ACMA/ICPA UEF-1-2009.)

From 1996 through 1998, the American Composites Manufacturers Association (ACMA), formerly named the Composites Fabricators Association (CFA), conducted styrene emissions testing. The ACMA testing program consisted of three test phases, which investigated the effects of process parameters on the styrene emissions from the open molding of composites. The test protocol used in the ACMA testing is described in the November 18, 1998 ACMA report entitled *Styrene Emissions Test Protocol & Facility Certification Procedures, Revision 2.1.* The results of the ACMA Phase I testing are detailed in the September, 1996 CFA report entitled *Phase I - Baseline Study; Hand Lay-up, Gel Coating, Spray Lay-up including Optimization Study.* The results of the ACMA Phase II and III testing are detailed in the report *Technical Discussion of the Unified Emission Factors for Open Molding of Composites.*

On February 28, 1998, Engineering Environmental Consulting Services (EECS) released a report entitled *CFA Emission Models for the Reinforced Plastics Industries* that details a set of equations developed from the ACMA test data. These equations predicted the styrene emission rates from typical lamination processes employed by the reinforced plastics industry. The report was subsequently posted on the EPA CHIEF website as a possible replacement for the obsolete AP-42 factors for reinforced plastics.

In 1997, the National Marine Manufacturers Association (NMMA) also conducted styrene emission testing using the CFA test protocol. The results of this testing are described in the August 1997 NMMA report entitled *Baseline Characterization of Emissions from Fiberglass Boat Manufacturing*. The NMMA report was also posted on the EPA CHIEF website as part of the AP-42 replacement process.

In November 1998, the CFA and NMMA agreed to merge the data from their respective test programs. The merged data sets were used to develop a new set of equations and factors that unify the methodology employed by boat builders and non-boat builders for estimating the VOC and HAP emissions from the open molding of composite parts. These new emission factors have been named the “Unified Emission Factors” (UEF). The United Emission Factor Table is the base data for this standard.

From 2006 through 2008, emission tests were conducted on machines used to prepare sheet molding compound (SMC), which is used to form composite parts via closed molding in compression and injection presses. In 2008, studies were conducted by Molded Fiberglass Company and Environmental Compliance and Risk Management (ECRM) Inc. to develop a predictive equation for emissions from SMC machines. The 2009 report *VOC Emissions from Production of Reinforced Composite Sheet Molding Compound* documents those study results and is the basis for the predictive equation in this standard.

Styrene emission testing for SMC Compression Molding was conducted beginning August 11, 2008, ending September 4, 2008 by Engineering Environmental Consulting Services. The test report SMC Compression Molding Test Results was issued November 30, 2008.

Styrene emission testing for BMC and LCM Compression Molding was conducted beginning September 4, 2008, ending September 12, 2008 by Engineering Environmental Consulting Services. The test report BMC/LCM Compression Molding Test Results was issued October 12, 2009,

The test procedures and test methods for this testing were previously described in a test protocol report entitled "*Test Protocol to determine the Process Emissions from Compression Molding using a TTE Enclosure to measure the VOC Emissions from Charge Preparation and Material Handling*" that was submitted to Ohio EPA for comments on July 21, 2008.

This testing and the cited reports serve as the technical basis for the addition of styrene emission factors for compression molding of SMC, BMC, and LCM contained in this standard.

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This standard was developed under procedures accredited as meeting the criteria for American National Standards. The list of canvassees that reviewed this proposed standard was balanced to assure that individuals from competent and concerned interests had an opportunity to participate. The standard is available for public input from industry, academia, regulatory agencies and the public-at-large. ACMA does not "approve," "rate" or "endorse" any item or proprietary device described in this standard. Participation by federal /state agency representative(s) or persons associated with industry is not to be interpreted as government or industry endorsement of this standard.

Requests for interpretations or suggestions for revision should be sent to
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1.0 Scope and Purpose

1.1 Scope

The Emission Factors will include emission estimates from open molding and other processes used in the composites industry. It will provide the user with a mechanism to estimate emissions based on the production process, materials being used and techniques employed. The final emission estimates will satisfy state and federal requirements for permit compliance and reporting emissions on Form R.

