

IH for the CSP 1: Air Sampling Calculations

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Abstract

Risk assessment in Industrial Hygiene involves quantifying, or measuring, the concentration of contaminants in the air. Perhaps the most commonly used method is air sampling. A sampling pump is used to draw workroom air through some type of sampling media, such as a filter or charcoal sorbent tube, which traps the contaminant. The sampling media is then sent to a laboratory for analysis. The laboratory determines the total amount of the contaminant trapped in the media. Given the volume of air drawn through the sampling media, the laboratory can calculate the concentration of contaminant in the air.

Conversion Factors

Conversion factors are ratios, or fractions, equal to one. Any quantity may be multiplied by any conversion factor without changing its value. They are used to simplify the units resulting from a calculation. For example, if a current of 12 amps runs through a wire for 10 minutes, the total charge passing through the wire is given by,

$$Q = I t = (12 \text{ amps}) (10 \text{ minutes}) = 120 \text{ amp-minutes.}$$

The above equation is perfectly correct. However the unit amp-minute is very cumbersome. The unit "Coulomb," is usually preferred. It is abbreviated by "C." To convert amp-minutes to Coulombs, we use two conversion factors. Since $60 \text{ sec} = 1 \text{ min}$, and $\text{an amp} = \text{C/sec}$,

$$\frac{60 \text{ sec}}{1 \text{ min}} = 1 \quad \text{and} \quad \frac{\text{Coulomb/sec}}{\text{amp}} = 1$$

Inserting these conversion factors,

$$Q = I t = 12 \text{ amps} \frac{\text{Coulomb/sec}}{\text{amp}} 10 \text{ min} \frac{60 \text{ sec}}{1 \text{ min}} = 7,200 \text{ Coulombs .}$$

Amps, minutes, and seconds all cancel out leaving only Coulombs. We could go one step further. People (for what ever reason) like numbers between 1 and 100. If we prefix a unit with "k," for kilo we have a unit 1,000 times as large, e.g. 1 kC (kiloCoulomb) = 1,000 C or 10^3 C .

Therefore,

$$Q = 7,200 C \frac{kC}{10^3 C} = 7.2 kC .$$

Sampling

While sampling, the Industrial Hygienist takes great care to insure that the pump volume flow rate, Q , (the rate at which air is drawn through the media) and the time of sampling, t , are known with great precision. The total volume of air drawn through the media, V_{air} , is given by,

$$V_{air} = Q t . \quad 1$$

The concentration is then calculated by some measure of the amount of contaminant trapped divided by the volume of air in which that contaminant was found (the volume drawn through the pump).

For vapors, such as organic solvents, and for gasses, such as carbon monoxide, the most commonly used measure of concentration is the part per million, ppm. Parts per million is a volume ratio. The volume that the contaminant alone would occupy at the same temperature and pressure as the workroom air is divided by the volume of air sampled. Volumes are usually measured in units of liters. If one liter of contaminant is found in every one million liters of workroom air, the concentration is 1 ppm. Since ppm is dimensionless, 10^6 ppm can be thought of as a conversion factor equal to one.

The volume the contaminant would occupy at a given temperature and pressure is calculated from the mass. The mass, m , in grams, divided by the molecular weight, MW , of the compound gives the number of gram-moles present. Each gram-mole occupies 24.45 l at 1 atm and 25 OC (77 OF). The ideal gas law is used to calculate the volume at the desired temperature and pressure. The volume of contaminant, V_{con} , is then given by,

$$V_{con} = \frac{m}{MW} \frac{24.45 l}{g - mole} \frac{(T + 273)}{(25 + 273)} \frac{1 atm}{P} . \quad 2$$

Remember that the temperature in the ideal gas law must be measured on an absolute scale such as Kelvin or Rankin, hence 273 must be added to temperatures in $^{\circ}C$, and 460 must be added to temperatures in $^{\circ}F$.

The molecular weight can be thought of as having the units "grams / g-mole."

The concentration, C , (in ppm) can then be calculated by,

$$C = \frac{V_{\text{con}}}{V_{\text{air}}} 10^6 \text{ ppm} \quad . \quad 3$$

If the temperature or pressure of a sample of contaminated air varies, the volume of contaminant changes proportionally to the total volume of the sample, and the concentration of contaminant expressed in ppm does not change.

