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# **CALCULATING EXCESS EMISSIONS FROM SURFACE COATING OPERATIONS**

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**INTRODUCTION:**<sup>1</sup>

Excess emissions occur when the emissions from an operation exceed the emissions that would normally occur if the operation were in compliance with all applicable regulatory requirements. By design, excess emissions were supposed to have been controlled through the implementation of a State Implementation Plan (SIP) strategy, such as a daily mass emission limit or a regulation limiting the mass of VOC per liter of coating. When excess emissions occur, additional mitigation is required if the emission reductions projected and committed to under the SIP are to be achieved. In addition, excess emissions are often a significant factor in the preparation of penalty settlement agreements for rule violations.

Because surface coating operations contribute significantly to the emission inventory, and because excess emissions play such an important role in air quality attainment planning, excess emissions should always be calculated when surface coating rule violations occur. This paper provides a background on general coating properties and presents methods that can be readily used to calculate the excess emissions from violations. General formulas and descriptions of the necessary calculations to evaluate the emissions from coating operations are provided.<sup>2</sup> Discussions follow regarding coating composition, general coating calculations, and excess emissions calculations.

**COATING COMPOSITION:**

Some coatings may be single component coatings, applied directly from their containers, while other coatings are mixed from multiple components. Multi-component coatings typically include the coating base, catalyst(s), and reducer(s). Each of the coating components are composed of solids and liquid solvents, where solvents can be a mixture of one or more volatile organic compounds, water, or "exempt compounds." Thus, the total mass and volume of an applied coating consist of four basic compounds: coating solids, volatile organic compounds (VOCs), water, and exempt solvents.

Because the mass and volume of coating components and their compounds are necessary for emissions calculations, it is important to clarify the mix ratio on a volume-to-volume basis before beginning any calculations. For example, when a coating operator states that they have "reduced the coating by 10 percent," the operator often means that an additional 10% has been added to the original volume (i.e. 1.0 liter becomes 1.1 liters); however, the operator may mean that the original volume plus the reducer now equals 100% (i.e. 0.9 liters becomes 1.0 liter).

<sup>1</sup> The author gratefully acknowledges the assistance and valuable contributions of Steven Giorgi of the California Air Resources Board and Kelly Fortin of EPA Region IX.

<sup>2</sup> All formulas in this paper employ SI units, although English units can be used throughout. One pound per gallon equals approximately 119.8 grams per liter.

**SURFACE COATING REGULATIONS:**

Surface coating regulations limit the amount of solvent contained in a surface coating and are designed to minimize the emissions of volatile organic compounds (VOCs) when a given surface area is coated. Because the solids content of the coating determines the surface area that may be covered by the coating, the logic behind the control requirement is to reduce the VOC per volume of solids applied.

In the original development of the Control Techniques Guideline, EPA staff proposed to establish solids content regulatory limits. A volume percent solids limit, however, would have been difficult to quantify in a lab test and enforce at the time the CTG was developed. EPA therefore converted their solids content limits to volumetric limits, i.e. grams of VOC per liter of coating "less water and exempt solvent," by assuming an average VOC density of 882 g/l.

The volume based emission limits in current regulations must be converted to solids based limits for use in all excess emission comparisons. The solids based limit, expressed as "grams of VOC per liter of solids" is back-calculated from the volume based limit, using the same average solvent density of 882 g/l that was originally used by EPA.

Certain solvent components have been designated by EPA to be exempt from regulatory requirements and are not regulated as smog precursors by local agencies. Scientific evidence indicates that these exempt solvents are negligibly photochemically reactive and do not participate appreciably in atmospheric reactions that form ozone.<sup>3</sup> Coatings may contain the exempt solvents methylene chloride (1330 g/l) or 1,1,1-trichloroethane (1320 g/l). The mass and volume of the water and exempt solvents are not counted when calculating VOC content and volume applied. This prevents sources from simply diluting coatings with water or exempt solvents to meet a VOC limit that is established per liter of coating.

If one liter of coating contains 500 grams of VOC, the VOC content is 500 g/l. If one liter of this coating is reduced with one liter of water (0 grams of VOC per liter), the volume of water is excluded from the total amount of coating, and the VOC content is  $(500 \text{ g} + 0 \text{ g}) / (2 - 1) = 500 \text{ g/l}$ . Dilution with water or exempt solvent does not change the VOC content.

