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Title:	Some Comments on the ORD Paper on the FRP Model submited for publication to the AWMA RA Haberlein January 1999

Some Comments on the ORD Paper on the FRP Model Submitted for Publication to the A&WMA

January 29, 1999
by Robert A. Haberlein, Ph.D., QEP

I appreciate the opportunity the review committee has provided me to submit comments concerning the paper entitled "Empirical Model to Predict Styrene Emissions from Fiber-Reinforced Plastics Fabrication Processes" (identified as manuscript #681).

I have taken the time to submit these comments because of my professional involvement in the development of emissions factors for reinforced plastics, and because of the importance of the issues raised in the paper to the industry, the states, and the EPA. This paper will have a profound impact upon these stakeholders. There is considerable debate at the present time among these parties regarding the best method to predict styrene emissions from these operations. I believe that any paper published by the Air & Waste Management Association (A&WMA) should be scientifically rigorous, make a constructive contribution to the ongoing technical discussions, address all of the important impacts, and add to the understanding among the interested parties.

Please let me begin with the following observation. A model that is perfectly adequate for one purpose may be inadequate for another purpose. The FRP model discussed in this paper appears to be a research tool designed to help identify future areas of pollution prevention experimentation. As such, I believe this model is an excellent research tool. Unfortunately, the FRP model is also being suggested as appropriate for use in the field by companies and state agencies to estimate emissions for the purposes of reporting facility emissions, demonstrating compliance with regulations, and establishing enforceable permit conditions. Publication of this paper, in its present form, may unintentionally sanction such a use unless the regulatory concerns are clearly and broadly addressed in the paper.

Finally, I spoke to the paper's lead author, Mr. Carlos Nunez. Mr. Nunez informed me that the draft paper that I first reviewed had been revised to correct several problems that were identified by the review committee. This morning, Mr. Nunez sent me a copy of the newest draft, which I quickly reviewed. The FRP model program and model equations have not been revised in the newest draft. All of the following comments concern the unrevised parts. Incidentally, Mr. Nunez asked me to include comments on the regulatory and enforcement problems with the FRP model, because they are germane to the issue at hand.

INTRODUCTION

The FRP model is presently available to the public as a stand-alone Windows 95 (*.exe) program. According to the EPA text provided with the model:

> "EPA's APPCD, in cooperation with Research Triangle Institute (RTI), has developed a mathematical model to provide better styrene emission estimates for selected open molding fiber-reinforced plastics (FRP) manufacturing processes. The model highlights 10 relevant parameters impacting styrene emissions in FRP processes and helps identify future areas of FRP pollution prevention (P2) research. Seven different emission studies were evaluated and used as model inputs."

The FRP model program has a very professional looking "Windows-style" user interface. The model program screens follow the standard Windows 95 format, and are simple and easy to understand. The input of data by mouse and keyboard is also very easy. Unfortunately, this professional appearance and ease-of-use may foster undue confidence in the model results, because the possible underlying flaws and deficiencies in the model equations are difficult for the typical user to uncover or understand.

The following technical comments are arranged into a section of general comments that apply to the model as a whole, and a section of specific comments that address each particular element of the model. These comments are based on the output of the FRP model program, the ORD's draft paper entitled "Empirical Model to Predict Styrene Emissions from Fiber-Reinforced Plastics Fabrication Processes" submitted to the A&WMA in 1998, a phone conversation with Carlos Nunez, a presentation by Mark Bahner at the CFA Composites 98 convention, correspondence with Bob Lacovara (principle author of the CFA studies), correspondence with John Schweitzer (principle author of the PIC pultrusion study), communication with John Stelling, (principal author of NMMA study), and correspondence with Larry Craigie (principal author of the Dow filament winding study).

