**FUNDAMENTALS OF INDUSTRIAL HYGIENE, 6TH ED.**

**HOMEWORK #2**

**INDIVIDUAL DETERMINATION OF EXPOSURE CONCENTRATIONS**

**Objective:** Students will become familiar with the determination of exposure levels, including the concentration levels in a variety of units.

**Background:** *Exposure assessment* is the process of measuring or estimating the magnitude, frequency, and duration of human exposure to an agent in the environment. An exposure assessment includes some discussion of the size, nature, and types of human populations exposed to the agent, as well as discussion of the uncertainties in the above information. Exposure assessment considers both the exposure pathway (the course an agent takes from its source to the person(s) being contacted), as well as the exposure route (means of entry of the agent into the body). Exposure to substances in the workplace can occur through inhalation, absorption through the skin, or ingestion. Most exposure occurs through the inhalation of vapors, dusts, fumes, or gases and for this reason, even though it is acknowledged that absorption through the skin or ingestion may constitute significant sources of exposure, this exercise will focus on determination of airborne concentrations of contaminants that may result in inhalation hazards.

The response of the body from exposure to substances depends on the nature of the substance, the health effects it can cause, and the amount of the substance absorbed by the body. The extent to which a worker is exposed depends on the concentration of the substance in the air, the amount of time the worker is exposed (the topic of Homework #1), and the effectiveness of controls.

Occupational Exposure Levels (OELs), whether they be regulatory (PELs) or advisory (TLVs, RELs) set forth acceptable concentrations for a variety of hazardous chemicals and physical agents. Airborne concentrations may be expressed *gravimetrically* as milligrams of the substance per cubic meter of air (*mg/m3*) or indicated *volumetrically* in parts per million (*ppm*), although a variety of other units may be used. Since there are a variety of means for reporting concentrations, it is important to not only know how to calculate concentrations in a variety of units of measure, but also how to convert concentrations between different units of measure. To determine whether an exposure standard is exceeded, air monitoring may be required. The method of air sampling, the number and volume of the air samples, and the method of analyses of the air samples is determined according to the nature of the operations or processes and the characteristics of the agent. For particular agents, specific requirements have been established by regulatory agencies (e.g., OSHA, NIOSH, ISO).

**Unit Conversions**

1000 *ng* (nanograms) = 1.0 *μg* (microgram)

1000 *μg* (micrograms) = 1.0 *mg* (milligram)

1000 *mg* (milligrams) = 1.0 *g* (gram)

1000 *g* (grams) = 1.0 *kg* (kilogram)

1000 *μL*(microliters) = 1.0 *mL* (milliliter) = 1.0 *cc* (cubic centimeter)

1000 *mL* (milliliters) = 1.0 *L* (liter)

1000 *L* (liters) = 1.0 *m*3 (cubic meter)

Examples: 7465 *ng* = 7.456 *μg*

9.372 *μg* = 0.009372 *mg*

0.339 *mg* = 339 *μg*

244.7 *mL* = 0.2447 *l*

1428.7 *L* = 1.4287 *m*3

0.7891 *Kg* = 789.1 *g*

1.349 *m*3 = 1349 *l*

546 *cc* = 546 *ml*

**Part I: Calculating Air Volumes**

Calculating accurate air volumes (exact amounts of air drawn through sampling media) is imperative in reaching meaningful results.

The *air volume* is simply the product of two terms: flow rate and sampling time.

Air Volume = Flow Rate  Sampling Time

The flow rate is usually expressed in liters per minute (*L/min*) or in milliliters per minute (*mL/min*).

Remember that *ml/min* is the same as cubic centimeters per minute (*cc/min*).

The sampling time needs to be expressed in minutes and, therefore, the product of these two terms (the air volume) will be expressed in either liters or milliliters.

**Example Problem:** What is the total volume of air sampled if a pump moves 11.7 liters of air per minute over a time span of 4 hours (240 minutes)?

**Example Problem:** What is the total volume of air sampled if a pump moves 20 milliliters of air per minute over a time span of 7.7 hours (462 minutes)?

**Part II: Calculating Concentrations**

Concentration is an important concept in expressing analytical results in environmental and industrial hygiene testing.

A *concentration* is so much of something *per* something else.

When dealing with concentrations, the word *per* is used to separate two quantities, such as in “parts *per* million” (*ppm*) and “milligrams *per* cubic meter” (*mg/m*3).

