I. ENVH 557 Exposure Controls
M. Yost, Winter 2006 Problem set I (due Thurs. Jan 19, 2006)

1. Fill in the following table, expressing each of these values in both ppm and mg/m$^3$, assuming standard conditions. If it is not appropriate to do so, say why.

| Contaminant | (ppm) | (mg/m$^3$) |
|---|---|---|
| Lead fume | NA | 0.24 |
| Styrene | 45 | 192 |
| Chlorine | 2.4 | 7.0 |
| cadmium dust | NA | 0.07 |

At the time the styrene concentration given above was measured, the actual ambient temperature was 105$^0$ F, and the pressure 13.6 psia.
ANS: Note the density factor is d= (P2/P1)*(T1/T2) = .88 (i.e. the air is less dense), so, the styrene concentration measured at the above conditions would be:
45* (MW/24.45)* d = 45* (104/24.45)*0.88 = 168.6 mg/m3

These pressure and temperature values were estimated from a crude instrument with a relative uncertainty (repeatability) of +/- 30% and overall stated accuracy of 10%. Compare the concentration of styrene in mg/m$^3$ to the standard Threshold Limit Values (TLV) or other stated exposure limit you select. What factors should be taken into account when making this comparison, and why are they important?

RMS uncertainty for T and P is = Sqrt(30^2+10^2)= +/-31.6% and Max uncertainty is 30+10=40% applying this max uncertainty value to the reading at elevated temp gives an approximate range for the mg/m3 values of 236 to 101. (Note this assumes the errors are correlated (dependent) and act to give a max error in temp and pressure). If we further assume these values are 95% uncertainties, then the true value would lie in this range 95% of the time. For comparison, the TLV of 20 ppm can be <u>directly</u> compared to the styrene measurement of 45 ppm, and since this value is not affected by temp and pressure it offers a more reliable comparison. Using a TLV standard based on mg/m3 (e.g. 85 mg/m3 TLV for styrene) would need to consider the uncertainty in the temp and pressure. We would need to assess the uncertainty of the ppm measured value separately depending on the instrument used to collect that data. Comparisons to TLV's should be based on standardized conditions (if using for mg/m3) and on a full shift (8 hr) time weighted average. Note that values in ppm don't change with temp and pressure but mg/m3 will.

2. You are using an instrument that measures particle size based on the electrical mobility of the particles (electrical mobility analyzer). The instrument has an "absolute" calibration that depends only on the physical dimensions of the measuring cell. The mobility of collected particles is given by the formula:

$$\text{Mobility} = \frac{VD^2}{LP}$$

Where:

V = air velocity

D = collector spacing

L = collector length

P = collector voltage

Given the following data, estimate the uncertainty in the mobility measurement, assuming all the errors are independent.

| Quantity | Operating value | Error tolerance | Error fraction |
|---|---|---|---|
| velocity (V) | 252 fpm | 30 fpm | =30/252= 0.12 |
| spacing (D) | 5.0 mm | 0.2 mm | =0.2/5=0.04 |
| length (L) | 6.0 in | 1/8 in | =0.021 |
| voltage (P) | 50 volts | 5% | =0.05 |

The uncertainty, assuming independent errors, is given by the square root of the sum of the relative errors of the components (note it there is an exponent we multiply by the exponent):

$Em/M = ( 0.12^2 + 2*0.04^2 + .021^2 + .05^2)^{1/2} = 0.143$ or 14.3 percent

Also, we can compute the worst case assuming the errors are additive:

$Em/M = ( 0.12 + 2*0.04 + .021 + .05) =.27$ or 27 percent

This refers to the accuracy of the measurement, since these are tolerances for manufacture and the device has an absolute calibration that only depends on these physical dimensions. To estimate the precision we would need repeated measurements showing the variability of each term (note variability of some terms (length or spacing could be very small). The effect of changing the voltage tolerance would be negligible since most of the error comes from the velocity; if the voltage were controlled to 0.1% the relative uncertainty would still be 13.3%. Assuming independent errors, the RMS error for the accuracy is 14.3% and the maximum error is 27% (all errors dependent). Controlling the voltage only reduced the error to 13.3% and 22.1% respectively, which is not significant. A more significant impact would be achieved by controlling air velocity instead because it has the largest relative error.