<sup>3</sup> Although perchloroethylene (perc) was deemed by EPA as negligibly photochemically reactive in the Federal Register, perc has not been established as an exempt compound. Perc is currently under review by the EPA as a potentially toxic air contaminant and has been implicated in stratospheric ozone depletion and global warming. According to the EPA, perc must continue to be regulated as a volatile organic compound until further notice in the Federal Register (Hathaway, 1989).

<sup>4</sup> Methylene Chloride was designated by the California Air Resources Board as a toxic air contaminant in 1989 (CARRB, 1989) and may become the subject of future regulations.

**GENERAL COATING CALCULATIONS:**

The following sections describe how to perform the basic calculations to determine the VOC content, solids content, and component density of coatings. Coating regulations impose limits on an "as applied" basis; thus, the mixing of multiple components must be accounted for. All calculations refer to the properties of the coating after multiple components have been mixed.

The regulations that govern coating operations stipulate that coatings must meet a prescribed VOC content "less water and exempt solvents" and care must be taken to ensure that calculations are performed correctly. This paper presents calculations that may be used to determine certain properties of coatings "including water and exempt solvent" and "less water and exempt solvent."

**Coating\_Mass:**

The mass of coating, including water and exempt solvents, is the sum of all component masses:

$$M = M_{voc} + M_w + M_{es} + M_s$$

Where:

M = mass of coating  
 $M_{voc}$  = mass of VOC  
 $M_w$  = mass of water  
 $M_{es}$  = mass of exempt solvents<sup>3</sup>  
 $M_s$  = mass of solids

**Volume of Coating Applied:**

The volume of coating, including water and exempt solvents, is the sum of all component volumes:

$$V = V_{voc} + V_w + V_{es} + V_s$$

Where:

V = volume of coating  
 $V_{voc}$  = volume of VOC  
 $V_w$  = volume of water  
 $V_{es}$  = volume of exempt solvents<sup>3</sup>  
 $V_s$  = volume of solids

The emission calculations that will follow later in this paper employ laboratory results and coating properties and must be undertaken with

5 Many exempt solvents, such as 1-1-1-trichloroethane, contain VOCs as stabilizing agents. The mass and volume of these VOC based stabilizing agents should be included in the total mass and volume of VOC applied and excluded from the total mass and volume of exempt solvent applied.

consistent units. Thus, the volume applied must be adjusted to have the same "less water and exempt solvent" units.

To determine the volume of coating applied, less water and exempt solvents (R):

$$R = V - V_w - V_{es}$$

$$V = (V_1 + V_2 + \dots + V_n)$$

$$V_w = (V_{w,1} + V_{w,2} + \dots + V_{w,n})$$

$$V_{es} = (V_{es,1} + V_{es,2} + \dots + V_{es,n})$$

Where: R = volume of coating applied (l)\*

V = total volume of coating applied (l)

$V_1 \dots V_n$  = volume of components 1...n (l)

$V_w$  = volume of water in the mix (l)

$V_{w,1} \dots V_{w,n}$  = volume of water in components 1...n (l)

$V_{es}$  = volume of exempt solvent in the mix (l)

$V_{es,1} \dots V_{es,n}$  = volume of exempt solvent in components 1...n (l)

\* (less water and exempt solvents)

Many exempt solvents, such as 1-1-1-trichloroethane, contain VOCs as stabilizing agents. The total volume of stabilizing agent in the mix should be added to the calculated R.

Alternatively, the volume of coating less water and exempt solvents can be found from laboratory results. When a sample is sent to the laboratory, the weight percent of water and each exempt compound contained in the sample should be requested. This is not a burden on the laboratory, because the test methods for determining VOC content require that the weight percentages be determined. The following formula can then be used:

$$R = V [1 - (wt\%_{es}/\rho_{es})(\rho) - (wt\%_{w}/\rho_w)(\rho)]$$

Where: R = volume of coating applied (l)\*

V = total volume of coating applied (l)

$wt\%_{es}$  = weight percent exempt solvent

$\rho_{es}$  = exempt solvent density (g/l)

$\rho$  = coating density (g/l)

$wt\%_{w}$  = weight percent water

$\rho_w$  = density of water = 1000 (g/l)

\* (less water and exempt solvents)

**Coating Density:**

The density of a coating is the mass per unit volume of the coating. Coating density is usually expressed in grams per liter, however, coating

density is often reported as specific gravity on coating specification sheets.<sup>6</sup>

The density of each component of the coating will determine the total density once the components are mixed. Generally, the densities of solvents range from 600 g/l to 1400 g/l, but the densities of coating solids are much higher. Coating compositions typically range from 10% to 70% solids. Thus, the net coating density is dependent upon both the mass and volume of the solvents and solids present. Coating density is easily tested in the laboratory and is often provided by the manufacturer on a coating specification sheet.