The most commonly used concentrations are:

*mg/kg* (milligrams per kilogram)

*mg/m*3 (milligrams per cubic meter)

*ppm* (parts per million)

*fibers/cc* (fibers per cubic centimeter)

*mg/L* (milligrams per liter)

A few handy conversions as they relate to concentrations to review are:

**ppm** = *mg/kg* milligrams per kilogram (w/w)

*μg/g* micrograms per gram (w/w)

*mL/m*3 milliliters per cubic meter (v/v)

*mg/L* milligrams per liter (w/v)

**ppb** = *μg/kg* micrograms per kilogram (w/w)

*μL/m*3 microliters per cubic meter (v/v)

*mg/m*3 milligrams per cubic meter (w/v)

*μg/L* micrograms per liter (w/v)

**Types of Concentrations**

There are two basic types of concentrations: *weight-per-weight* and *weight-per-volume*.

** weight-per-weight**

Weight-per-weight concentrations (e.g., *μg/g*, *mg/Kg*) are used to express contaminant levels of solids, such as the level of lead in paint chips.

To make everything a bit easier, always think in terms of reporting weight-per-weight concentrations in terms of either *μg/g* or *mg/Kg.*

This is because there are one million micrograms in a gram and one million milligrams in a kilogram . . . which will make converting these values to parts-per-million incredibly easy.

**Example Problem:** A 0.6 *kg* sample of petroleum-contaminated soil (PCS) was sent for analysis and was found to contain 12.3 *mg* of petroleum products. What is this contamination level reported in *mg/kg*?

** weight-per-volume**

Weight-per-volume concentrations (e.g., *mg/m*3 and *mg/l*) are used to express contaminant levels of both air and liquids.

The concentration can always be determined if the amount of contaminant and the volume of air drawn through the sampler are known.

Start with the weight amount of contaminant found on the entire sample, then divide by the air volume to arrive at the concentration level.

The amount of benzene vapor in air and the amount of iron in water (most likely expressed in terms of *mg/m*3 and *mg/l*, respectively) would both be weight-per-volume concentrations.

Note: For chemicals, the chemical regulation (OEL, TLV, PEL, etc.) is usually expressed in parts per million (*ppm*) for gases and milligrams per cubic meter (*mg/m*3) for particulates.

Note: Obviously, concentrations are necessary to make sense out of analytical results.

Knowing only the total weight of metal found on a filter is useless without knowing the exact amount of air in which that amount of metal was contained.

Therefore, when sending samples out for analysis, you must include the air volumes if they are air samples . . . the concentration cannot be calculated without the air volume.

**Example Problem:** A charcoal tube is sent to the lab for benzene analysis after having sampled a volume of air of 24.17 *l*. The lab produced a result of 0.03 *mg* benzene. Determine the concentration so these results can be compared to a PEL or TLV.

**fiber counts**

For fiber counting, as in asbestos analysis, the application is similar, but the concentrations will be reported as the number of fibers per volume of air rather than the weight of fibers per volume of air.

In part, this is because only those asbestos fibers meeting certain criteria (e.g., length) will be counted . . . not necessarily all asbestos fibers.

Further, fibers in the sample that are not asbestos will not be counted.

Thus, using the total weight of all fibers in the sample would be inappropriate.

**Example Problem:** A filter used for a 1243.7 *l* air sample was sent to the lab for asbestos analysis. The lab produced a result of 7847 fibers. Determine the concentration so these results can be compared to a PEL or TLV.

Remember: When working with concentrations, both the weight value and the volume value can be changed into the preferred units before the division is done.

For example, a result of 517.3 *mg/l* chlordane in water can be correctly expressed as 517,300 *μg/l* or 517.3 *μg/ml* without changing the result.

** parts per million**

Parts per million (*ppm*) is frequently used to express concentrations such as volume-per-volume of air, volume per volume of liquid (usually aqueous solutions), and weight-per-weight.

Regardless of the approach, it is important to remember that the units must be the same (e.g., volume-per-volume or weight-per-weight).

There are three conversions involving concentrations given in *ppm*: for converting percent to *ppm* to a percent, converting weight-per-weight to *ppm*, converting volume-to-volume to *ppm*, and converting weight-per-volume to *ppm*.

** *ppm* as a percent**

Converting a percent (%) value into parts per million is a relatively simple process if the relationship between the two units is remembered.

