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#03 Laboratory Ventilation and Risk Assessment Exercise

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INTRODUCTION



This exercise is designed to introduce students to the analysis of health risks in the laboratory, particularly from vapors from organic solvents. In the analysis the students must consider quantitative measures of risk such as threshold limit values (TLVs), the amount of the compound that is used in a laboratory experiment, and the volume and ventilation rate of the laboratory under consideration.

Description

Students are presented with a scenario that requires them to make a decision on whether an experiment in which certain amounts of volatile organic solvents are vaporized is “safe” to do in a particular laboratory room. They need to find the TLV data for the solvents under consideration from the MSDS (Material Safety Data Sheet) for the compounds which can be retrieved on the Internet. They will also need to measure the volume of a laboratory room and the ventilation rate of the fume hoods in the laboratory.

Student Audience

The author does this exercise with second-year chemical technology students in a course at a community college in which there is a three-week module in chemical health and safety. All of these students have completed general college chemistry. The exercise is simple and easy to perform for students, and most are interested in it and seem to enjoy it. The calculations are more challenging and require students to pay careful attention to the units with which they are dealing.

Goal for the Exercise

There are a number of skills that students learn or practice in the process of doing this exercise including:

- Understanding the importance of safety in planning lab operations
- Finding and using MSDSs and TLV data
- Using the Internet and search engines to retrieve information
- Measuring and understanding ventilation rates in laboratories
- Doing calculations emphasizing unit cancellation or factor-label analysis

Recommended Placement in the Curriculum

In addition to using it with chemical technology students, this exercise is very well suited as an exercise to be done at the start of the laboratory in an organic chemistry course to emphasize the need to be aware of hazards of organic solvents. It also would be appropriate as a special project for interested first-year college chemistry students.

STUDENT HANDOUT

Lab Ventilation and Risk Assessment Exercise

A common laboratory situation that illustrates the concept of **relative risk** deals with laboratory ventilation and exposure to volatile materials such as organic solvents. There are three important variables to consider when attempting to estimate the risk from exposure to vapors in the open laboratory (by open lab, we mean one in which experiments are done on bench tops rather than in fume hoods where the vapors are directed away from the worker). These three variables are:

- TLV or other health standard
- amount of the chemical in the vapor state
- effective ventilation rate of the lab

One way to estimate the risk in a reasonable worst-case situation is to estimate the amount of air needed to dilute the vapor to the TLV. If the mass of vapor in milligrams released is m and the TLV is in mg/m^3 (milligrams of chemical per cubic meter of air), then m/TLV is the volume of air required to dilute the chemical to the TLV in m^3 . The ratio m/TLV can be used as a measure of the relative risk of exposure to the vapors of that chemical.

Suppose the ventilation rate for a laboratory is Q (in cubic meters per minute) and there will be n students in the lab for t minutes. The volume of air available for each student is kQt/n cubic meters where k is a mixing factor that allows for the fact that the air in the lab will not be perfectly mixed before it is exhausted. A reasonable worst-case value for k is 0.3. Thus we are assuming that the mixing of air in the lab occurs with only 30% efficiency.

A lab with modest ventilation can be expected to exchange 10-40 m^3 per student per hour. Suppose we take 20 m^3 as a typical value. Thus in a three-hour laboratory 60 m^3 of air would be available for each student. If the m/TLV value of the vapor is substantially less than 60 m^3 , then it should be safe to do that operation in an open lab. If it is near or above 60 m^3 , then either the operation should be done in the fume hood or some other chemical should be used or some other change made in the procedure to bring the risk down to an acceptable level.

Scenario

Suppose you are an instructor for a chemistry course and you need to make a decision on whether to do an experiment or particular operation on the bench top or in a fume hood in your laboratory. The experiment requires that each student in a lab section of 20 students lasting 3 hours evaporate 10 mL of an organic solvent to recover a solid product. You are considering using acetone, benzene, and dichloromethane as possible solvents. Which solvent(s) would be safe to use in an open lab? Determine the length of time that it would take to completely exchange the air in the lab assuming that the only ventilation comes from the fume hoods in the room. Comment on the risks involved and include any suggestions to make the procedure safer.