GENERAL COMMENTS

The FRP model is not practical for application in the field

The FRP model requires input values for nine or ten different parameters (depending upon the lamination process being modeled). The paper does not describe any of the methodologies used to measure these parameters. Many of these input parameters are extraordinarily difficult to measure under laboratory conditions. Most of these input parameters cannot be practically measured in the field. The difficulties in measuring each parameter are discussed under the "Specific Comments" section below.

The FRP model has little practical utility for field application without a clear description of the proper measurement methodologies, because the input parameters for the model are so difficult to measure. How can other researchers duplicate these measurements? Without proper measurements, how could the FRP model be applied to real world processes in a consistent

manner? The paper should discuss this difficulty.

There is another complication. The model parameter input measurements should be expressed as mass-weighted average values to accurately reflect their effect upon the styrene emissions, which is a mass-based rate. To determine the mass-weighted average, each parameter measurement must be weighted with the corresponding amount of mass (resin or monomer) applied at that measured value. The need to mass-weight the parameter values greatly complicates the measurement requirements.

The FRP model baseline values become unsubstantiated "default" industry characterizations

Each input parameter in the FRP model has a baseline value and an acceptable value range. The baseline values established for the FRP model are listed in the first numerical column on the left side of the FRP model screen, and are initially inserted as the input values in the second numerical column. According to the text included with the model:

> *"Baseline emission values were calculated for each process to simplify this modeling approach. The baseline emission values were calculated under fixed, typical operating conditions. If all the conditions at a particular plant were equal to baseline conditions, each of the modification factors would be given a value of 1.0, and the predicted emissions would equal the baseline value. An overall emission factor is then determined by the product of each independent modification factor. At present, the model assumes that the effect of each modification factor is independent from those of the others."*

The model user can type different values into the input column, and new emissions factor can then be calculated. If a new value is outside the "acceptable" range for the parameter, the following error message is displayed:

> *The input value for "[parameter]" is [out-of-range value], which is out of the normal range. The result may not be reliable. Go ahead anyway?*

If the error message is ignored, the calculation is still allowed,.

The paper states that the selection of the default baseline values was "somewhat arbitrary" and based upon the authors' beliefs. Still, the paper implies that the baseline values represent reasonable default input values for a "typical" reinforced plastics facility.

Unfortunately, no study was performed to develop these default values, and no statistical analysis was conducted to verify their accuracy. The midpoint values were apparently selected from the limited available test data for the different parameters. This is particularly troubling, because the test data does not seem to correlate with "typical" industry practices. For example, according to Bob Lacovara, technical director at CFA [Jan 29 '99 email]:

> *"The choice of a 70 mils (.070 in) thickness is totally arbitrary and does not represent a standard thickness used anywhere in the FRP industry."*

Consider the possible regulatory implications of these arbitrary selections. In a recent letter to Tennessee, EPA Region 4 specified the FRP model for emissions estimates [Sep 16 '98 letter from Neeley to Carter]. In this letter, EPA Region 4 stated:

> *"The ORD* [FRP] *model provides a user friendly format which allows facilities to specify their particular process parameters and provide a comparison to "baseline" data in the model. Please note that the instructions included with the ORD model apply to each individual spray application. The ORD model therefore requires the user to quantify multiple layer, coats, or thicknesses which are applied to a specific product. Whenever possible, the model's default setting [baseline value] should be replaced with actual site specific data to ensure accurate emissions estimates."*

Note how Region 4 was influenced by the professional appearance of the model program. Based upon this directive, a typical reinforced plastics facility must now perform hundreds of model calculations to estimate the emission rates from all of the possible layer, coat, and spray combinations for their parts. Presumably, any deviation from the baseline must be demonstrated by the facility, to the satisfaction of the proper permit officials and EPA inspectors. Realistically, most facilities will probably be forced to use the default values, due to the extraordinary difficulty in obtaining accurate site-specific values. Hence, the model baseline values become the "default" for the entire industry.

The reinforced plastic industry is noted for its wide diversity. These default values are not representative of any one reinforced plastic facility, let alone a majority of them. This recommendation of a set of "baseline" descriptors becomes the unsubstantiated default characterization of the reinforced plastics industry. The paper should clearly explain the origin and limitations of these baseline values.