**(percent to *ppm)***

Therefore: 3.5% = 35,000 *ppm* (i.e., given a percent concentration, simply move the decimal place four places to the right to obtain the *ppm* concentration).

**(*ppm* to percent)**

Therefore: 472 *ppm* = 0.0472% (i.e., given a *ppm* concentration, simply move the decimal place four places to the left to obtain the percent concentration).

** weight-per-weight to *ppm***

In testing paint for lead before a demolition project, it was found that it contained 34 *μg* of lead per gram of paint chips.

The result could be reported as 34 *μg* of lead per gram of paint, or the result could be reported as 34 *ppm*, since there are one million micrograms in one gram.

Note: Notice that an understanding of basic metric units makes this conversion much easier. (see “Conversion” section above)

**Example Problem:**  A 0.6 *kg* sample of petroleum-contaminated soil (PCS) was sent for analysis and was found to contain 12.3 *mg* of petroleum products. What is this contamination level reported in *ppm*?

Recall that there are one million milligrams per kilogram. Therefore, converting *mg/kg* to *ppm* is a relatively straight-forward procedure.

** weight-per-volume to *ppm* (solid/liquid contaminants)**

**Example Problem:** Applying *ppm* values to contamination in water is not difficult if it is remembered one very important premise in chemistry . . . one milliliter (1.0 *ml*) of water weights precisely one gram (1.0 *g*).

If water contains 69 *μg* of arsenic per milliliter, then the concentration of arsenic in the water is 69 *ppm* (since 69 *μg/ml* is the same as saying *69 μg/g*) . . . and, as shown above, 69 *μg/g* is the same as 69 *ppm*, since there are one million micrograms in a gram.

** volume-to-volume to *ppm* (gaseous contaminants)**

PPM can also refer to the volume of contaminant per volume of air; however, this is only done if the substance exists as a gas or vapor at normal room temperature and pressure.

This type of *ppm* application is the most difficult to understand, but is based on the following two chemical principles:

1) A chemical’s molecular weight is the number of grams of that chemical found in one mole of that chemical.

2) At 25°C and one atmosphere of pressure, one mole of any chemical in a gaseous state (or vapor state if it is normally a liquid) occupies exactly the same amount of space (24.45 liters).

**Example Problem: (*mg/m*3 to *ppm*):** Methyl ethyl ketone (MEK) is a colorless liquid that has a sharp, sweet odor reminiscent of butterscotch and acetone. MEK has a chemical formula C4H8O, which gives it a molar mass of 72 [(C = 4  12) + (H = 8  1) + (O = 1  16)]. It is produced industrially on a large scale and is often used as an industrial solvent since it is soluble in water. Because it readily dissolves nitrocellulose, it was once a common ingredient in gun cleaning solvents. The air in a parts cleaning workshop was sampled and found to contain 450 *mg/m*3 of MEK, what would this be in parts per million?

**Example Problem: (*ppm* to *mg/m*3):**  Butanethiol (butyl mercaptan) is a volatile, clear to yellowish liquid with an extremely foul-smelling odor, commonly described as “skunk” odor. Butanethiol has a chemical formula of C4H10S, which gives it a molar mass of 90 [(C = 12  4) + (H = 1  10) + (S = 32  1)]. The scent of butanethiol is so strong that the human nose can easily detect it in the air at concentrations as low as 10 *ppm* (the threshold level is reported at 1.4 *ppb*). Butanethiol is used as a scenting agent for propane and natural gas, making even small leaks of these gases readily apparent. The air in the room where it is injected into a natural gas line is measured and found to contain 7.2 *ppm* butanethiol. What would this concentration be if reported in *mg/m*3?

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**Name:**

**EXERCISES:** Perform the calculations identified below. Show your work neatly and clearly in a manner similar to the examples provided above (i.e., write the formula, define each variable in the formula, show steps of your calculations).