**Solvent Density:**

The solvent density is determined by the mass and volume contributions of each solvent component. Coating solvents are usually a blend of many individual solvents. The solvent density of a coating, including water and exempt solvent, is simply the mass of solvent divided by the volume of solvent. The solvent density can be found in the coating specification sheet, by solvent distillation and direct measurement, or calculated from laboratory results:

$$\rho_s = M_s/V_s$$

Where:  $\rho_s$  = density of solvent (g/l)  
 $M_s$  = total mass of solvent (g)  
 $V_s$  = volume of solvent (l)

The density of a mixture containing water and exempt solvents is different than the density of the mixture with the water and exempt solvents removed. The VOC density can be thought of as the solvent density, less water and exempt solvents, and is calculated by removing the contribution of the water and exempt solvent from the total mass and volume of solvent:

$$\rho_{voc} = (M_{voc})/(V_{voc})$$

$$\rho_{voc} = (M_s - M_{es} - M_w)/(V_s - V_{es} - V_w)$$

Where:  $\rho_{voc}$  = density of VOC (g/l)  
 $M_{voc}$  = mass of volatile organic compounds (g)  
 $V_{voc}$  = volume of VOC (l)  
 $M_s$  = total mass of solvent (g)  
 $M_{es}$  = mass of exempt solvent (g)  
 $M_w$  = mass of water (g)  
 $V_s$  = volume of solvent (l)

6 Specific gravity of a coating component is essentially the mass of a given volume compared with the mass of an equal volume of water. If the density of water is 1000 g/l and a compound has a specific gravity of 0.835, the density of that compound is 835 g/l.

$V_{es}$  = volume of exempt solvent (l)  
 $V_w$  = volume of water (l)

**Solvent Content and VOC Content:**

The solvent content of a coating is the total mass of solvent per volume of coating (grams of solvent per liter of coating):

$$SOL = M_s/V$$

Where: SOL = solvent content (g/l)  
 $M_s$  = mass of solvent (g)  
 $V$  = volume of coating (l)

To determine the mass of solvent in a volume of coating, the density of the coating can be multiplied by the weight percent solvent. Often, coating manufacturers will provide weight percent solvent data on the coating specification sheet:

$$SOL = (\rho)(wt\%sol)$$

Where: SOL = solvent content (g/l)  
 $\rho$  = coating density (g/l)  
 $wt\%sol$  = weight percent of solvent in the coating

If a coating contains water or exempt solvents, the VOC content is different than the solvent content, because the VOC content excludes the mass and volume contribution of water and exempt solvents.

The grams of VOC per liter of coating, less water and exempt solvents, is the mass of VOC per the combined volume of VOC and coatings solids only. The volume contribution of water and exempt solvents are excluded when calculating VOC content "less water and exempt solvent:"

$$VOC = M_{voc}/(V_{voc} + V_{solids})$$

$$VOC = (M_s - M_w - M_{es})/(V_{voc} + V_{solids})$$

$$VOC = (M_s - M_w - M_{es})/(V - V_w - V_{es})$$

Where: VOC = VOC content (g/l), less water and exempt solvents  
 $M_{voc}$  = mass of VOC (g)  
 $V_{voc}$  = volume of VOC (l)  
 $V_{solids}$  = volume of solids (l)  
 $M_s$  = total mass of solvent (l)  
 $M_w$  = mass of water (g)  
 $M_{es}$  = mass of exempt solvent (g)  
 $V$  = volume of coating as applied (l)

7 Some coating specification sheets list "weight percent VOC" when they are actually reporting weight percent solvent. Care must be taken to ensure the correct data is used.