1.2 Purpose

Manufacturers are required to estimate their air emissions for permitting application and compliance and as may be required by local health officials. Also they must report air emissions from their facilities mandated by the federal Toxic Substance Control Act. Without these sanctioned factors, each facility may be required to conduct cost prohibitive emissions testing to satisfy all these reporting requirements.

2.0 Referenced Standards and Publications

Regulatory Section of : http://www.acmanet.org

40 CFR 63, Subpart WWWW – National Emission Standards for Hazardous Air Pollutants: Reinforced Plastic Composites Production

- Table 1 – The MACT Rule
- Appendix A – Test Method for Determining Vapor-Suppressant Effectiveness

SCAQMD Rule 1162, The Indiana Styrene Rule

3.0 Terms and Definitions

3.1 Terms applicable to Open Molding

3.1.1 Atomized

Atomized spray is any kind of spray application that is not non-atomized spray, but typically includes Conventional Air Atomizing, High Pressure Airless, Air-Assisted Airless, and High Volume Low Pressure applicators.

3.1.2 Controlled Spray

Controlled Spray is a specific set of three work practices that can be used to reduce material usage, worker exposures, and emissions. The three work practices included in a Controlled Spray program are spray gun set-up and pressure calibration, training in proper spray techniques, and mold-perimeter containment flanges. A full program description and training materials for Controlled Spray can be obtained from the technical resources section at *www.acmanet.org*.

3.1.3 Covered Cure

Covered cure means the use of vacuum bagging or other technology where a plastic sheet is use to cover the mold after resin is applied. Covered cure techniques are typically used where higher physical properties of the product are required. Vacuum infusion and other processes where the mold is covered before resin is applied are not considered to be open molding processes.

3.1.4 Filament Application

Filament application is an open molding process for fabricating composites in which reinforcements are fed through a resin bath and wound onto a rotating mandrel. The materials on the mandrel may be rolled out or worked by using manual tools prior to curing. Resin application to the reinforcement on the mandrel by means other than a resin bath, such as spray guns, pressure-fed rollers, flow coaters, or brushes is not considered filament application.

3.1.5 Gel Coat Application

Gel Coat Application is a process where a clear or pigmented formulated resin is applied to the mold by mechanical applicators. The gel coat will become the visible side of the composite part. If the gel coat resin is applied using a manual application method, the resin is no longer considered a gel coat for emission calculations purposes and emissions should be calculated using the manual application factors.

3.1.6 Gel Coat Non-Atomized Application

Mechanical non-atomized application means:

(a) the use of a device for applying gel coat that (1) has been provided by the device manufacturer with documentation showing that use of the device results in HAP emissions that are no greater than the emissions predicted by the applicable non-atomized application equation(s) in Table 1 to Subpart WWWW of Part 63 [the MACT rule]; and (2) is operated according to the manufacturer's directions, including instructions to prevent the operation of the device at excessive spray pressures. Non-atomized application equipment includes flow coaters, flow choppers, low tip pressure spray applicators, and pressure-fed rollers.

(b) any spray application that meets the non-atomized definition in SCAQMD Rule 1162, the Indiana Styrene rule, or the US EPA MACT rule. Non-atomized spray includes both an equipment design requirement and certain essential work practice requirements. The gun supplier and the applicable regulations specify the required work practices.

3.1.7 Gel Coat Lesser Atomized Application (LAGA)

The atomized gel coat factor has been found to over predict gel coat emissions, while the non-atomized gel coat factor has been shown to under predict gel coat emissions. LAGA equipment is designed to apply gel coat to an open mold with less atomization of the spray plume than older equipment designs, which results in lower styrene emissions from the gel coat.

3.1.8 Manual

Manual (application) is any non-mechanical application (without pumps or pressurized material flow), and includes bucket-and-brush and bucket-and-roller.

3.1.9 Mechanical

Mechanical (application) means the use of pumps to deliver a pressurized stream of resin or gel coat to a mold through some kind of application device. Spray and non-spray are the two types of mechanical application.

3.1.10 Mechanical Atomized

Mechanical Atomized (application) means application of resin or gel coat with spray equipment that separates the liquid into a fine mist. This fine mist may be created by forcing the liquid under high pressure through an elliptical orifice, bombarding a liquid stream with directed air jets, or a combination of these techniques.