**Part I: Calculating Air Volumes**

What is the total volume of air sampled if a pump moves 540 *cc* of air per minute over a time span of 6.1 hours? *(3 points)*

Calculation:

Convert this value into milliliters:

Convert this value into liters:

What is the total volume of air sampled if a pump moves 3.4 *L* of air per minute over a time span of 9.4 hours? *(4 points)*

Calculation:

Convert this value into cubic meters:

Convert this value into cubic centimeters:

Convert this value into milliliters:

**Part II: Concentrations and Conversions**

**weight-per-weight**

One of the first gasoline additives, tetraethyl lead was added to gasoline as an anti-knock agent. Use of this additive was banned in the U.S. in the early 1980s due to concerns over lead exposure. During initial site work, an abandoned underground storage tank (UST) was found. After contacting the appropriate agencies, the tank was sampled and found to contain a small amount of gasoline containing tetraethyl lead. After excavating around the tank, the tank was lifted out of the ground, whereupon staining of the soil under the tank was noticed indicating the tank had leaked. Under agency supervision, the dirt under the tank was excavated until no more staining was noticed. A total of three 10-yard dump trucks were filled with contaminated soil. A total of 15 soil samples were taken (5 from each dump truck) and sent to a lab for analysis. The total weight of the samples was 19.8 kilograms. The samples were found to contain 297 *mg* of tetraethyl lead. What is this contamination level reported in *mg/kg*? *(3 points)*

Formula:

Calculations:

Convert this value into parts-per-million:

**weight-per-volume**

While sampling a painter for exposure to acetone vapors (a chemical commonly used for both cleaning parts prior to painting and as a paint thinner), the sampling pump ran at 0.5 *L/min* for 6 hours and 15 minutes while the worker was painting. The worker spent the remainder of the 8-hour shift unexposed to solvent vapors. The lab reported a result of 34.4 *mg* of acetone for the charcoal tube. Determine the concentration so these values can be compared to the PEL-TWA or TLV-TWA). *(3 points)*

Calculation of Air Volume:

Calculation of Concentration:

Formula:

Calculations:

**fiber counts**

While sampling a basement following asbestos abatement, the sample pump was set to 4.5 *l/min* and allowed to operate for 5.8 hours to collect an adequate sample. The sample filter was sent off for analysis. Based on sampling estimates, the lab indicated a total of 846,215 fibers, of which 398,265 met the criteria for counting as asbestiform fibers. Determine the concentration so it can be compared against the PEL-TWA or TLV-TWA, both of which are 0.1 *fiber/cm*3. *(6 points)*

Calculation of Air Volume:

Calculation of Concentration:

Formula:

Calculations:

What is the conversion factor from liters to cubic centimeters?

What is the concentration in *fibers/cc*?

Would remodeling workers exposure exceed the PEL-TWA?

**weight-per-volume to *ppm* (solid/liquid contaminants):** Methyl ethyl ketone (MEK) is a colorless liquid that has a sharp, sweet odor reminiscent of butterscotch and acetone. MEK has a chemical formula C4H8O. It is produced industrially on a large scale and is often used as an industrial solvent since it is soluble in water. Because it readily dissolves nitrocellulose, it was once a common ingredient in gun cleaning solvents. The air in a parts cleaning workshop was sampled and found to contain 153 *ppm* of MEK, what would this be in *mg/m*3?

First, determine the molar mass of MEK. *(1 point)*

C =  =

H =  =

O =  =

Total =

Next, perform the conversion calculations. *(2 points)*

Formula:

**volume-per-volume to *ppm* (gaseous contaminants)**

Referring back to the tetraethyl lead problem above, after the visibly contaminated soil was removed, the regulatory agency charged with oversight of USTs required air monitoring of the atmosphere in the excavation before workers could enter. As the safety officer for the company performing the work, you also want the air sampled. The PEL-TWA for tetraethyl lead is 0.075 *mg/m*3, which is actually higher than the TLV-TWA (0.1 *mg/m*3). You conduct the air monitoring using an air sampler that operated for 5 minutes out of every 15 minutes throughout a 4-hour period. During operation, the pump moved 0.3 liters of air per minute. The charcoal tube from the sampler was sent in for analysis, and the results showed 0.0022 *mg* of tetraethyl lead. *(5 points)*

What was the total amount of time the air sampler operated?

What was the total amount of air sampled?

What was the concentration of tetraethyl lead in milligrams per liter?

Because the PEL/TLV is given in *mg/m*3, convert your results to these units.

Would a worker in this excavation be exposed above the PEL/TLV?

However, because the regulatory agency insists you report your findings in parts-per-million, convert the above value into *ppm*. (Remember, this is a volume-per-volume conversion to parts-per-million involving gaseous contaminants.) The chemical formula for tetraethyl lead is (CH3CH2)4Pb.

First, determine the molar mass of tetraethyl lead. *(1 point)*

C =  =

H =  =

Pb =  =

Total =

Next, perform the conversion calculations. *(2 points)*

Formula: