

Analyzing Cigarette Smoke

Students investigate the tar and carbon monoxide content of cigarettes

ACCORDING TO THE SURGEON GENERAL, smoking is the number one preventable cause of death in the United States. Studies show that the average smoker starts by age 15; 3000 teenagers per day start smoking; by age 6, more than 90 percent of children can identify “Joe Camel”; and approximately 400 000 people die from smoking related illnesses each year (Bartecchi et al., 1995).

These statistics are alarming, and numerous legal and educational initiatives have been proposed that target smoking and smokeless tobacco use by minors. Many of these initiatives focus on preventing minors from purchasing cigarettes or smokeless tobacco, restricting advertising of tobacco products, and educating young people about the hazards of using tobacco.

With this last goal in mind, we have developed a classroom activity in which students use their natural inquisitiveness about their personal environment to investigate the composition of cigarette smoke. We allow students to reach their own conclusions based on data they compile from experiments that use readily available laboratory equipment to measure the tar and carbon monoxide concentrations of cigarette smoke. These experiments can be done by students in groups of two to four or by the teacher as a demonstration.

BACKGROUND INFORMATION

We begin by telling students that cigarette smoke contains an array of gaseous and particulate matter. In approximate order by mass, this includes carbon dioxide, water, carbon monoxide, tar, nicotine, nitrogen oxides, hydrogen cyanide, ammonia, formaldehyde, phenol, and dozens of other well-known compounds. The relatively high concentrations of some constituents, like tar and carbon monoxide (CO), make it possible to conduct experiments with cigarette smoke without using highly sophisticated equipment. The visual and olfactory clues students receive in these labs are powerful stimuli that students cannot fail to process.

To narrow the scope of this investigation, we tell students that cigarette smoke contains higher concentrations of CO than the exhaust from a well-maintained vehicle and that the concentration of CO in a cigarette would be lethal if inhaled continuously for 30 minutes. Sadly, many students do not believe this fact.

To give the students a benchmark, we explain the standard methods developed by the Federal Trade Commission (FTC) for collecting cigarette smoke. The FTC method is intended to approximate the pattern of a typical smoker, which is considered to be one 35 cm³ “puff,” 2 seconds in duration, once per minute. We also define mainstream (MS) smoke as the smoke that is directly inhaled by the smoker and sidestream or second-hand smoke (SS) as the smoke that is released to the environment from the burning cigarette. Measurements on both SS and MS smoke have been made for many of the toxic constituents of cigarettes.

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PHOTO BY HILARY SCHWAB

Because the quantities and concentrations of the toxic constituents in cigarette smoke are quite high, it is possible to measure some of these using relatively inexpensive technology, available to most secondary science teachers. In developing these laboratory exercises, our goal was to minimize the complexities as much as possible while maintaining a scientifically valid approach. In this light we chose to ignore the differentiation between MS and SS smoke and to focus instead on a total smoke sample obtained by continuously "smoking" the cigarette.

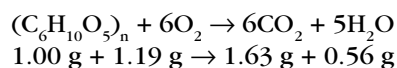
MEASURING TAR

The first part of our experiment measures the mass of tar and other particulate matter in one cigarette. Each group of students will need the following materials:

- Three cigarettes each of high-, medium-, and low-tar varieties;
- Balance capable of measuring to an accuracy of 0.001 gram;
- Small vacuum pump, house vacuum line, or aspirator;
- 47 mm filter holder;
- Control valve or pinch clamp;
- Flow meter (optional);
- Rubber stopper (size #0) and rubber or Tygon tubing (1/4" i.d.).

A typical cigarette has a mass of approximately 1 gram. Because the main constituent of a cigarette is cellulose,

its combustion can be approximated by the following equations (assuming complete combustion):



The mass given below each compound in the above equation is the mass consumed or produced in the combustion of a 1-gram cigarette. The fact that the cigarette is not completely consumed (ash is produced) and that the combustion is incomplete will reduce the amounts of CO_2 and H_2O produced, but it must be kept in mind that CO_2 and H_2O will always be the dominant constituents in the cigarette smoke.