The FRP model is not enforceable

The paper mentions the term "AP-42" twelve times, and also discusses the MACT standard for reinforced plastics. AP-42 is perhaps the most important and widely-used regulatory tool used by the EPA to estimate emissions. The paper does not inform the reader that the AP-42 factors for reinforced plastics were withdrawn by the EPA in early 1998, and that FRP model is currently under evaluation by the EPA as a possible AP-42 replacement. To the contrary, the paper incorrectly states that the withdrawn AP-42 factors are still used to estimate styrene emissions. Although the paper stresses that the FRP model is more accurate than AP-42 and suggests that the FRP model is superior to the old AP-42 factors, the paper never discusses the suitability of the FRP model as a regulatory tool or as a replacement for AP-42.
This should be a great concern to the review committee. I believe the current draft paper could lead to the *de facto* adoption of the FRP model as a replacement for the AP-42 factors for reinforced plastics, without any further debate regarding the suitability of the FRP model as a regulatory tool. This belief is shared by many industry representatives and even some members of the regulatory community. Hence, the paper should include a clear disclaimer or a well-balanced discussion of the enforcement aspects of this model.

I believe that the FRP model is not a feasible enforcement tool, because the input parameters for the model are too difficult or impractical to measure, record, and report, as discussed earlier and detailed below. Simply stated, the FRP model is not enforceable, because the critical input data to the model cannot be verified. An inspector or enforcement official would probably require a FRP facility to prove the accuracy of any site-specific input values used in the FRP model. These officials could even require proof of the applicability of the baseline (default) values assumed in the FRP model. This would be an extremely difficult task for any facility to undertake. A typical reinforced plastics facility could not comply with such a requirement.

The FRP model parameter ranges do not include all industry practices

The FRP industry consists of a diverse cohort of manufacturers who make many different products. These finished products are a result of a combination of the engineering properties of the input raw materials and the processing methods employed during the fabrication. These material and process parameters can vary significantly among the various products. The ranges established in the current FRP model do not include all of these diverse products and processes.

For example, the underground storage tank (UST) lamination process used by the leading UST manufacturer has three important parameter values that are substantially outside the acceptable input ranges in the FRP model:

Laminate thickness - much more than 150 mils, although highly variable
Overspray ratio - nearly zero
Spray gun-to-mold distance - much less than 12"

This manufacturer would be hard pressed to justify the use of "unacceptable" model inputs, even though they happen to be correct in their case. How would an EPA permit official or EPA inspector handle this situation? Moreover, how accurate will the model be if these factors are used? I could easily provide at least a dozen more real world examples of this problem.

The FRP model employs a series of "independent" multiplicative factors

The FRP model is based upon the following empirical equation form:
where:

EF = Emission factor, as a percentage of the styrene in the gel coat or resin.
EF_b = Baseline emission factor; i.e., the emission factor from a process under fixed, typical operating conditions.
$(MF)_{1,2,\ldots k}$ = Applicable modification factors, which are based on changes in parameters known to affect styrene emissions (gel time, styrene content, thickness, etc.).

Although this general equation is quite simple, the algorithms developed for the modification factors are much more complex and sophisticated. The values for each modification factor are computed in the FRP model using equations derived from the seven different emissions studies. However, most of these factors are derived from only one study - often using only a few data points.

The paper assumes that the individual modification factors are mutually independent, and ignores the possible interactions between the input parameters. The paper does not offer any discussions, justifications, or scientific arguments to support this critical assumption.