3.1.11 Mechanical Atomized Control Spray

Mechanical Atomized Control Spray is the use of an atomized spray gun in combination with a Controlled Spray program.

3.1.12 Mechanical non-atomized

Mechanical non-atomized (application) means (a) or (b):

(a) the use of a device for applying resin that a) has been provided by the device manufacturer with documentation showing that use of the device results in HAP emissions that are no greater than the emissions predicted by the applicable non-atomized application equation(s) in Table 1 to Subpart WWWW of Part 63 [the MACT rule]; and b) is operated according to the manufacturer's directions, including instructions to prevent the operation of the device at excessive spray pressures. Non-atomized application equipment includes flow coaters, flow choppers, low tip pressure spray applicators, and pressure-fed rollers.

(b) any spray application that meets the non-atomized definition in SCAQMD Rule 1162, the Indiana Styrene rule, or the US EPA MACT rule. Non-atomized spray includes both an equipment design requirement and certain essential work practice requirements. The gun supplier and the applicable regulations specify the required work practices.

3.1.13 Open Molding

Open molding is manual resin application, mechanical resin application, filament winding, and gel coat application. Resin Transfer molding (or other processes where resin is delivered in a closed or covered mold, pultrusion and compression molding are not open molding processes.

3.1.14 Roll-Out

Roll-out is the process used to compact and remove entrapped air from a laminate after the resin and reinforcement has been applied to a mold.

3.1.15 Spray

Spray means any material flow moving through the air to be deposited on a mold. Spray can be atomized or non-atomized.

3.1.16 Styrene Content

The styrene content of a resin or gel coat is the styrene content as applied, including any styrene added by the user. For non-gel coat resins the styrene content is calculated before any fillers or other non-styrene materials are added.

3.1.17 Vapor Suppressant

Vapor suppressant is an additive, typically a wax that migrates to the surface of the resin during curing and forms a barrier to seal in the styrene and reduce styrene emissions.

3.1.18 Vapor Suppressed Resin, VSR

VSR is a resin containing a vapor suppressant added for the purpose of reducing styrene emissions during curing**.**

3.1.19 Vapor Suppressed Resin Reduction Factor

The VSR Reduction Factor is a measure of the efficiency of a suppressant with a resin. It is determined by testing each resin/suppressant formulation according to the test method found in The US EPA MACT rule, Appendix A to Subpart WWWW--Test M.

3.2 Compression Molding Material Definitions

3.2.1 Sheet Molding Compound (SMC) is the feedstock used to produce reinforced plastic composite parts in injection and compression presses. SMC consists of styrenated resin paste and fiber reinforcement, sandwiched between two nylon-containing carrier films.

3.2.2 Bulk Molding Compound (BMC) is a feedstock used to produce reinforced plastic composite parts in injection and compression presses. BMC is a premixed blend of styrenated resin, reinforcements, initiators and fillers.

3.2.3 Liquid Composite Molding (LCM) is a term referring to the combination of a fiber reinforcement and a styrenated resin paste in a closed mold to produce reinforced plastic composite parts. Liquid resin is applied to the reinforcement before molding. The resin may be applied from a container or conveyance so that it covers typically 10-40% of the area of the reinforcement (poured), or it may be applied and then spread to increase the coverage to in excess of 50% of the area of the reinforcement (spread). .

3.3 Terms applicable to Production of Sheet Molding Compound

3.3.1 Doctor Boxes are the upper and lower reservoirs into which resin paste mixed upstream is introduced and spread in a thin film across nylon carrier film.

3.3.2 Lower Wet Length (L_l) is the distance in feet, measured along the path of lower film travel, between the downstream end of the lower doctor box and the point at which the upper and lower carrier films come together.

3.3.3 SMC Machine refers to the production line for SMC. In typical configurations, resin paste is pumped to upper and lower reservoirs (*doctor boxes*), from which it is distributed in a thin layer across upper and lower carrier films, which are impervious to styrene. Chopped fibers (usually glass) are spread across the lower carrier film, and the two films are brought together and fed through a series of compression rollers, after which the final product is either rolled or folded (festooned) for storage.