In this first experiment, tar in the cigarette smoke is collected on 47 mm filters and weighed. We experimented with glass wool, 47 mm Teflon filters, 47 mm quartz fiber filters, and 47 mm Whatman 41 paper filters. The most reproducible results, and those that most closely matched the FTC data, were obtained with the Whatman 41 paper filters.

The experimental setup for collecting the tar in the smoke is shown in Figure 1. If a flow meter is used, we aim for a flow of between 0.5 and 1 liter per minute, which is similar to the flow when a smoker inhales. We have performed the experiment both with and without the flow meter and found it helpful but not essential. To start the experiment, the equipment is assembled in a fume hood, and a piece of clean filter paper is weighed to the nearest milligram or tenth of a milligram. The filter is put into the filter holder, and the vacuum pump (or aspirator) is turned on. The air flow is adjusted using the valve or pinch clamp to get a flow of between 0.5 and 1 liter per minute or a burn time for the cigarette of between 2 and 3 minutes, and then the cigarette is lit.

The most consistent results are obtained if the flow is kept constant from one run to the next, which takes a bit of practice with the valve or pinch clamp. Once the cigarette is completely burned, the pump is turned off and the filter paper removed and immediately weighed. The filters can also be weighed after letting them sit overnight to dry. However we have found that this has very little effect using the Whatman 41 paper filters.

The filters must be weighed carefully so as not to lose any material. Each filter must be weighed individually before and after sampling.

Before and after sampling. If a milligram or a tenth of a milligram balance is not available, it is possible to collect the smoke from more than one cigarette on each piece of filter paper or to collect and weigh all of the filter papers together from the entire class and divide by the number of filters weighed.

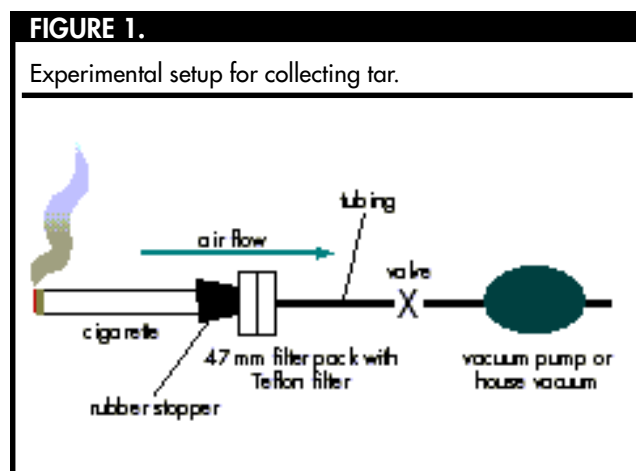


FIGURE 2.
Data obtained using Whatman 41 paper filters.

Tar content	Brand	Avg. mass collected (mg)	Number of trials	Standard deviation (mg)	FTC tar (mg per cigarette)
high	Lucky Strike	33.3	6	4.3	26
medium	Camel Filters	11.5	6	1.5	18
low	Carlton	4.3	6	1.0	1

*Filters were weighed prior to sampling and immediately after collecting the smoke samples.

EXPERIMENTAL DATA

Using the above procedure, we obtain data similar to those listed in Figure 2. It is possible that we collect other compounds besides tar. Also, because we collect a total smoke sample (MS + SS) we might expect our mass to be larger than the FTC value, which reports only MS values. However, it must be kept in mind that the conditions under which we “smoke” these cigarettes are quite different from the FTC procedure. Although we should not expect good agreement between our data and the FTC tar content, our data indicate that we can clearly differentiate between the high-tar and low-tar brands and that we are collecting about the right amount of material.