For example, the effects of thickness and gel time are tightly coupled. A thicker laminate will develop greater exothermic heating, which causes a shorter gel time. The effect of vapor suppressant is also coupled to many of the other parameters. A vapor suppressant forms a barrier film on the "still" surface of a layer of wet resin, and completely dominates the "static" emissions from the undisturbed surface. Hence, the effect of other parameters, such as overspray ratio, thickness, gel time, application rate, air flow, and air temperature, on the static emission rate would be masked by the effect of a vapor suppressant. The spray gun distance and overspray ratio parameters affect the "dynamic" emissions from the suspended wet aerosol droplets moving from the gun to the mold surface. Extremely large overspray ratios and long gun distances would not have independent effects, nor would very small ratios and short gun distances. In fact, I believe that most of the modification factors are dependent, and the interaction effects between the factors are probably very significant in many cases.

Bob Lacovara, technical director at CFA, also shares this belief regarding this model assumption. According to Mr. Lacovara [Jan 29 '99 email]:

> *"In actuality there is a high level of interdependence on each modification factor. In some cases three or four variable factors create a confounding of modifications to a single factor. This assumption facilitates an expedient mathematical resolution of multiple factors, but produces an overly simplistic and inaccurate resolution of the complex interactions."*

These observations question the basic mathematical foundation of the FRP model. The paper should discuss this problem in greater detail.

The FRP model can return impossible results using "acceptable" inputs

A mathematical expression that contains a long series of multiplicative modification factors can result in unlikely or even impossible results, due to the significant cumulative impact of seemingly insignificant variations in the individual factors. For example, the product of nine relatively insignificant 0.95 modification factors will result in a highly significant cumulative 0.63 (0.95^9) factor. Likewise, the product of nine relatively insignificant 1.05 factors will result in a highly significant cumulative 1.55 (1.05^9) factor. The inaccuracy of this approach is particularly apparent, if the factors are incorrectly presumed to be independent. Hence, a model based on such an expression could predict an unrealistic emission rate that would still be judged "acceptable" by the model.

Now consider the FRP model results for spray lay-up. Assuming 50% monomer, non-suppressed resin, 40" gun distance, 10% overspray, 50 mil thick, 1 lb/hr, 50 minute gel time, 95°F, and 200 fpm, ***which are all acceptable model inputs***, the FRP model yields a spray lay-up

modification factor of 5.46 that is then applied to the baseline emission rate of 18.9%. Using these "acceptable" inputs, the FRP model results in a **103.1%** emission rate, which is physically impossible.

On the other hand, assuming 30% monomer, vapor-suppressed resin, 12" gun distance, 1% overspray, 150 mil thick, 4 lb/hr, 5 minute gel time, 60°F, and 20 fpm, which are all equally acceptable model inputs, the FRP model yields a spray lay-up modification factor of 0.23 that is then applied to the baseline emission rate of 18.9%. Using these "acceptable" inputs, the model now returns an unrealistically low **4.3%** emission rate, which is equally unlikely.

Hence, the FRP model can return acceptable factors for spray lay-up that range from 4.3 to 103.1%. This extreme range suggests that the FRP model may be seriously flawed.

The FRP model was derived from limited and incompatible data sets

According to the paper, seven different emission studies were evaluated and used as model inputs. Six of the seven studies are listed in Table 3 - the seventh study is presumably the NMMA study. However, this statement regarding the studies can be misleading. Ten of the seventeen factors listed in Table 3 (including all of the baseline factors) were derived from only one study, six factors were derived from only two studies, and only one factor was derived from three studies. At no time, were more than three studies used to derive a model factor. The paper should carefully discuss the limited amount of data used to derive these factors.

Then, there is the question of data compatibility. The three CFA/Dow studies and the NMMA study used the same test protocol, which is publically available, so those data sets are probably consistent and compatible. Unfortunately, serious problems were reportedly experienced during the EPA/RTI filled resin study, which question the validity of the data from that testing. The paper does not discuss the protocols used in the EPA/RTI studies, which are still not publically available. Were these protocols consistent with the CFA/Dow protocol? If not, why were these data sets combined?