3.3.4 Total Wet Area (A_t) is calculated as defined in section 4.

3.3.5 Upper and Lower Open Doctor Box Areas (A_{du} and A_{dl}) are the areas of each doctor box that are uncovered, measured in square feet.

3.3.6 Upper Wet Length (L_u) is the distance in feet, measured along the path of upper film travel and including vertical sections, between the downstream end of the upper doctor box and the point at which the upper and lower carrier films come together.

3.3.7 Wet Width (W) is the width in feet of the layer of resin paste deposited under the doctor box as carrier film moves below it.

4.0 Instructions and Examples for the Emission Factor Table

A simple tabular format has been developed to encapsulate the new Emission Factor information on one sheet of paper. This tabular format is called the “EF Table 1.”

This section contains instructions for using EF Table 1 to find the proper emission factor for a specific resin or gel coat material and application process.

4.1 How to find the proper open molding emission factor using EF Table 1

4.1.1 Before using EF Table 1, the following information must be obtained:

4.1.1.1 Styrene content of the resin/gel coat material

The styrene content of the resin/gel coat materials can be obtained from the associated MSDS information, the Q/A certification sheet sent with most bulk resin shipments, or by calling the resin supplier or manufacturer. Occasionally, the MSDS will specify a broad range for the styrene content, such as 20 to 50% styrene by weight. This is a short-cut used by the resin supplier to avoid listing more specific information for each resin formulation. The average value for such a broad range (average 35% for the example above) should not be used. Instead, the resin supplier should be asked to provide more precise estimates of the actual monomer contents for each material.

4.1.1.2 Application process used to apply the material

The correct application process must be identified from the following major types; Manual, Mechanical Atomized, Mechanical Non-Atomized, Filament, or Gel coat Spraying.

4.1.1.3 Vapor-suppressant data - the VSR reduction factor (if used)
Determine if vapor suppressant is added to the resin formulation. If so, the VSR reduction factor for that specific resin/suppressant mixture must be obtained from the resin supplier, or must be determined at the plant according to procedures detailed in the Vapor Suppressant Effectiveness Test (this test protocol can be found in Appendix A to Subpart WWWW – Test Method for Determining Vapor Suppressant Effectiveness, Federal Register Volume 68, No. 76.

4.1.1.4 Special pollution prevention techniques (if used)
Determine if Controlled Spraying and/or Covered-Cure are used with any of the application processes.

4.1.2 With this information refer to EF Table 1.

4.1.2.1
Find the correct application process in the left-most column of EF Table 1.

4.1.2.2
Find the correct styrene content across the top row of EF Table 1.

4.1.2.3
Locate the cell at the intersection of the selected row and column. This cell contains the correct emission factor that corresponds to the application process and styrene content resin or gel coat selected. If the styrene content is below 33 percent, use the equation in the left-most column to compute emission factors. If the styrene content is above 50 percent, use the equation on the far right column to compute emission factors. For both equations the styrene content value should be expressed as a decimal fraction, i.e. where the equation calls for “52%” use “0.52”.

4.1.2.4
(For vapor-suppressed resins) If a vapor suppressed resin is used, first determine the factor as if the resin was non-suppressed. Then the VSR reduction factor for the specific resin/suppressant mixture and the corresponding non-vapor suppressed emission factor are inserted into the equation in EF Table 1.

4.1.2.5
(For non-suppressed resins that use the covered-cure technique) The appropriate covered-cure factor depends on whether the covering is placed after the wet laminate is rolled out or whether the covering is applied directly to the wet laminate without any rolling taking place. The covered cure factor is multiplied by the corresponding non-vapor suppressed resin application process emission factor as shown in EF Table 1. Vapor suppressants are not used in conjunction with covered-cure because the impervious cover takes the place of the film formed by the suppressant.

