

**SAN DIEGO AIR POLLUTION CONTROL DISTRICT  
SMALL BUSINESS ASSISTANCE**

**VOLATILE ORGANIC COMPOUND (VOC) CALCULATIONS**

**PROCEDURES FOR CALCULATING VOC CONTENT OF  
MIXTURES WHEN WATER OR EXEMPT COMPOUNDS ARE PRESENT**

To determine compliance with most District volatile organic compound (VOC) standards, VOC content is expressed as the mass of VOC per volume of material not including the volume of water and exempt compounds present in the material. This measure of VOC content is referred to as the mass of VOC per volume of material less water and exempt compounds. Exempt compounds are organic compounds that are not considered VOCs for purposes of determining compliance with VOC standards.

Situations often arise where the VOC content of a material must be calculated from the VOC contents of one or more components that are mixed together. For example, if two coating components are mixed together prior to application, the VOC content of the mixture must be calculated since compliance is based on the VOC content of the coating as applied. When there is no water or exempt compounds present, calculating the VOC content of such a mixture is relatively simple (see equation 4 below). However, if one or both of the coating components contain water or exempt compounds the calculation of the VOC content of a mixture expressed as mass of VOC less water and exempt compounds is more complex. The methods for calculating the VOC content in this case are discussed below.

**Calculating VOC Content as Mass per Volume Less Water and Exempt Compounds**

Consider a volume,  $V_{m1}$ , of material 1 and a volume  $V_{m2}$  of material 2. If these two volumes are mixed together, the total mass of VOC present in the mixture is given by:

$$W_{ca} = V_{m1}C_{m1} + V_{m2}C_{m2}$$

where:

$W_{ca}$  is the total mass of VOC present in the mixture,

$C_{m1}$  is the VOC content of material 1 expressed as mass of VOC per volume of material, and

$C_{m2}$  is the VOC content of material 2 expressed as mass of VOC per volume of material.

Assuming no volume change on mixing, the total volume of the mixture is given by:

$$V_{ma} = V_{m1} + V_{m2}$$

where  $V_{ma}$  is the total volume of the mixture. However, total volume of the mixture less water and exempt compounds is given by:

$$V_{nxa} = (1 - v_{x1})V_{m1} + (1 - v_{x2})V_{m2}$$

where:

## Calculating VOC Content of Mixtures when Water or Exempt Compounds are Present

$V_{nxa}$  is the mixture volume less water and exempt compounds,

$v_{x1}$  is the volume fraction of water and exempt compounds of material 1, and

$v_{x2}$  is the volume fraction of water and exempt compounds of material 2.

Therefore, for a mixture of two materials, a formula for calculating the VOC content as mass of VOC per volume of material less water and exempt compounds is:

$$(1) \quad C_{ca} = \frac{W_{ca}}{V_{nxa}} = \frac{V_{m1}C_{m1} + V_{m2}C_{m2}}{(1 - v_{x1})V_{m1} + (1 - v_{x2})V_{m2}}$$

where:

$C_{ca}$  is the VOC content of the mixture expressed as mass of VOC per volume of material less water and exempt compounds,

$C_{m1}$  is the VOC content of material 1 expressed as mass of VOC per volume of material,

$C_{m2}$  is the VOC content of material 2 expressed as mass of VOC per volume of material,

$v_{x1}$  is the volume fraction of water and exempt compounds of material 1, and

$v_{x2}$  is the volume fraction of water and exempt compounds of material 2.

### Calculating VOC Content as Mass per Volume

In cases where the VOC content expressed as mass of VOC per volume of material is needed, the following formula can be used:

$$(2) \quad C_{ma} = \frac{W_{ca}}{V_{ma}} = \frac{V_{m1}C_{m1} + V_{m2}C_{m2}}{V_{m1} + V_{m2}}$$

where  $C_{ma}$  is the VOC content of the mixture expressed as mass of VOC per volume of material.

### Calculating Volume Fraction of Water and Exempt Compounds

If the volume fraction of water and exempt compounds for an individual material are not known directly but the weight fractions of water and each exempt compound in the material are known, the volume fraction of water and exempt compounds can be estimated. For each component of an individual material, the volume fraction of that component in the material can be calculated by:

$$v_i = w_i \left( \frac{\rho_m}{\rho_i} \right)$$

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where:

$v_i$  is the volume fraction of the component in the material,

$w_i$  is the weight fraction of the component in the material,

$\rho_i$  is the partial density of the component in the material<sup>1</sup>, and

$\rho_m$  is the density of the material.

The volume fraction of water and each exempt compound are calculated separately. The total volume fraction of water and exempt compounds in the material,  $v_x$ , can then be determined by summing the volume fractions of water and all components that are exempt compounds.

Alternatively, if the volume fraction of VOCs and volume fraction of solids are known, the volume fraction of water and exempt compounds in the material can be found from:

$$v_x = 1 - v_c - v_s$$

where:

$v_c$  is the volume fraction of VOCs in the material and

$v_s$  is the volume fraction of solids in the material.

The volume fractions of VOCs and solids can be estimated from their individual or composite weight fractions and densities, if necessary (see above).

### **Additional Calculation Techniques**

For a given material, the VOC content expressed as VOC mass per volume of material less water and exempt compounds is related to the VOC content expressed as VOC mass per volume of material,  $C_m$ , by:

$$(3) \quad C_c = \frac{C_m}{1 - v_x}$$

where  $C_c$  is the VOC content expressed as mass per volume of material less water and exempt compounds. Note that, if  $C_m$  and  $C_c$  are greater than zero, equation 3 can be rearranged to give the volume fraction of water and exempt compounds,  $v_x$ :

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<sup>1</sup> Note that the partial density of a component in the material is in general not equal to the density of the pure component. However, in the likely absence of other information, the partial density of the component in the material,  $\rho_i$ , can be assumed to be equal to the density of the pure component in order to estimate the component volume fraction. This is equivalent to assuming that there is no volume change on mixing (or that the solvent is an ideal solution).

## Calculating VOC Content of Mixtures when Water or Exempt Compounds are Present

$$v_x = 1 - \frac{C_m}{C_c}$$

In this case, the volume fraction of water and exempt compounds can be determined if the VOC content of material and the VOC content of material less water and exempt compounds are known. Substituting for  $v_x$  in equation 1 gives an alternate formula<sup>2</sup> for calculating the VOC content of the mixture expressed as mass VOC per unit volume less water and exempt compounds:

$$(1a) \quad C_{ca} = \frac{V_{m1}C_{m1} + V_{m2}C_{m2}}{\frac{C_{m1}}{C_{c1}}V_{m1} + \frac{C_{m2}}{C_{c2}}V_{m2}}$$

Equations 1 and 1a can be extended to more than two components by simply including appropriate terms in the numerator and denominator on the right hand side of the equations for each additional component (see Appendix).

If no exempt compounds or water are present, then  $v_{x1} = 0$ ,  $C_c = C_m$ , and equation 1 for calculating the VOC content,  $C_{ca}$ , of a 2-material mixture can be rewritten as:

$$(4) \quad C_{ca} = \frac{V_{m1}C_{c1} + V_{m2}C_{c2}}{V_{m1} + V_{m2}}$$

where  $C_{c1}$  and  $C_{c2}$  are the VOC contents expressed as mass of VOC per volume less water and exempt compounds of materials 1 and 2, respectively<sup>3</sup>. However, equation 4 will not give correct results if exempt compounds or water are present—and the error may be large. Some examples calculating  $C_{ca}$  with equations 1 (correct) and equation 4 (incorrect) are given below. Using equation 4 to calculate the VOC content may give mixture VOC contents that are too high (Example 1), too low (Example 2), or—fortuitously—correct (Example 3).

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<sup>2</sup> This equation is not valid if either of the materials do not contain any VOC. In this case, both  $C_c$  and  $C_m$  for the material would be zero.

<sup>3</sup> Even though no water or exempt compounds are present in either material the VOC content of the material is still specified as mass of VOC per volume of material less water and exempt compounds for compliance purposes. Since there is no water or exempt compounds present, this specified VOC content is identical to the VOC content expressed as mass of VOC per volume of material.

## Conclusion

The key to calculating VOC contents of mixtures when water and exempt compounds are present is knowing the volume fraction of water and exempt compounds. This can be determined in several ways when one of the following pieces of information is known for a material:

- (1) The volume fraction of water and exempt compounds (see equation 1); or
- (2) If the VOC contents are not zero, the VOC content expressed as mass per volume of material less water and exempt compounds and the VOC content expressed as mass per volume of material (see equation 1a); or
- (3) The volume fraction of solids and volume fraction of VOCs; or
- (4) The weight fraction of water and all exempt compounds, the partial density of water and each exempt compound, and the total density of the material; or
- (5) The weight fraction of solids, the density of each solid, the weight fraction of VOCs, the partial density of each VOC, and the total density of the material.