Perhaps the most serious concern regarding the data is the use of the Pultrusion study and Dow Filament Winding study data to modify the other open molding processes. According to the paper, the pultrusion study was used to establish the modification factor for air velocities below 40 fpm for all of the processes. Pultrusion is a fundamentally closed molding process. The argument that emissions from the open resin dip baths employed in pultrusion is somehow related to the emissions from spray lay-up or gelcoating is not supportable. Bob Lacovara also noticed this incompatibility. According to Mr. Lacovara [Jan 29 '99 email]:

> *"The pultrusion process is a closed molding process that bares little resemblance to open molding spray-up of hand lay-up. Because of significant physical and resin chemistry differences between the wet-out of continuous roving in pultrusion and reinforcement in open molding, emissions from a pultrusion bath cannot be construed to be related to those of hand lay-up or spray-up. For example, the resin is cured with a heat-activated initiator. The heat source is within the closed die. The resin in the wet-out bath is constantly in the "uncured" state at room temperature. In contrast, the hand lay-up and spray-up methods use room*

temperature curing resins. Therefore the polymerization is taking place progressively immediately upon the introduction of the resin on the mold. Additionally, it has been shown that static evaporation of resin in paint can lids bears no correlation to the actual measured emissions from the laminating process."

The Dow filament winding data was apparently used to establish the air temperature modification factor for all of the lamination processes. Filament winding is a process that applies resin to a continuous glass filament passing through a resin dip bath. This winding process does not relate to the atomization that occurs in spray lay-up and gelcoating. This difference should be explained in the paper.

SPECIFIC COMMENTS

Neat resin styrene content

The equations derived for the styrene content modification factor appear to be contradictory and inconsistent. The paper states that:

"This type of curve [quadratic] is probably more accurate than a linear regression in describing emissions at very low styrene contents, which is obviously a physical impossibility."

In accordance with this concept, the equation for the resin spray-up modification factor is the quadratic form, $\mathbf{0.003\ x + 0.000614\ x^2}$. However, the equation for the modification factor for resin hand lay-up, flow coater and pressure-fed roller is the linear form, $\mathbf{0.24 + 0.02\ x}$. The paper first argues against this type of equation, then uses it anyway. Moreover, this equation would yield a modification factor of 0.24 for monomer levels near zero, which is also physically impossible. Further, the equation for the gelcoating modification factor is the quadratic form, $\mathbf{0.55 + 0.003\ x + 0.000614\ x^2}$. As with hand lay-up, this equation would yield a modification factor of 0.55 for monomer levels near zero, which is just as physically impossible as a negative emission rate. The paper should be revised to either correct or discuss these inconsistences.

Vapor suppressant & filler level

The FRP model relied upon the EPA/RTI filled resin study for the derivation of the effect of vapor suppressants and filler level. However, the suitability of this study has been questioned. According to Bob Lacovara [Jan 29 '99 email]:

"The experimental design for this study called for the modification of styrene content to achieve a uniform resin viscosity. In resolving the data from this study, viscosity was a constant, and styrene content was a variable. It is difficult to resolve comparative emissions with a variable styrene content in this study. The experimental design was inappropriate and complicated the resolution of emissions based on available styrene."

Spray gun-to-mold distance

The paper relied upon the CFA studies and the NMMA study to determine the effect of spray gun distance. However, the authors of both studies have objected to this use of their data.

The paper computed an average spray gun distance of 23 inches for the 1996 CFA data. According to Bob Lacovara, this information was not reported in the CFA test data, but was instead based on a series of assumptions made in the paper. The paper concedes that the 1996 CFA test data was confounded by variations in spray gun pressure, which affected the atomization of the resin and probably dominated the emission rate, yet the paper appears to have used the data anyway. The 1997 CFA data measured peak exhaust concentrations, not emission rates. Although the paper admits that peak concentrations do not necessarily correlation with emissions, the paper appears to have used the data anyway.