4.2 Calculation of the methyl styrene factor

4.2.1 This methyl styrene factor will be equal to 55% of the equivalent UEF non-atomized resin application factor. The following is an example calculation that shows how the methyl styrene factor will be determined:

4.2.1.1
UEF styrene emission factor for 5% styrene content = 10.7% of styrene weight

4.2.1.2
Methyl styrene emission factor for 5% methyl styrene content resin=
55% x 10.7% = 5.89% of methyl styrene weight

5. Estimation of VOC Emissions from Production of SMC

SMC machine emissions of volatile organic compounds (VOC) can be estimated from the following equation:

E = 0.1457 At - 0.1454

where:
E = VOC emission rate, lb/hr, when paste is on the line
At = Total wet area of SMC machine = Adl + Adu + W*(Ll+Lu)
Adl = open area of the lower doctor box, ft2
Adu = open area of the upper doctor box, ft2
W = wet width of SMC, ft
Ll = Lower wet length, ft
Lu = Upper wet length, ft

6.0 Estimation of VOC Emissions from Compression Molding of SMC

The emission factor for SMC is expressed as a percentage of the available styrene monomer contained in the uncured SMC material that is processed in the compression mold. The emission factor for SMC part compression molding is:

1.5% of the styrene monomer content (weight) in the SMC material

7.0 Estimation of VOC Emissions from Compression Molding of BMC

The emission factor for BMC is expressed as a percentage of the available styrene monomer contained in the uncured BMC material that is processed in the compression mold. The emission factor for BMC part compression molding is:

1.15% of the styrene monomer content (weight) in the processed BMC material

8.0 Estimation of VOC emissions from Compression Molding of LCM

The emission factor for LCM part compression molding consists of two separate equations. The first equation is for the spread of LCM paste, the second equation is for poured LCM paste.

- LCM spread paste factor (% of paste weight) = .0072 x % styrene + 0.0008
- LCM poured paste factor (% of paste weight) = .0022 x % styrene + 0.0008

NOTE: The "% styrene" input value in these equations must be in decimal form instead of percentage (0.20 instead of 20%). These equations generate the factor as a decimal fraction of the processed paste weight..

9.0 Emissions factors for the cast polymer open molding manufacturing process

Gel coat emissions factors are derived from the UEF Table 1 and apply to the various forms of gel coat application listed.

Emissions from the matrix casting (pouring) process are listed in *AP-42 - Table 4.4-2 Emissions Factors for Uncontrolled Polyester Resin Production Processes* and are described as Marble Casting 30800766 – Polymer Casting (Cultured Marble or Marble Casting).