Important aspects of this experiment are the visual and olfactory, but nonquantitative, data obtained by each student. After the smoke from one cigarette has been collected, the filters have a dark brown appearance and an intense, unpleasant odor. The students cannot fail to notice this and process it as part of their overall learning about cigarettes.

CARBON MONOXIDE CONTENT

The second part of this experiment is the nonquantitative analysis of the carbon monoxide content of cigarette smoke. The following materials are needed for each group of students:

- Three cigarettes each of high-, medium-, and low-tar varieties;

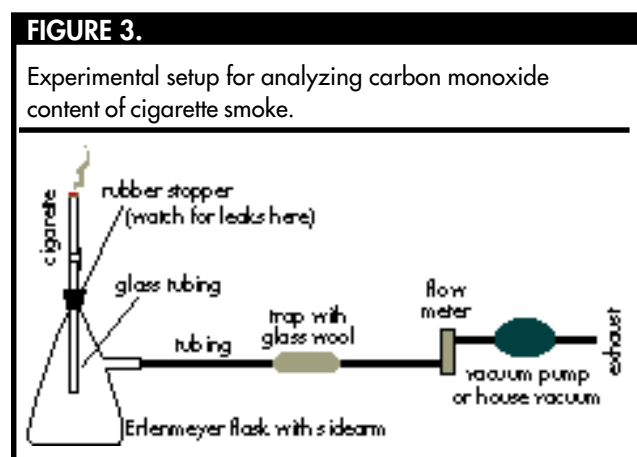


FIGURE 4.
CO concentrations (percent v/v) that were found in the smoke from four cigarettes as determined by both gas chromatography and Drager indicating tubes.

Method	Gas chromatography results (percent v/v)	Indicating tubes results (percent v/v)
mean	2.6	2.0
s.d.	0.7	0.5
range	1.6-3.0	1.5-2.7

- 250 or 500 mL Erlenmeyer flask with sidearm;
- Small vacuum pump, house vacuum line, or aspirator;
- Control valve or pinch clamp;
- Rubber stopper (size #0) and rubber or Tygon tubing (1/4" i.d.);
- Commercially available visual indicator badges for CO (such as the “Dead Stop” badge available from Houston Atlas, 2001 North Park Dr., Kingwood, TX 77339-3804; phone 281-348-1700).

Cigarette smoke contains approximately 0.5-5 percent CO, expressed as a mole fraction. The range is due to variations in the cigarettes and how they are smoked. By comparison, we tell students, a well-tuned car will have CO concentrations that are much lower than 0.1 percent. In many regions of the country vehicles must be tested annually for CO emissions, and the CO standard for auto emissions is 1 percent volume/volume (v/v). It is a remarkable fact that cigarette smoke contains much higher CO than all but the dirtiest vehicles and exhaling cigarette smoke into the vehicle exhaust analyzer would likely register a failing concentration! Those who inhale this harmful mixture have higher than normal incidences of cardiovascular disease, and this is due, in part, to the fact that CO tightly binds to hemoglobin in the bloodstream. (Godish, 1988).

For this part of the experiment the cigarette is connected, using a small piece of Tygon tubing (1/4" i.d. x 1/16" wall) and connected to the glass tubing, which runs into the one-hole rubber stopper in the Erlenmeyer flask. A CO indicator badge is placed inside the flask. The Dead Stop badges we use have a bright orange section that turns black when exposed to dangerous levels of CO (greater than 100 parts per million). The vacuum is then pulled through the sidearm of the flask (Figure 3), and the glass tubing is put through the stopper and into the flask. The flow adjustments are made using the valve or pinch clamp as described earlier.