For particulates (fumes, mists, dusts, smokes, etc.) the volume of contaminant is not well defined, and the unit ppm can not be used. The preferred unit of measure is the milligram per cubic meter, mg/m^3 . The concentration is calculated simply by,

$$C = \frac{m}{V_{\text{air}}} \quad . \quad 4$$

Conversion factors equal to one are used to obtain the desired units. Although the unit mg/m^3 is more easily calculated, it can be more difficult to use in practice. When the temperature or pressure of a sample of contaminated air changes, the volume of that sample changes, but the mass of contaminant within it does not. Therefore, the concentration of the sample of air expressed in mg/m^3 does change with temperature and pressure. This has one very important ramification; when the concentration of contaminant in the workplace is measured in mg/m^3 , it must be corrected for temperature and pressure before it can be compared to published limits such as the OSHA Permissible Exposure Limits (PEL's) or the ACGIH Threshold Limit Values (TLV's).

Three other units bear mention here. When extremely low concentrations are of interest, the units parts per billion, ppb, and microgram per cubic meter, $\mu\text{g}/\text{m}^3$ are often used ($\text{ppb} = 10^{-3} \text{ ppm}$ and $\mu\text{g}/\text{m}^3 = 10^{-3} \text{ mg}/\text{m}^3$). Concentrations of fibers, such as asbestos, are usually measured in fibers per cubic centimeter, fpcc, due to the optical methods used in analysis. Calculation of concentrations requires one additional consideration. When calculating the airborne concentration, only the mass of contaminant removed from the air drawn through the sampling media should go into the calculation. The filtering media, however, may become contaminated from other sources (e.g. solid material on the industrial hygienist's hand or workplace surfaces). In order to account for these other possible sources, blanks are taken. A blank is a filter cassette or sorbent tube which is taken to the workplace and handled in every way exactly like the media used for sampling, except that no air is drawn through the blank. The assumption is that the best estimate of the amount of contaminant on the samples due to sources other than the air drawn through them, is the mass on the blank. The blank is analyzed exactly as are the samples, and the mass of the contaminant on the blank is subtracted from the mass of contaminant on each sample. The mass that goes into the concentration calculations is the net mass = gross mass - blank mass.

Sample Problem

Consider the following example. A personal air sampling pump is used to draw air through a treated XAD-2 sorbent tube. The sorbent tube collects formaldehyde (MW = 30.0) from the air which passes through it. The sampling media (in this case the sorbent tube) was placed on the pump at 8:07 am. The tube was removed and sealed at 10:22 am. Workroom air was at approximately 28 °C and 755 torr. It was determined through pre- and post-calibration that the volume flow rate during sampling was 2.15 liters per minute (lpm). The sorbent tube was sent to the laboratory for analysis and was found to contain 0.0032 g of formaldehyde. The blank contained 0.0009 g of formaldehyde. What was the concentration of formaldehyde in the workroom air? Calculate in units of both ppm and mg/m³.

The first step is to determine the volume of air pulled through the sorbent tube. The difference in hours times 60, plus the difference in minutes is the total time air was drawn through the media, in minutes, giving,

$$V_{\text{air}} = Q t = 2.15 \frac{\text{l}}{\text{min}} \left[(10 \text{ hr} - 8 \text{ hr}) \frac{60 \text{ min}}{\text{hr}} + (22 \text{ min} - 7 \text{ min}) \right] = 290.25 \text{ l} .$$

Note the conversion factor, 60 min/hour.

The net mass, *m*, of formaldehyde on the sample, subtracting for the blank, is,

$$m = 0.0032 \text{ g} - 0.0009 \text{ g} = 0.0023 \text{ g} .$$

The volume that would be occupied by 0.0023 g of formaldehyde at a temperature of 28 °C and a pressure of 755 torr (760 torr = 1 atm) is given by,

$$V_{\text{con}} = 0.0023 \text{ g} \frac{24.45 \text{ l/g-mole}}{30.0 \text{ g/g-mole}} \frac{28 + 273}{25 + 273} \frac{1 \text{ atm}}{755 \text{ torr}} \frac{760 \text{ torr}}{1 \text{ atm}} = 0.001905 \text{ l} .$$