$V_w$  = volume of water as applied (l)  
 $V_{es}$  = volume of exempt solvents as applied (l)

Alternatively, the mass of VOC in a volume of coating can be determined by multiplying the density of the coating by the weight percent VOC. Often, the coating manufacturer will provide the weight percent solvent on the coating specification sheet. However, if the coating contains water or exempt solvents, the manufacturer supplied data usually includes the contributions of these exempt components and the provided weight percent solvent cannot be used.

$$VOC = (\rho)(wt\%_{VOC})$$

Where: VOC = VOC content (g/l)\*  
 $\rho$  = coating density (g/l)\*  
 $wt\%_{VOC}$  = weight percent VOC\*  
 \* (less water and exempt solvents)

When a coating sample is analyzed in the laboratory, the VOC content is calculated according to EPA Method 24 (Code of Federal Regulations, 1989). The reported VOC content from Method 24 is "less water and exempt solvent."

Volume Solids and Solids Content:

The amount of solids in the coating (liters of solids per liter of coating) determines the surface area of a substrate that can be coated.<sup>8</sup>

The volume percent solids of the coating, including water and exempt solvents, is the volume of solids per volume of coating, and can be calculated from the solvent content of the coating and the solvent density:

$$VS = V_{solids}/V$$

$$VS = 1 - V_s/V$$

$$VS = [1 - (SOL/\rho_s)]$$

Where: VS = volume percent solids, including water and exempt solvents

$V_{solids}$  = volume of solids (l)  
 $V$  = total volume of coating (l)  
 $V_s$  = volume of solvent (l)  
 $SOL$  = solvent content (g/l)  
 $\rho_s$  = solvent density (g/l)

When a coating contains water and/or exempt solvents, the solids content, less water and exempt solvent, is different than the volume solids.

<sup>8</sup> This assumes that a "standard" coating thickness (mil thickness) is applied, even though the actual mil thickness does actually vary from coating to coating and substrate to substrate.

Including water and exempt solvent. Remembering that the mass and volume of the water and exempt solvent must be excluded, the solids content is calculated from the VOC content of the coating and the VOC density rather than the solvent content and solvent density. Solids content (volume percent), less water and exempt solvent, can be calculated as follows:

$$SC = V_{solids}/(V_{voc} + V_{solids})$$

$$SC = 1 - (V_{voc}/(V_{voc} + V_{solids}))$$

$$SC = [1 - (VOC/\rho_{voc})]$$

Where: SC = solids content\*  
 $V_{solids}$  = volume of solids (l)\*  
 $V_{voc}$  = volume of VOC (l)\*  
 $VOC$  = VOC content (g/l)\*  
 $\rho_{voc}$  = VOC solvent density (g/l)<sup>9</sup>  
 \* (less water and exempt solvent)

Example 1:

One liter of coating contains 25% by volume solids, 25% VOC, and 50% water, as supplied by the manufacturer, and is applied to a substrate without dilution. The volume percent solids, including water and exempt solvent, is 0.25/1.0 = 25%. The solids content, less water and exempt solvent, is:

$$SC = 0.25/(1.0 - 0.50) = 50\%$$

If the coating is diluted with an additional one gallon of water prior to application, the volume percent solids, including water and exempt solvent, is now .25/2.0 = 12.5%. The solids content, less water and exempt solvent, is:

$$SC = 0.25/(2.0 - 1.5) = 50\%$$

The dilution of a coating with water or exempt solvent does not change the solids content, less water and exempt solvents.

<sup>9</sup> This is the density of the VOC portion of the solvent only. Most coating solvents are composites of many different individual solvents and it may be difficult to determine the true VOC density. Information provided by the coating manufacturer in the coating specification sheet should always be used to obtain the solids content. Some individuals have assumed an average solvent density (882 g/l) for ease of calculation. However, the use of an assumed solvent density, instead of the actual solvent density, can make a significant difference in the final emission calculation (Guenster, 1989). EPA policy is to always use coating specific data to calculate solids content whenever possible.

**VOC CONTENT AFTER MIXING MULTIPLE COMPONENTS:**

The VOC content of the coating after mixing multiple components can be calculated from the VOC content of each component (coating, catalysts, and reducers) and the volumetric mix ratio of the components. The volume of each component in the mixture is multiplied by its VOC content to obtain the mass of VOC contributed by each component. The VOC content information for each component can usually be found in the coating manufacturer specifications or from laboratory analyses.