3. Workers in a fiberglass boat plant experienced exposures to styrene over an 8-hour shift. The following table gives the estimated amounts of styrene released over different time periods during the operation into a room volume of 150 m.$^3$ The room is well mixed and ventilated: your measurements show the airflow into the room is 175 ft$^3$ /min.

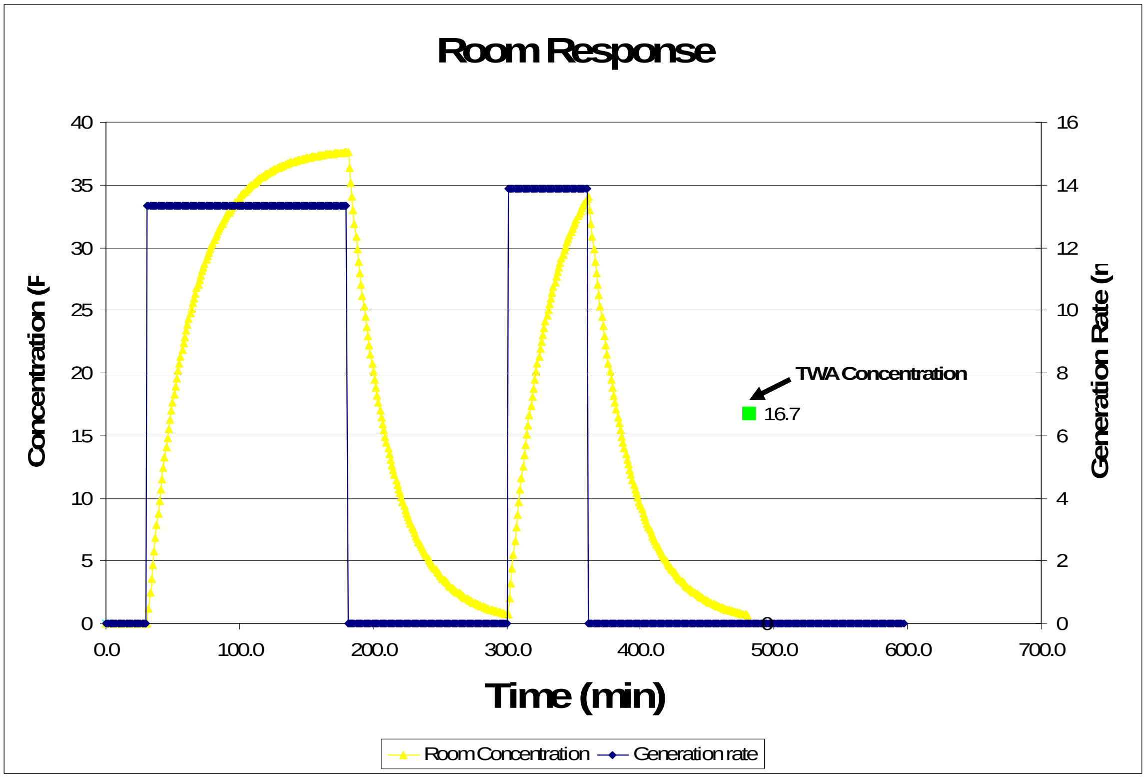
| Styrene (grams) | Time (hrs) |
|---|---|
| 0 | 0.5 |
| 120.0 | 2.5 |
| 0.0 | 2.0 |
| 50.0 | 1.0 |
| 0 | 2.0 |

Using the dilution ventilation (well mixed room) approach, compute the estimated concentration over time for styrene in each time period and estimate the TWA exposure over 8 hours. State what assumptions you need to make to estimate the exposure and comment on the exposure relative to the TLV = 20 ppm and STEL=40 ppm. Is your analysis likely to give conservative exposure estimates? What factors make your estimate more or less conservative? How would your analysis approach and results change if the airflow were reduced to only 70 ft$^3$ /min?