John Stelling, the NMMA consultant who performed the NMMA study and developed the NMMA data set, has strongly objected to both the analysis and use of the NMMA gun distance data in the FRP paper. I have asked Mr. Stelling to provide the review committee with his written comments and criticisms. Mr. Stelling is also a member of the A&WMA, and is a QEP.

Finally, the effect of spray gun distance on gel coat spray emissions appears to be a curve fit through two points.

The spray gun distance would be extremely difficult to measure. The spray gun is hand-operated, and is in continuous motion. The path of the gun tip would be practically impossible to predict from mold to mold, let alone to measure. However, the inherent difficulty with this measurement did not deter a state EPA official, who was considering requiring the FRP model, from recently making the following recommendation to a reinforced plastics company during initial permit negotiations:

A laser or ultrasonic distance sensor would be attached to the tip of the spray gun.
A digital flow meter would be attached to the spray gun resin line.
This sensor and flow meter would be connected to a real-time PC data logger.
The datalogger would record and compute the mass-weighted spray gun distance.
The output from the datalogger would be used to demonstrate compliance.

Everything that the state official proposed seemed to be reasonable at first, but the practical implications had not been considered. No such instrument package is commercially available at present. Hence, this recommendation would require the company to engage in basic scientific research and development. Such effort would be very expensive, and would require outside expertise. Moreover, the dirty environment inside the spray booth would probably quickly foul the ultrasonic or laser distance sensor, jeopardizing this effort at the very onset.

For the sake of argument, let us assume that just such a device could be built to record the spray gun distance, although I believe that this type of instrument is many years in the future at best. What do we do with the record? The gun distance will vary for each mold shape, for each spray operator, and probably during the week for the same operator. How do we establish the proper

value for enforcement purposes? If this value is then exceeded, will the company be in violation of its permit? Will the company be subject to enforcement action?

This real example illustrates both the impracticality and enforceability problems with most of the FRP model parameters.

Dry material off mold / material sprayed (overspray ratio)

The effect of overspray on emissions is very complex, and I believe that the FRP model has oversimplified this effect. In general, overspray can hang in the air a little longer, consist of smaller diameter aerosols, produce a thinner overspray layer, and take longer to cure. These properties of overspray would tend to increase the relative emission rate. However, none of these tendencies are absolute. Some overspray streams are no different than the resin stream transferred to the mold. To the contrary, some overspray deposits could buildup into much thicker layers than the laminate, with shorter gel times, which would reduce the relative emission rate.

The equation for the overspray modification factor for resin spray-up is the quadratic form, **0.90 + 0.0007 x + 0.0025 x^2**. Note that this equation would yield a modest modification factor of **0.90** for overspray ratios levels near zero. However, at baseline conditions, this equation would yield an emission rate of over 100% for overspray ratios greater than 41%. For corrosion-resistant isophthalic resins, which have a typical monomer content of about 46%, the emission rate is over 100% for overspray ratios greater than 33%. Such high overspray ratios are uncommon, but they are possible and they do occur for small parts or poorly-supervised operators. Further, the equation for the gelcoating modification factor is the linear form, **0.862 + 0.023 x**. Why is one equation quadratic and the other linear? Isn't the physical phenomenon the same? Note that this equation would yield a modification factor of **0.86** for overspray ratios levels near zero. As before, this equation would also yield an emission rate over 100% for overspray ratios greater than 41%, which is again physically impossible.

The mass balance method (also known as the material balance mathod) is the only feasible approach for measuring the overspray ratio. The mass balance method is simple in concept, but very difficult to perform in a fiberglass shop. Normally, the overspray is collected on thin plastic film sheets, which are then weighed. The total raw weight is compared to the weight of overspray material to determine the overspray ratio. These measurements are messy, tedious, and error-prone. Consider the following narrative description of actual mass balance field measurements attempted by Bob Lacovara [Jan 29 '99 email]:

> *"This* [mass balance] *method of measuring transfer efficiency has limited application in a laboratory setting, however it is an improbable method of accurately measuring "off spray" in an actual fabrication plant. Because of the profound regulatory implications of this prediction model, it is important that critical parameters can be accurately measured under field conditions.*
>
> *First, it was found during initial design experiments of the CPA Emissions Study that the weight of the floor covering paper could significantly change based on what was suspected to*

be a combination of humidity absorption and picking up debris from the floor under the paper. When attempting to measure small quantities of "off-spray", it was found that the weight of the overspray was sometimes less than the variation in floor covering weight between "clean" material and paper which has simply laid on the floor for a period of time, than picked-up and weighted.