The final VOC content is determined by dividing the sum of the total VOC mass by the volume of coating created after mixing, less water and exempt solvents:

$$\text{VOC} = M_{\text{voc}} / (V_{\text{voc}} + V_{\text{solids}})$$

$$\text{VOC} = M_{\text{voc}} / (V - V_w - V_{\text{es}})$$

Where: VOC = VOC content (g/l), less water and exempt solvent

$M_{\text{voc}}$  = total mass of VOC in coating mix (g) \*

$V_{\text{voc}}$  = total volume of VOC in the coating mix (l) \*

$V_{\text{solids}}$  = total volume of solids in coating (l) \*

$V$  = total volume of coating applied (l) \*

$V_w$  = total volume of water in the coating mix (l) \*

$V_{\text{es}}$  = total volume of exempt solvent in the mix (l) \*

\* this is the total of the contributions from all mixed components (e.g.  $V_{\text{voc}} = V_{\text{voc},1} + V_{\text{voc},2} + \dots + V_{\text{voc},n}$ ).

When VOC solvents, in the form of thinners and reducers, are added to coatings prior to application, the VOC content of the coating increases. When only water or exempt solvents are added to the coating, the VOC content theoretically remains the same because the mass and volume of the water are excluded from the less water and exempt solvent calculations.

It should be noted, however, that when exempt solvents are added to the coating, the VOC content of the coating increases slightly. This is due to the fact that typical exempt solvents, such as 1-1-1-trichloroethane, will contain as much as 5% VOC in the form of stabilizing agents. Knowing how much VOC an exempt solvent actually contains is critical when calculating the resulting VOC content of a multi-component coating. Care should be taken to ensure that the mass and volume of the VOC are included in the calculation.

**EXCESS EMISSIONS:**

A violation of surface coating VOC content requirements can result in excess emissions; however, the methods of excess emissions calculation are not as straightforward as they appear. Two factors contribute to the excess emissions: 1) the VOC content of the coating is greater than the regulation allows; thus, for the entire liter of coating applied, the difference between

the VOC limit and the VOC content applied is in excess of the rule requirement, and 2) the excess solvent in the coating displaces a certain volume of solids normally residing in a complying coating (causing an increased volume of coating to be applied to cover the same surface area).

To perform excess emissions calculations, the following lab test information associated with the Method 24 analysis and calculation procedures should be requested from laboratory staff: VOC content (less water and exempt solvents) (g/l), weight percent water as applied, weight percent exempt solvent as applied, coating density as applied (g/l), and solvent density.<sup>10</sup> Calculations will employ the volume of coating, less water and exempt solvents (R).

**SOLIDS CONTENT EFFECT ON EXCESS EMISSION CALCULATIONS:**

As previously mentioned, when the VOC content of the coating is increased, the solids content of the coating decreases because some of the solids that would normally reside in the complying coating have been displaced by additional solvents. The ratio of the required solids content and the applied solids content (g) is the solids content ratio:

$$\eta = SC_r / SC_a$$

$$\eta = [1 - (\text{VOC}_r / 882)] / [1 - (\text{VOC}_a / \rho_{\text{voc}})]$$

Where:

$\eta$  = solids content ratio

$SC_r$  = required solids content \*

$SC_a$  = applied solids content \*

$\text{VOC}_r$  = required VOC content (g/l) \*

882 = EPA's VOC density of standard coating (g/l)

$\text{VOC}_a$  = VOC content of coating applied (g/l) \*

$\rho_{\text{voc}}$  = VOC density of the coating (g/l)

\* (less water and exempt solvents)

The solids content ratio yields the percentage increase in coating usage that results from the non-complying coating:

$$\% \text{RI} = \eta - 1$$

$$\% \text{RI} = (SC_r / SC_a) - 1$$

$$\% \text{RI} = [1 - (\text{VOC}_r / 882)] / [1 - (\text{VOC}_a / \rho_{\text{voc}})] - 1$$

Where:  $\% \text{RI}$  = percentage increase in coating usage \*

$\eta$  = solids content ratio

$SC_r$  = required solids content \*

<sup>10</sup> When the laboratory cannot readily determine solvent density, a solvent specification can be requested so that the solvent density may be calculated. However, data may already be available in manufacturer's coating specification sheets to accomplish this task without a lab test. Manufacturers can often supply the solids content information for single component coatings directly, if you contact their chemists.