EF Table 1: Unified Emission Factors for Open Molding of Composites

Revised and Approved: 10/13/2009

Emission Rate in Pounds of Styrene Emitted per Ton of Resin or Gelcoat Processed

Styrene content in resin/gelcoat, % (1)	<33 (2)	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	>50 (2)
Manual	0.126 x %styrene x 2000	83	89	94	100	106	112	117	123	129	134	140	146	152	157	163	169	174	180	((0.286 x %styrene) - 0.0529) x 2000
Manual w/ Vapor Suppressed Resin VSR (3)	Manual emission factor [listed above] x (1 - (0.50 x specific VSR reduction factor for each resin/suppressant formulation))																			
Mechanical Atomized	0.169 x %styrene x 2000	111	126	140	154	168	183	197	211	225	240	254	268	283	297	311	325	340	354	((0.714 x %styrene) - 0.18) x 2000
Mechanical Atomized with VSR (3)	Mechanical Atomized emission factor [listed above] x (1 - (0.45 x specific VSR reduction factor for each resin/suppressant formulation))																			
Mechanical Atomized Controlled Spray (4)	0.130 x %styrene x 2000	86	97	108	119	130	141	152	163	174	185	196	207	218	229	240	251	262	273	0.77 x ((0.714 x %styrene) - 0.18) x 2000
Mechanical Controlled Spray with VSR	Mechanical Atomized Controlled Spray emission factor [listed above] x (1 - (0.45 x specific VSR reduction factor for each resin/suppressant formulation))																			
Mechanical Non-Atomized	0.107 x %styrene x 2000	71	74	77	80	83	86	89	93	96	99	102	105	108	111	115	118	121	124	((0.157 x %styrene) - 0.0165) x 2000
Mechanical Non-Atomized with VSR (3)	Mechanical Non-Atomized emission factor [listed above] x (1 - (0.45 x specific VSR reduction factor for each resin/suppressant formulation))																			
Mechanical Non-Atomized application of resins that contain Methyl Styrene monomer (10)	Mechanical Non-Atomized Styrene monomer emission Factor (listed above) x .55																			
Mechanical Non-Atomized Filled DCPD resins (11)	0.144 x % styrene x 2000	95	98	101	104	108	111	114	117	120	124	127	130	133	136	140	143	146	149	((0.1603 x % styrene)-0.0055) x 2000
Filament application	0.184 x %styrene x 2000	122	127	133	138	144	149	155	160	166	171	177	182	188	193	199	204	210	215	((0.2746 x %styrene) - 0.0298) x 2000
Filament application with VSR (5)	0.120 x %styrene x 2000	79	83	86	90	93	97	100	104	108	111	115	118	122	125	129	133	136	140	0.65 x ((0.2746 x %styrene) - 0.0298) x 2000
Gelcoat Application	0.445 x %styrene x 2000	294	315	336	356	377	398	418	439	460	481	501	522	543	564	584	605	626	646	((1.03646 x %styrene) - 0.195) x 2000
Gelcoat Controlled Spray Application (4)	0.325 x %styrene x 2000	215	230	245	260	275	290	305	321	336	351	366	381	396	411	427	442	457	472	0.73 x ((1.03646 x %styrene) - 0.195) x 2000
Gelcoat Non-Atomized Application (8)	SEE Note 9 below	196	205	214	223	232	241	250	259	268	278	287	296	305	314	323	332	341	350	((0.4506 x %styrene) - 0.0505) x 2000
Lesser Atomized Gelcoat Application (12)	for < 30 : 0.323 x % styrene x 2000	229	241	252	264	276	287	299	311	322	334	346	357	369	381	392	404	416	428	((0.5842 x % styrene)-0.07825) x 2000
Covered-Cure after Roll-Out	Non-VSR process emission factor [listed above] x (0.80 for Manual <or> 0.85 for Mechanical)																			
Covered-Cure without Roll-Out	Non-VSR process emission factor [listed above] x (0.50 for Manual <or> 0.55 for Mechanical)																			

Emission Rate in Pounds of Methyl Methacrylate Emitted per Ton of Gelcoat Processed

MMA content in gelcoat, % (6)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	≥20
Gel coat application (7)	15	30	45	60	75	90	105	120	135	150	165	180	195	210	225	240	255	270	285	0.75 x %MMA x 2000

Notes

1. Including styrene monomer content as supplied, plus any extra styrene monomer added by the molder, but before addition of other additives such as powders, fillers, glass,...etc.
2. Formulas for materials with styrene content < 33% are based on the emission rate at 33% (constant emission factor expressed as percent of available styrene), and for styrene content > 50% on the emission rate based on the extrapolated factor equations; these are not based on test data but are believed to be conservative estimates. The value for "% styrene" in the formulas should be input as a fraction. For example, use the input value 0.30 for a resin with 30% styrene content by wt.
3. The VSR reduction factor is determined by testing each resin/suppressant formulation according to the procedures detailed in the ***CFA Vapor Suppressant Effectiveness Test.***
4. SEE the ***CFA Controlled Spray Handbook*** for a detailed description of the controlled spray procedures.
5. The effect of vapor suppressants on emissions from filament winding operations is based on the ***Dow Filament Winding Emissions Study.***
6. Including MMA monomer content as supplied, plus any extra MMA monomer added by the molder, but before addition of other additives such as powders, fillers, glass,....etc.
7. Based on gelcoat data from ***NMMA Emission Study.***
8. SEE the July 17, 2001 EECS report ***Emission Factors for Non-Atomized Application of Gel Coats used in the Open Molding of Composites*** for a detailed description of the non-atomized gelcoat testing.
9. Use the equation **((0.4506 x %styrene) - 0.0505) x 2000** for gelcoats with styrene contents between 19% and 32% by wt.; use the equation **0.185 x %styrene x 2000** for gelcoats with less than 19% styrene content by wt.
10. Refer to Section 3.0, Instructions and Examples for the Emission Factor table, 3.2 Calculation of the methyl styrene factor
11. Use this factor for the non-atomized application of DCPD or DCPD-blend resin, when filled to 30% or more by weight
12. Table from 30% TO 32% styrene content :

30	31	32
194	206	217