The concentration of formaldehyde in the workroom air is then,

$$C_1 = \frac{V_{\text{con}}}{V_{\text{air}}} 10^6 \text{ ppm} = \frac{0.001906 \text{ l}}{290.25 \text{ l}} 10^6 \text{ ppm} = 6.57 \text{ ppm} .$$

Calculation of the concentration in mg/m³ is much simpler,

$$C_2 = \frac{m}{V_{\text{air}}} = \frac{0.0023 \text{ g}}{290.25 \text{ l}} \frac{\text{mg}}{10^{-3} \text{ g}} \frac{10^3 \text{ l}}{\text{m}^3} = 7.92 \text{ mg/m}^3 .$$

Before the concentration above can be compared to established limits, it must be converted to 25 °C and 1 atm.

$$C_{\text{STD}} = C_2 \frac{T + 273}{25 + 273} \frac{1 \text{ atm}}{P}$$

$$= 7.92 \text{ mg/m}^3 \frac{28 + 273}{25 + 273} \frac{1 \text{ atm}}{755 \text{ torr}} \frac{760 \text{ torr}}{1 \text{ atm}} = 8.06 \text{ mg/m}^3 .$$

Because concentrations of vapors and gases can be expressed in a variety of units, it is often necessary to convert from ppm to mg/m³ or vice versa. To express rules for changing units, a different notation is used. The concentration as measured in ppm, C(ppm), refers only to the number before the unit and does not include the unit. For example, if the concentration were 10 ppm, then C(ppm) = 10, not 10 ppm.

$$C(\text{ppm}) = \frac{C(\text{mg/m}^3) 24.45}{\text{MW}} , \quad 6$$

and,

$$C(\text{mg/m}^3) = \frac{C(\text{ppm}) \text{ MW}}{24.45} . \quad 7$$

All the factors in the above expressions are numbers only, without units. Remember, only concentrations in mg/m³ that have been converted to 25 °C (77 °F) and 1 atm may be converted to ppm using the above expressions. Observe from the example above,

$$C(\text{mg/m}^3) = \frac{C(\text{ppm}) \text{ MW}}{24.45} = \frac{6.57 30}{25.45} = 8.06 , \text{ not } 7.92 .$$

Time-Weighted Average

When an employee is exposed to many different concentrations during the day, an average must be taken to assess the risk. The method of averaging which best describes the ability of the contaminants to do harm, or to accumulate in the body is the time-weighted average. The actual time-weighted average concentration, C_{A-TWA} is given by,

$$C_{\text{A-TWA}} = \frac{C_1 t_1 + C_2 t_2 + \dots + C_N t_N}{t_1 + t_2 + \dots + t_N} , \quad 8$$

where t_i is the duration of the exposure to concentration C_i .

Suppose an employee were exposed to some contaminant at the levels given below for the times stated. What is the actual time-weighted average?

Time	125 min	200 min	135 min	20 min
Concentration	27 ppm	32 ppm	20 ppm	200 ppm

$$\begin{aligned}
C_{A-TWA} &= \frac{C_1 t_1 + C_2 t_2 + C_3 t_3 + C_4 t_4}{t_1 + t_2 + t_3 + t_4} \\
&= \frac{27 \text{ ppm } 125 \text{ min} + 32 \text{ ppm } 200 \text{ min} + 20 \text{ ppm } 135 \text{ min} + 200 \text{ ppm } 20 \text{ min}}{125 \text{ min} + 200 \text{ min} + 135 \text{ min} + 20 \text{ min}} \\
&= 34.4 \text{ ppm}
\end{aligned}$$

Observe that ppm-min distributes out of every term in the numerator, and min distributes out of every term in the denominator, canceling min above, and leaving only the unit ppm. If any mixed units are used, conversion factors must be inserted.

The time-weighted average described above is called the “actual” TWA to distinguish it from the 8-hour TWA. OSHA law requires that a concentration of zero be assumed for any time during the 8-hour shift which is not monitored. To simplify calculations, the denominator of the above expression is simply replaced with 480 min (8 hours), hence the name. The 8-hour TWA is only used for compliance. It should not be used as a measure of risk to your employees. If you should sample only for six hours out of an eight-hour shift, your employees are not exposed to any less contaminant than if you had sampled the full eight hours.