SC<sub>a</sub> = applied solids content\*  
 VOC<sub>r</sub> = required VOC content (g/l)\*  
 ρ<sub>voc</sub> = VOC density of the coating (g/l)  
 \* (less water and exempt solvents)

Example 2:

A source uses a 400 g/l coating instead of the required 275 g/l coating. The excess volume applied is as follows:

$$\begin{aligned} \text{SC required} &= 1 - (275/882) = 69\% \\ \text{SC applied} &= 1 - (400/882) = 55\% \\ \eta &= .69/.55 = 1.25 \end{aligned}$$

Due to the change in solids content, 25% more coating was applied than would have been, had the source used a complying coating.

The excess volume applied for a non-complying coating can be found from the solids content ratio (η):

$$\Delta R = R(1 - 1/\eta)$$

Where: ΔR = excess volume applied (l)\*  
 $\eta = \{(1 - \text{VOC}_r/\rho_{\text{voc}})/(1 - \text{VOC}_a/\rho_{\text{voc}})\}$   
 VOC<sub>a</sub> = VOC content applied (g/l)  
 VOC<sub>r</sub> = VOC content required by the rule (g/l)\*  
 ρ<sub>voc</sub> = VOC density of the coating (g/l)\*  
 \* (less water and exempt solvents)

Example 3:

In Example 2, the excess volume applied is:

$$(R)(1 - 1/1.25) = 0.2(R)$$

For every liter of the non-compliant coating applied, 0.2 liters is excess. Thus, only 0.8 liters, or 80%, of a compliant coating would have been applied. Note: the percentage increase in volume applied is  $\{0.2/(1 - 0.2)\} = 25\%$ , confirming Example 2.

DERIVATION OF THE EXCESS EMISSION FORMULA:

To ensure that excess emissions that are due to the effects of increased VOC content and reduced solids content are not inadvertently double counted, excess emissions are prepared for each of the emission factors separately.

The emissions resulting from the increased volume of coating applied (ΔR), due to the decrease in solids content, are:

$$EE_1 = \Delta R (\text{VOC}_a)$$

Where: EE<sub>1</sub> = excess emissions due to ΔR (g VOC)  
 ΔR = change in volume from change in solids (l)\*  
 VOC<sub>a</sub> = VOC content applied (g/l)\*  
 \* (less water and exempt solvents)

The emissions resulting from the volume of coating that would have been applied (R - ΔR) had a compliant coating been used, are:

$$EE_2 = [(R - \Delta R)(\text{VOC}_a - \text{VOC}_r)]$$

Where: EE<sub>2</sub> = excess emissions due to R - ΔR (g VOC)  
 R = volume applied (l)\*  
 ΔR = change in volume from change in solids (l)\*  
 VOC<sub>a</sub> = VOC content applied (g/l)\*  
 VOC<sub>r</sub> = VOC content required by the rule (g/l)\*  
 \* (less water and exempt solvents)

The single equation that reflects excess emissions due to the VOC limit violation and the reduced solids content is:

$$EE = [(R - \Delta R)(\text{VOC}_a - \text{VOC}_r)] + \Delta R(\text{VOC}_a)$$

Where: EE = excess emissions (g VOC)  
 R = volume applied (l)\*  
 ΔR = change in volume from change in solids (l)\*  
 VOC<sub>a</sub> = VOC content applied (g/l)\*  
 VOC<sub>r</sub> = VOC content required by the rule (g/l)\*  
 \* (less water and exempt solvents)

By substituting the equations for ΔR and η into the equation for EE, the final excess emission calculation results:

$$\begin{aligned} EE &= [R - R(1 - 1/\eta)](\text{VOC}_a - \text{VOC}_r) + R(1 - 1/\eta)\text{VOC}_a \\ EE &= [R/\eta][\text{VOC}_a - \text{VOC}_r] + (R)(\text{VOC}_a) - (R/\eta)(\text{VOC}_a) \\ EE &= R(\text{VOC}_a) - (R/\eta)(\text{VOC}_r) \\ EE &= (R)(\text{VOC}_a - \text{VOC}_r)/(1 - \text{VOC}_a/\rho_{\text{voc}})/(1 - \text{VOC}_r/882) \end{aligned}$$

Where:  $R$  = volume applied (l)\*  
 $VOC_a$  = VOC content applied (g/l)\*  
 $VOC_r$  = VOC content required by the rule (g/l)\*  
 $\rho_{voc}$  = VOC density of the coating (g/l)\*  
 882 = EPA's VOC density of standard coating (g/l)  
 \* (less water and exempt solvents)