**EXAMPLES**

**Example 1**

<b>Material property</b>	<b>Coating 1</b>	<b>Coating 2</b>
$C_m$ = VOC content, g/l	200	80
$v_x$ = Volume fraction water and exempt compounds	0	0.9
$C_c$ = VOC content, g/l less water and exempt compounds	200	800
$V_m$ = volume of material added to mixture, liters	1	1

VOC content expressed as grams per liter less water and exempt compounds calculated by equation 1:

$$C_{ca} = \frac{(1)(200) + (1)(80)}{(1-0)(1) + (1-0.9)(1)} = 255 \text{ g/l}$$

VOC content expressed as grams per liter less water and exempt compounds calculated by equation 4:

$$C_{ca} = \frac{(1)(200) + (1)(800)}{1 + 1} = 500 \text{ g/l}$$

## Calculating VOC Content of Mixtures when Water or Exempt Compounds are Present

### Example 2

Material property	Coating 1	Coating 2
$C_m$ = VOC content, g/l	600	20
$v_x$ = Volume fraction water and exempt compounds	0	0.9
$C_c$ = VOC content, g/l less water and exempt compounds	600	200
$V_m$ = volume of material added to mixture, liters	1	1

VOC content expressed as grams per liter less water and exempt compounds calculated by equation 1:

$$C_{ca} = \frac{(1)(600) + (1)(20)}{(1-0)(1) + (1-0.9)(1)} = 563 \text{ g/l}$$

VOC content expressed as grams per liter less water and exempt compounds calculated by equation 4:

$$C_{ca} = \frac{(1)(600) + (1)(200)}{1 + 1} = 400 \text{ g/l}$$

## Calculating VOC Content of Mixtures when Water or Exempt Compounds are Present

### Example 3

Material property	Coating 1	Coating 2
$C_m$ = VOC content, g/l	200	20
$v_x$ = Volume fraction water and exempt compounds	0	0.9
$C_c$ = VOC content, g/l less water and exempt compounds	200	200
$V_m$ = volume of material added to mixture, liters	1	1

VOC content expressed as grams per liter less water and exempt compounds calculated by equation 1:

$$C_{ca} = \frac{(1)(200) + (1)(20)}{(1-0)(1) + (1-0.9)(1)} = 200 \text{ g/l}$$

VOC content expressed as grams per liter less water and exempt compounds calculated by equation 4:

$$C_{ca} = \frac{(1)(200) + (1)(200)}{1 + 1} = 200 \text{ g/l}$$

### APPENDIX

For a 3-material mixture, equations corresponding to equations 1, 1a, and 2 become, respectively:

$$C_{ca} = \frac{V_{m1}C_{m1} + V_{m2}C_{m2} + V_{m3}C_{m3}}{(1-v_{x1})V_{m1} + (1-v_{x2})V_{m2} + (1-v_{x3})V_{m3}}$$

$$C_{ca} = \frac{V_{m1}C_{m1} + V_{m2}C_{m2} + V_{m3}C_{m3}}{\frac{C_{m1}}{C_{c1}}V_{m1} + \frac{C_{m2}}{C_{c2}}V_{m2} + \frac{C_{m3}}{C_{c3}}V_{m3}}$$

$$C_{ma} = \frac{V_{m1}C_{m1} + V_{m2}C_{m2} + V_{m3}C_{m3}}{V_{m1} + V_{m2} + V_{m3}}$$

For an n-material mixture, equations corresponding to equations 1, 1a, and 2 become, respectively:

$$C_{ca} = \frac{V_{m1}C_{m1} + V_{m2}C_{m2} + \dots + V_{mn}C_{mn}}{(1-v_{x1})V_{m1} + (1-v_{x2})V_{m2} + \dots + (1-v_{xn})V_{mn}}$$

$$C_{ca} = \frac{V_{m1}C_{m1} + V_{m2}C_{m2} + \dots + V_{mn}C_{mn}}{\frac{C_{m1}}{C_{c1}}V_{m1} + \frac{C_{m2}}{C_{c2}}V_{m2} + \dots + \frac{C_{mn}}{C_{cn}}V_{mn}}$$

$$C_{ma} = \frac{V_{m1}C_{m1} + V_{m2}C_{m2} + \dots + V_{mn}C_{mn}}{V_{m1} + V_{m2} + \dots + V_{mn}}$$

In the above equations:

$C_{ca}$  is the VOC content of the mixture expressed as mass of VOC per volume of material less water and exempt compounds,

$C_{ma}$  is the VOC content of the mixture expressed as mass of VOC per volume of material,

$C_c$  is the VOC content of a material expressed as mass per volume of material less water and exempt compounds,

$C_m$  is the VOC content of a material expressed as mass of VOC per volume of material, and

The indices (1, 2, 3, ... , n) indicate individual materials in the mixture.