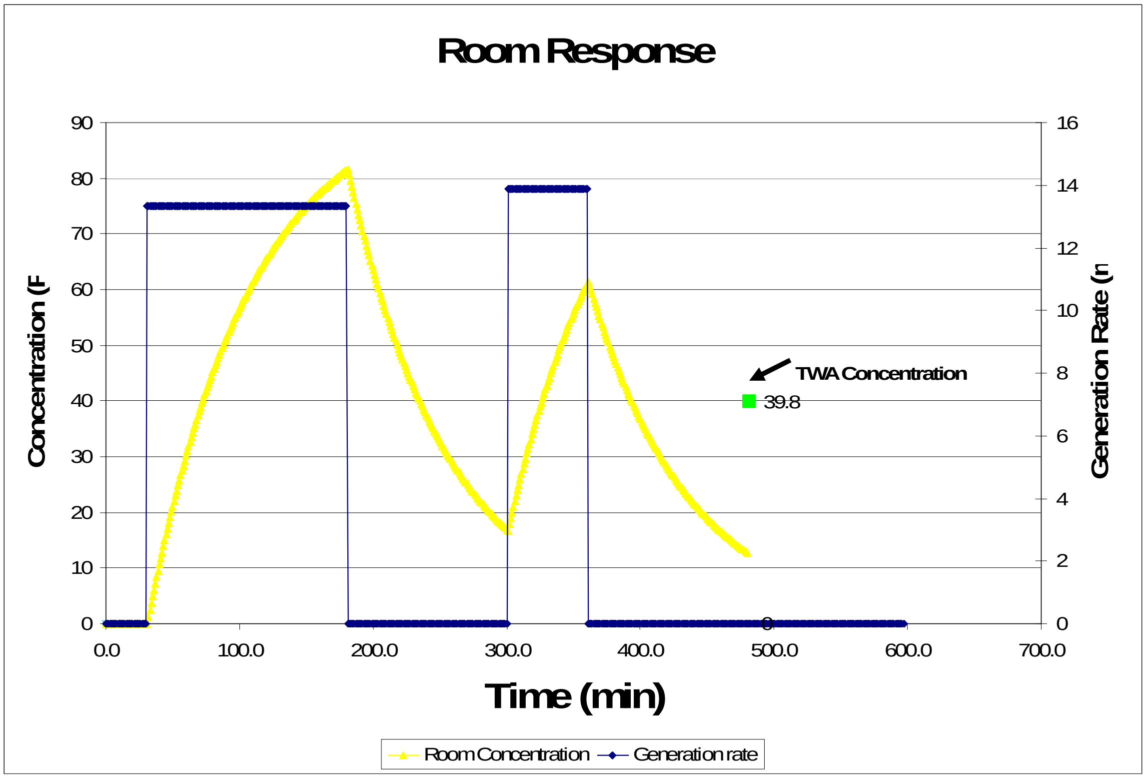
ANS: Several approaches are possible: we can start by computing the room time constant: tau = V/Q = 150/4.96 ~ 30 min. Comparing this to the time values above we note that even for the shortest time period the time constant is about half of the interval. Thus at the end of the period, the room will be close to the equilibrium (steady state) concentration. The simplest approach is to assume that the mass is released uniformly during the time period, and that the steady state concentration applies to each interval, and compute the TWA based on that concentration. This yields the following table:

| | | | | | |
|---|---|---|---|---|---|
| **Problem 3 (approx)** | | | 1cuft= m3 | 1m3=cuft | |
| Q (cuft/min) | 175 | | 0.02831685 | 35.3146667 | |
| Q (m3/min) | 4.96 | | note for 150 cuft/min set Q=4.25 | | |
| Tau (min) | 30.27 | | | | |
| Room Vol (m3) | 150 | | | | |
| 1ppm=>mg/m3 | 4.26 | | Steady State | | |
| Styrene (grams) | Time (hrs) | G (mg/min) | mg/m3 | ppm | ppm-hrs |
| 0 | 0.5 | 0 | 0.00 | 0.00 | 0.00 |
| 120 | 2.5 | 800 | 161.44 | 37.90 | 94.74 |
| 0 | 2 | 0 | 0.00 | 0.00 | 0.00 |
| 50 | 1 | 833.33 | 168.17 | 39.48 | 39.48 |
| 0 | 2 | 0 | 0.00 | 0.00 | 0.00 |
| **Total** | **8** | | | **TWA** | **16.78** |

If we want a more exact calculation, we need to use a time-dependent solution. Using the spreadsheet posted with this problem set notes, we can compute the following graph:



Note that this graph also assumes a steady release rate in each time period (shown in blue) and perfect mixing in the room. We see that for the two time periods involving a release, the steady state calculation overestimates the concentration vs time because the true concentration generally lags behind the steady state value. At the end of the second time period, the concentration peaks at a little over 37 ppm and comes close to the STEL of 40 ppm. The TWA calculated for the whole period is shown on the graph, 16.7 ppm. Note that the concentration vs time graph depends critically on knowing the generation rate and how generation changes during each time period. Assuming the generation is constant in each period gives the <u>least</u> conservative result! Also we see that in this case the steady state concentration approximation gives a TWA estimate that is very close to the time dependent solution. Note that reducing the volume flow rate to 70 CFM will make the concentration go higher (TWA=39.8) and make the time constant of the room longer, so that only a time-dependent solution is reliable. It also will make the concentrations unacceptable. This is shown in the graph below.