Second, in any real world application it is probable that extraneous materials, other than overspray, will be introduced to the floor covering. Debris from operator's feet are commonly observed across the surface of floor coverings. When dealing with the spray-up process, a fatal flaw in this method develops; the off-mold spray contains both resin and chopped glass fiber. It is neither possible to separate these materials or to accurately predict the off-spray ratio of resin the glass fiber.

Third, in many plants small molds are arranged in a congested fashion in the molding area. The off-mold-material may overlap between two or more molds, making the measurement of this material impossible to resolve for an individual mold, and impractical to measure for an entire area."

Even if there were a feasible method to measure the overspray ratio, the measured value would vary for different mold shapes, for different spray gun operators using the same mold, and for the same operator and mold at different times during the work shift. The degree of variation can be extreme.

Thickness

All of the equations for the thickness modification factors are step-wise. The paper presents one equation for thicknesses below 40 mils, and another equation for thicknesses above 40 mils. What is the scientific basis for this? It appears that the available data sets were used to develop these relationships, without considering the underlying physical phenomena. Although expedient, this approach may not be accurate.

Thickness is not difficult to measure, although the process can be a little messy for wet layers. The measurement of one part would take a significant amount of time. It would be very difficult to thoroughly measure the average thickness of most fiberglass parts under production conditions, and still maintain a reasonable production rate.

As with most of the model parameters, the thickness will vary significantly. The thickness will vary for different part shapes, for different spray gun operators using the same mold, and for the same operator and mold at different times during the work shift. The degree of variation can be substantial. How will the plant engineer or EPA field inspector actually measure the thickness of a fiberglass part? How many thickness measurements should are required? How often should these measurements be made? What type of record should be kept?

Air temperature

According the draft paper, the Dow Filament Winding study was the only source of data for this derivation. Based on this data, the paper recommends a modification factor for air temperature

which varies about 1% for every 1°F above and below 75°F. However, according to Mr. Larry Craigie, the author of the Dow study [Jan 27 '99 email Craigie to Haberlein]:

> *"The data from the completed filament winding study showed that the temperature had an impact of 0.25% emission per degree F. The number was extremely small in relationship to the effect of styrene content and suppressant. The report cited was an interim report and only 2/3 of the study had been completed when the report was issued. The completed study has been presented several times and the complete data set is available."*

Furthermore, according to Bob Lacovara , there is no data from open molding studies that could back up this factor. The statements offered by both men contradict the derivation of the FRP model temperature factor.

The paper did not discuss the role of vapor pressure nor the suitability of air temperature as a predictor. Temperature affect styrene emissions from lamination processes, because of the relationship between the vapor pressure and temperature of the styrene monomer. Vapor pressure is the "force" that drives evaporation, so vapor pressure normally increases at higher temperature. The relationship between temperature and vapor pressure is generally exponential, not linear.

There is another complication. Ambient air temperature does not directly measure or predict the temperature of the resin monomer or laminate. Occasionally, the resin temperature is significantly lower than the ambient air temperature, especially for pumped-resin delivery systems during the summer months. Also, the exothermic reaction within the catalyzed resin causes the laminate temperature to be much higher than the ambient air temperature surrounding the mold during curing. Hence, ambient air temperature is a poor predictor of the resin or laminate temperature.