The procedure for this lab is quite simple. The vacuum is turned on, and the flow is adjusted to an appropriate value as in the tar experiments above. Once the cigarette is lit, a striking pattern of smoke appears in the flask. At first the smoke may be so dense that the indicator badge disappears. However, once the smoke clears it will be obvious that the badge has changed color to indicate a dangerous level of CO. We tried to use the badges as a semiquantitative measure of CO by measuring the time it took for the color change to take place. Unfortunately the color change is so rapid that we were unable to get any quantitative results. This should not be surprising because the badges are intended to turn black at approximately 100 parts per million v/v, and we exposed them to about 10 000 parts per million. Thus, the students realize that cigarette smoke has CO levels that are about 1000 times greater than the level considered dangerous.

QUANTITATIVE ANALYSIS

We finish this lab by quantitatively analyzing the CO content of cigarette smoke. The materials needed for this procedure are:

- Filtered and/or unfiltered cigarettes;
- 250 or 500 mL Erlenmeyer flask with sidearm;
- Small vacuum pump, house vacuum line, or aspirator;
- Control valve or pinch clamp;
- Rubber stopper and rubber or Tygon tubing;
- Commercial detection system for CO (available from Lab Safety Supply, Janesville, WI) consisting of: Visual indicator tubes for CO in the range of 0.3-7.0 percent v/v and a calibrated hand pump for use with the indicator tubes.



In our school, we used a Drager Accurox hand pump with Drager CO indicating tubes. The pump draws a measured volume of air through the indicating tubes, which contain a material that changes color in the presence of CO. After the air sample is drawn through the tube, the CO concentration is read from the tube based on how far the color change extends down the tube. The indicating tubes used for this lab can detect CO in the range of 0.3-7.0 percent. Indicating tubes for lower CO concentrations can also be purchased, but the CO content in cigarette smoke is high enough that it will saturate the tubes and not yield quantitative data.

The data reported below were obtained by burning Camel 100 filtered cigarettes in an apparatus very similar to that shown in Figure 3. We used both gas chromatography and the indicating tubes to determine the CO concentration in the smoke from the same samples. However the samples for the two methods were obtained somewhat differently. For the gas chromatography the samples were obtained by inserting a syringe into the tubing immediately after the Erlenmeyer flask and withdrawing the sample. For the indicator tubes, the sample was obtained by removing the cigarette, inserting the indicating tube where the cigarette had been, and withdrawing the sample directly into the tube with the hand pump. In both cases the flow through the system was turned off before the sample was collected.

Figure 4 shows the CO concentrations (percent v/v) that were found in the smoke from four cigarettes as determined by both gas chromatography and Drager indicating tubes. In general, the analysis by gas chromatography gave higher CO concentrations than the indicating tubes. Because gas chromatography makes a direct comparison of the CO concentration with a known calibration standard it should be more accurate than the indicating tubes. However, the differences in sampling methods could also explain the differences in the data.

What is clear from the above data is that these simple indicating tubes can be used to give quantitative data on CO concentrations in cigarette smoke. This opens up a variety of interesting possibilities for class-

room use. For example, students can compare the CO concentration of auto exhaust and cigarette smoke. In a recent comparison that we conducted using gas chromatography, we found that 16 vehicles had a mean CO concentration of 0.24 percent v/v as compared to 10 samples of cigarette smoke,

which had a mean CO concentration of 2.8 percent v/v. We also found that filtered and unfiltered cigarettes showed essentially no difference in the concentrations of CO. Using the indicating tubes, we would expect that the exhaust from most vehicles would show nondetectable levels of CO whereas we have always detected CO in cigarette smoke using them. If desired, the indicating tubes for the lower concentration levels could be purchased to allow for a wider range of observations. No matter how students gather their data, we know they will carry this lesson with them—for life! ✧

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INTERNET RESOURCES

- Food and Drug Administration home page on Children and Tobacco: <http://www.fda.gov/opacom/campaigns/tobacco.html>
- Centers for Disease Control's Tobacco Information and Prevention home page (TIPS): <http://www.cdc.gov/nccdphp/osh/>
- Environmental Protection Agency home page on Indoor Air Quality and Secondhand Smoke: <http://www.epa.gov/docs/iedweb00/ets.html>