In order to arrive at a meaningful answer to this problem, you will need to gather three different pieces of information: 1) toxicity data on the organic solvents; 2) the volume of the laboratory; and 3) the ventilation rate of the laboratory. The toxicity data you need is the TLV (threshold limit value) or STEL (short-term exposure limit) for the compound. This is the concentration of the compound in air at or above which it is considered unsafe to be exposed to the compound. This data is most easily found on the **MSDS** (Material Safety Data Sheet). MSDSs for chemicals

should be available in or near labs in which the chemical is used. MSDSs are now conveniently available on the Internet. To find the MSDS you might start by doing a search in Netscape or Internet Explorer using one of the search engines such as AltaVista, Yahoo, Lycos, Excite, etc. Try searching using the keyword "MSDS" or "material safety data sheet." This should bring up several Internet sources of MSDSs. Click on one and try to locate your compound. In most of the Internet MSDS resources you will be asked to type in the name of the compound or locate it alphabetically in some way - just follow the directions. If you fail to locate the compound, try another Internet MSDS source (clicking on BACK is usually the easiest way to do this). When you locate the MSDS, find the section on toxicity of the compound. The TLV (or STEL) is usually given in units of ppm (parts per million in air). If you find more than one value, use the lowest value. TLV and STEL values can and do change over time as additional toxicity testing is done and the data is re-evaluated. Using the lowest value of the TLV or STEL is erring on the side of safety.

You should be able to determine the volume of the laboratory using a yardstick, meterstick or tape measure. If the room is not a rectangular solid (e.g., if the ceiling is at a different height in different parts of the room), you could use an average value of that dimension that gives a close estimate of the actual volume.

The ventilation rate of the laboratory can be estimated. To err on the side of safety, we will assume that the only air that is exhausted in the lab is from the fume hoods. Thus, you need to determine the face velocity of the hood when the hood sash is open to a certain height. (On some hoods there will be a sticker with a mark listing the face velocity, usually in ft./min., when the sash is opened to that height.) You can measure the face velocity of the hood by opening the hood approximately halfway and using an anemometer or similar instrument to measure air velocities. It would be best to take several readings of the face velocity and average them. You will need to know the width of the hood and the height to which the hood is opened to determine the cross-sectional area. If there are several hoods in the lab, you should record the measurements on each hood.

You now should have enough information to answer the questions. Remember that with calculations involving numbers with units, pay attention to the units you have and the units you need in your answer.

References

1. "Prudent Practices in the Laboratory: Handling and Disposal of Chemicals", National Research Council, National Academy Press (Washington, D.C., 1995)
2. Microscale Organic Laboratory, D.W. Mayo, R.M. Pike, P.K. Trumper, 3rd ed., John Wiley & Sons (New York, 1994) p. 5-14.

INSTRUCTOR NOTES

Lab Ventilation and Risk Assessment Exercise

Time Required

Measuring the volume of a lab takes approximately 10 min. Measuring the face velocity and areas of the hoods takes about 15-30 min. Depending on the students familiarity with computers, finding the TLV data and locating the MSDSs should take 30-60 min.

Group Size

The author has done this exercise with groups of 8-12 students; it should be able to be done with larger or smaller groups with no difficulty.

Materials Needed

Face velocities of the hood can be measured with velocity meters (velometers, air flow meters or anemometers). A variety of models are available from major scientific suppliers such as Fisher, VWR or Flinn (prices start at about \$50). Students may need to be reminded that the units of ventilation rates are volume per unit time (usually in ft^3/min or cfm), and that they need to measure the cross-sectional area of the hood opening when they measure the face velocity of the hood.

Material Safety Data Sheets (MSDSs) are readily available on the Internet, and most obtained using a web browser such as Netscape Navigator or Microsoft Internet Explorer. If students have difficulty locating MSDSs online, they can be directed to the URLs listed below which have MSDSs for most common chemicals:

University of Utah	gopher://atlas.chem.utah.edu/11/msds
Fisher Scientific	http://fisher1.com/index.html
Cornell University	http://www.pdc.cornell.edu/issearch/msdssrch.htm

Points to Cover in the Pre-Lab Discussion

In addition to a general discussion of the necessity for safety in the lab, students should be informed of the purpose and types of information that are found on MSDSs. In addition students should know the meaning of health safety standards including TLV values. A good discussion of these topics can be found in the references.

The exercise incorporates a variety of calculations including conversions from volume to mass, mass to moles, conversion from metric to English units, an ideal gas law calculation and a dilution problem. The importance of keeping track of units and using unit cancellation to solve problems should be emphasized to students.

Sample Results

The TLVs the author used for the solvents in the problem scenario are:

acetone	750 ppm
benzene	1 ppm
dichloromethane	50 ppm

Note: As previously noted TLVs from different sources can and do vary. Health standards for chemicals change as more toxicity research is reported or data is reevaluated.