4. A person working in a small room of volume V=640 Cuft uses a solvent containing 1 part benzene in 19 parts hexane at a rate of 2 pints/day. The room is ventilated at a rate of 3 air changes per hour. If the solvent evaporates slowly and constantly during the day, estimate the air concentration for each solvent component in both ppm and mg/m$^3$. What would be the maximum concentration if he spilled half of the day's usage and it evaporated all at once?

ANS: In the first case we can assume a slow release over a time >> the time constant (20 min), this gives the steady-state solution C=m_dot/Q. In the second case we must assume a very rapid release over a time << the time constant so that the ventilation in the room is not a factor and C=mass/(RoomVolume). Note the spill is likely an IDLH condition.

| | | | | | | |
|---|---|---|---|---|---|---|
| **Question 4: Solvent Mixture** | | **Liters/pint** | **SpGr_benz** | **SpGr_Hex** | **Mw_benz** | **Mw_Hex** |
| **Assume an 8 hr day** | | 0.473 | 0.88 | 0.66 | 78.11 | 86.18 |
| **Part A: assume steady state concentration, M=1 (or another #)** | | | | | 8 | =hours/day |
| **# pints/day** | **Liters/day** | **Fract Benz** | **L Benz/day** | **L Hex/day** | **mg Benz/hr** | **mg Hex/hr** |
| 2 | 0.946 | 0.05 | 0.0473 | 0.8987 | 5203.00 | 74142.75 |
| **Room V CuFt** | **Air Ch/hr** | **Q = cuft/hr** | **Q m3/hr** | | | |
| 640 | 3 | 1920 | 54.38 | | | |
| | **Benz mg/m3** | **Hex mg/m3** | **ppm Benz** | **ppm Hex** | | |
| | 95.7 | 1363.5 | 30.0 | 386.8 | | |
| **Part B: assume instant release of 1/2 of days usage, and dilution only into the room volume** | | | | | | |
| **Benz mg** | **Hexane mg** | **Benz mg/m3** | **Hex mg/m3** | **ppm Benz** | **ppm Hex** | |
| 20812.0 | 296571.0 | 1143.4 | 16292.9 | 357.9 | 4622.4 | |

5. Compute a Xi (individual value) control chart for the following flow rate data. You are told the first 20 data points represent the normal condition for this measurement. What conclusions can you make from the data? Should the initial data be screened for outliers? Do you think the first 20 points really represents the “in control” condition?

| Sample # | Flow L/m | | |
|---|---|---|---|
| 1 | 0.3 | 16 | 17.8 |
| 2 | 15.9 | 17 | 10.8 |
| 3 | 9.2 | 18 | 14.5 |
| 4 | 23.8 | 19 | 14.2 |
| 5 | 4.2 | 20 | 22.0 |
| 6 | 6.7 | 21 | 49.6 |
| 7 | 14.3 | 22 | 47.6 |
| 8 | 7.2 | 23 | 49.9 |
| 9 | 3.7 | 24 | 51.3 |
| 10 | 11.7 | 25 | 47.8 |
| 11 | 7.6 | 26 | 51.2 |
| 12 | 15.0 | 27 | 52.6 |
| 13 | 16.6 | 28 | 52.4 |
| 14 | 25.8 | 29 | 53.6 |
| 15 | 2.1 | 30 | 52.1 |

ANS: The Control Chart is given in the following graph. It appears that the data in the first 20 points is ~ normally distributed and no outliers seem to appear (none exceed Chauvenet’s criterion with c=2.33 for n=25). However the pattern in the remaining 10 values is clearly ‘out of control’ compared to the first 20 values. This could be due to a shift in the process to a new operating point, or it could be a real loss of control. You would need to investigate further to see what changed in the second time period.