Air temperature is not difficult to measure - there are many low-cost instruments that can be used. The problem starts when the plant engineer or EPA field inspector actually undertakes to measure the air temperature over an open mold. Where should these temperature measurements be taken? How many measurements should are required? How often should these measurements be made? What type of record should be kept? These are difficult details with no simple solutions.

However, the average resin temperature, which is the temperature that should really be recorded, would be very hard to measure during the lamination process of an entire fiberglass part in the mold (including the overspray fraction).

Air velocity over mold

The results of the CFA phase I study contradict the FRP model findings. The CFA study investigated the effect of air flow on emissions from open molding processes, and concluded that air velocity over the mold had no significant impact on emissions. According to the CFA study findings, air velocity between 50 and 100 fpm has little effect on emissions The paper does not

mention the lack of relevant open molding data, which might support the prediction.

Air velocity is not difficult to measure. Many low-cost instruments are available that can quickly and accurately measure air velocity. As discussed above, the problem begins when the plant engineer or EPA field inspector actually attempts to measure the air velocity over an open mold. Where should these velocity measurements be taken? How many measurements should are required? How often should these measurements be made? What type of record should be kept? How should the complex flow patterns around a complicated mold shape be measured? How should the average air velocity be calculated for molds that have large "dead area," with practically no air motion.

In fact, the paper provides no discussion regarding the measurement of any of the model parameters.

FINAL CONCLUSIONS

I believe the above comments support the following conclusions regarding the present draft of the paper on the FRP model:

Many important issues are not discussed in the paper.

Many of the model assumptions are incorrect, unclear, or unsupported.

Some of the factor derivations are contradictory, inconsistent, or physically impossible.

The paper suggests that the model is superior to AP-42, but does not address the regulatory impact or suitability of the model.

No comparison or verification of the test protocols used in the referenced studies is included.

The publication of the FRP model paper, in its present form, could seriously undermine the AP-42 selection process and eventually compromise the permitting process and emissions inventories for the reinforced plastics industry.

I respectfully request that the manuscript review committee consider these comments, and ask the authors to revise their paper accordingly before publication.

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A&WMA Technical Review Committee
c/o Ms. Christina DiMeo
Peer Review Coordinator
Department of Environmental Health, School of Public Health
Harvard University
Boston, MA

Dear Ms. DiMeo,

As promised earlier this week, I have enclosed my comments concerning the paper entitled "Empirical Model to Predict Styrene Emissions from Fiber-Reinforced Plastics Fabrication Processes" (identified as manuscript #681) that was submitted by Carlos Nunez *et al.*

I have forwarded these comments to the Carlos Nunez, the lead author of the paper, under separate cover letter.

Please share these comments with the review committee at your earliest opportunity. Also, please inform the review committee that I am available for further comments or assistance at their request.

Please advise me if the committee decides not to consider these comments.

Finally, please convey my apologies to the committee for the lateness of these comments.

Sincerely,

Robert A. Haberlein, Ph.D., QEP
A&WMA member # 296047

cc: Carlos Nunez, ORD
John Schweitzer, CFA

John McKnight, NMMA

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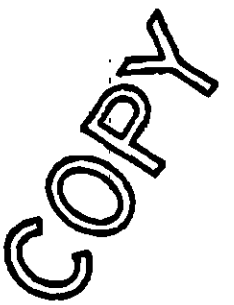

January 29, 1999

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Mr. Carlos M. Nunez
U.S. EPA
NRML/APPCD/ECPD
MD-61
Research Triangle Park, NC 27711

Dear Carlos,

Thank you so much for sending me the latest draft of your paper. I was able to quickly review it before I finished my comments.

As I promised, I have attached my comments for your review. I already forwarded these comments to the A&WMA review committee for their consideration. I have attached my cover letter to the committee for your file.

Please review these comments at your convenience, and then contact me to discuss them. I am very interested in your reactions and thoughts. I look forward to our meeting in two weeks.

Sincerely,

Robert A. Haberlein, Ph.D., QEP