#### ADD-ON CONTROL EQUIPMENT:

Add-on control equipment can either capture VOC emissions for later processing (e.g. carbon adsorption) or destroy the VOC on site (e.g. incineration). When add-on control equipment is used, a portion of the mass and volume of VOC in the coating is eliminated. The mass and volume of the VOC after control equipment is applied is dependant upon the collection efficiency and abatement efficiency of equipment. To determine if the coating application is in compliance with surface coating regulations, a solids basis must be used for comparison (Rhoads, 1980).<sup>11</sup>

The "equivalent" VOC content and volume applied (after control) can be calculated and used in the formulas provided in this paper. However, the detailed calculation methods to determine equivalent VOC content and volume are somewhat complex. Instead, it is easier to determine excess emissions by comparing the actual VOC emissions to the allowed VOC emissions, on a solids basis.

First, the actual mass of VOC emissions from the operation are determined by:

$$E_a = R(VOC_a)(1 - CE)$$

Where:  $E_a$  = mass emissions of VOC applied (g)  
 $R$  = volume of coating applied (l)\*  
 $VOC_a$  = VOC content of the coating applied (l)\*  
 $CE$  = overall efficiency of control system<sup>12</sup>  
 \* (less water and exempt solvents)

11 The author's previous paper, Preparation of Alternative Emission Control Plans for Surface Coating Operations (Guenster, 1989), erroneously implies that a solids basis is only applied to control equipment calculations when emission trades are conducted. EPA policy requires that a solids basis be used for all compliance determinations, regardless of whether an emission trade is conducted. The paper was updated in August 1989 to correct the error and copies of the latest version may be obtained from the author.

12 The overall efficiency of the control system is the product of capture efficiency and control device efficiency. That is, the control efficiency is the percentage of the VOC that is kept from entering the atmosphere. If control equipment captures 90% of the emissions and destroys 90% of the captured emissions,  $CE = 0.81$ .

Second, the mass of VOC emissions allowed under the provisions of the regulation can be calculated from:

$$E_r = (R - \Delta R)(VOC_r)$$

Where:  $E_r$  = emissions allowed by the regulation (g)  
 $R$  = volume of coating applied (l)\*  
 $\Delta R$  = change in volume from change in solids (l)\*  
 $VOC_r$  = VOC content required by the regulation (g/l)\*  
 \* (less water and exempt solvents)

and where, as in the previous calculations:

$$\Delta R = R(1 - 1/\eta)$$

$$\eta = SC_r/SC_a = \{1 - (VOC_r/882)\} / \{1 - (VOC_a/\rho_{voc})\}$$

thus:  $E_r = R(VOC_r) \{1 - (VOC_a/\rho_{voc})\} / \{1 - (VOC_r/882)\}$

Finally, the excess emissions are the difference between the actual and allowed emissions:

$$EE = E_a - E_r$$

$$EE = R(VOC_a)(1 - CE) - R(VOC_r)(SC_a/SC_r)$$

$$EE = R(VOC_a)(1 - CE) - R(VOC_r) \{1 - (VOC_a/\rho_{voc})\} / \{1 - (VOC_r/882)\}$$

Where:  $EE$  = excess emissions (g)  
 $E_a$  = mass emissions of VOC applied (g)  
 $E_r$  = emissions allowed by the regulation (g)  
 $R$  = volume of coating applied (l)\*  
 $VOC_a$  = VOC content of the coating applied (l)\*  
 $CE$  = overall efficiency of control system  
 $VOC_r$  = VOC content required by the regulation (g/l)\*  
 $SC_a$  = applied solids content\*  
 $SC_r$  = required solids content\*  
 $\rho_{voc}$  = VOC density of the coating (g/l)  
 \* (less water and exempt solvents)

#### CONCLUSION:

The calculation methodologies presented in this paper can be used to readily determine the excess emissions from coatings that do not comply with surface coating regulations. Excess emissions play a key role in determining if regulations are achieving the emission reductions that they were designed to achieve; thus they should be considered in the development of attainment



plans. Because local agencies are now being asked to participate with EPA staff in conducting Rule Effectiveness Evaluations (under the new Phase III rule effectiveness program) the development and understanding of excess emission calculation methodologies is important for local agency engineering and enforcement staff.

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