Sample data: Our laboratory, whose volume is 16,000 ft³, has three fumes hoods, each of which is 5 ft. wide and draws 100 ft./min. when the sash is open to a height of 18 in. (1.5 ft.).

Solution: There are a number of ways to approach the problem. One is first to calculate the total ventilation rate for the lab assuming all ventilation occurs via the hoods. For our lab with three hoods, we use the cross-sectional area of the hood and the face velocity as below:

$$3 \text{ hoods} \times 5 \text{ ft} \times 1.5 \text{ ft} \times 100 \text{ ft} / \text{min} = 2250 \text{ ft}^3 / \text{min}$$

In this example the length of time to completely exchange the air in the lab is

$$\frac{16000 \text{ ft}^3}{2250 \text{ ft}^3 / \text{min}} = 7.1 \text{ min}$$

Next we calculate the volume of air available per student to dilute the vapors over a 3 hour (180 min.) lab period assuming a mixing factor of 0.3 to account for the fact that perfect mixing and dilution of vapors does not occur.

$$\frac{0.3 \times 2250 \text{ ft}^3 / \text{min} \times 180 \text{ min}}{20 \text{ students}} = 6075 \text{ ft}^3 / \text{student}$$

Now we determine the volume of the vapor formed when 10 mL of each solvent is evaporated in the experiment. First use the density and molecular mass of each solvent to determine the number of moles present. Then use the ideal gas law ($PV = nRT$) to calculate the volume of vapor formed per student when each solvent is evaporated (room temperature is assumed to be 25°C or 298 K and the atmospheric pressure is assumed to be 1.00 atm. for this calculation). Finally the volume of air required per student to dilute the solvent vapor to the TLV can be calculated. The results are shown in the table below for acetone, benzene, and dichloromethane (DCM).

Solvent	d (g/mL)	MW (g/mol)	# moles	vol (L)	vol (ft ³)	dil. vol. to TLV (ft ³)
acetone	0.791	58.08	0.136	3.33	0.118	157
benzene	0.874	78.11	0.112	2.74	0.0968	96,800
DCM	1.325	84.93	0.156	3.81	0.135	2,700

Since there are 6,075 ft³ of air available per student, we can conclude that it would be safe to use acetone and dichloromethane but not benzene in this experiment in the open lab since there is sufficient air available to dilute the concentration of acetone and DCM vapors to below their TLV values.

However, it should be pointed out that these calculations are based on an **average** concentration of the vapors of the organic solvent. The implicit assumption is that the vapor concentration is near the average throughout the 3-hour lab period. This may not be a realistic assumption. For example, the students may all be doing the evaporation of the solvent in the last hour of the experiment. If dichloromethane were being used in the lab, its vapor concentration could easily

rise above the TLV, making the procedure unsafe under these conditions. Also the concentration of solvent vapors will differ by location in the lab and will probably be higher in the immediate vicinity of where the student is working. This is one of the reasons we assume a mixing factor in doing the calculations.

Benzene and dichloromethane are both known or suspect **carcinogens** and should only be used very cautiously and under conditions where the ventilation in the lab is known to be adequate. It can be pointed out to students that the TLVs of these compounds are so low because of their relatively high toxicity.

Extensions and Variations

There are a number of possible variations in the scenario presented. It can be converted to a scenario in a production facility by increasing the amounts of chemicals being used. Individual students could be assigned different solvents or classes of solvents to evaluate for the lab process under consideration. Some of the information presented in the student handout could be eliminated to allow the students to discover it for themselves. Some instructors may want to present more detailed information on the calculations (given above in the Sample Results section) to students or run through an example with one solvent and assign others to the students.

If it not possible or convenient for students to obtain the MSDSs online, they may be obtained in print form from the manufacturer of the compound. You should have MSDSs on hand for every chemical that you have in stock in your laboratory. If it is not possible to measure the face velocities of the fume hoods, you may give the students a reasonable value for the purposes of doing the calculation (see ref. 1, p. 178).

References

1. "Prudent Practices in the Laboratory: Handling and Disposal of Chemicals", National Research Council, National Academy Press (Washington, D.C., 1995)
2. Mayo, D.W.; Pike, R.M.; Trumper, P.K. "Microscale Organic Laboratory"; 3rd ed., John Wiley & Sons: New York, 1994, pp. 5-14.