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Brief Reports

SHOULD THE PLACEMENT OF CARBON MONOXIDE (CO) DETECTORS BE INFLUENCED BY CO'S WEIGHT RELATIVE TO AIR?

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□ Abstract—Background: Numerous states and localities have recently passed legislation mandating the installation and use of residential carbon monoxide (CO) detectors/alarms. Interestingly, there seems to be confusion about the optimal placement, if any, of CO alarms inside the home. Objectives: It was the goal of this study to demonstrate the behavior of CO in air and to help provide a data-based recommendation for CO alarm placement. Methods: CO was calculated to be slightly lighter than air. An 8-foot-tall airtight Plexiglas chamber was constructed and CO monitors placed within at the top, middle, and bottom. CO test gas (15 L, 3000 parts per million) was infused at each of the three heights in different trials and CO levels measured over time. Results: Contrary to a significant amount of public opinion, CO did not layer on the floor, float at the middle of the chamber, or rise to the top. In each case, the levels of CO equalized throughout the test chamber. It took longer to equalize when CO was infused at the top of the chamber than the bottom, but levels always became identical with time. Conclusions: As would have been predicted by the Second Law of Thermodynamics, CO infused anywhere within the chamber diffused until it was of equal concentration throughout. Mixing would be even faster in the home environment, with drafts due to motion or temperature. It would be reasonable to place a residential CO alarm at any height within the room. © 2011 Elsevier Inc.

□ Keywords—carbon monoxide; poisoning; alarm; detector

INTRODUCTION

In recent years, there has been an increased effort to prevent carbon monoxide (CO) poisoning in the United States. Strategies utilized have included enhanced public education and promotion of residential CO detectors (alarms) (1). Numerous states and municipalities have enacted legislation requiring the installation of residential CO alarms (2). Unfortunately, there seems to be significant ambiguity on the Internet about whether CO is heavier or lighter than air and whether this should play a role in the placement of residential alarms, yielding the potential for public confusion.

Ambiguity regarding placement of CO alarms has the potential to influence both their purchase and application. An Internet search quickly reveals a confusing contrast of opinions and divergent recommendations in this area. For example, a site that evaluates consumer products says about carbon monoxide detectors, "Sources are conflicted about the best placement of the detector. Some say that because carbon monoxide sinks, CO detectors should be installed close to the ground. Others say that CO detectors should be placed near the ceiling." (3). Later, without providing supporting evidence, the same article goes on to conclude, "Plugging them into sockets near the floor are [sic] less effective because gas rises. Battery-operated options are better because you can mount them on the ceiling."

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This is only one example of hundreds of sources available to "guide and inform" the potential purchaser and user of these devices. It is not surprising that confusion exists. Because sales will continue to grow as state and local requirements recently enacted come into effect and new legislation is passed, it is important that clear recommendations exist regarding the application of CO alarms.

The issue of whether CO is heavier or lighter than air is easily resolved with basic chemistry. Because the molecular weight of a carbon atom is 12, nitrogen atom 14, and oxygen atom 16, weights of various molecules are: CO 28, nitrogen (N_2) 28, and oxygen (O_2) 32. Accepting the simplification that air is essentially 79% nitrogen gas and 21% oxygen gas, calculation reveals that CO gas is approximately 3% lighter than gaseous air.

At issue is whether this slight difference in molecular weight affects the distribution of CO in the indoor environment. If CO indeed rises in air because it is lighter, a logical conclusion might be to install CO detectors on the ceiling. This seems contrary to the fact that many CO alarms are constructed for installation into standard AC (alternating current) electrical outlets. Conjuring an image of a layer of CO floating just above the middle of a room, one source advises, "Because carbon monoxide is slightly lighter than air and also because it may be found with warm, rising air, detectors should be placed on a wall about 5 feet above the floor" (4). Few households have AC outlets located either on the ceiling or on a wall 5 feet above the floor. To attempt to make a reasonable recommendation, we examined CO distribution after infusion into a test chamber without interference from ongoing airflow, obstructing objects, internal motion, or changing temperatures.

MATERIALS AND METHODS

A CO exposure chamber measuring 2 feet wide, 2 feet deep, and 8 feet tall was constructed of 3/16-inch Plexiglas sheeting assembled over a 2 × 2-inch wood frame. Junctions were sealed with silicone caulk. The chamber was 8 feet tall to simulate a typical residential floor-to-ceiling distance. The resultant booth had a volume of approximately 32 cubic feet, or 896 liters.

Three new industrial CO gas detectors (MiniMAX XT, Honeywell, Morristown, NJ) were used to make CO measurements inside the booth. These devices have a resolution for CO of 1 part per million (ppm), an accuracy of 1 ppm, and a range of 0–200 ppm. After initial calibration, the three instruments were shown to measure identically when simultaneously placed into a plastic bag containing CO in the 0–100-ppm range. The CO detectors were mounted at the top (8 feet), middle (4 feet), and bottom inside the test chamber.

Valves through the wall at the top, middle, and bottom of the chamber wall opposite the respective CO detector allowed infusion of CO test gas (3000 ppm in nitrogen) at each of the three levels in different experiments. Tests were performed in a temperature-controlled room. Temperature inside the chamber was monitored with a dual-input digital thermistor-type thermometer (model DT20A, UEi, Beaverton, OR) and two air probes. One probe was suspended in the center of the test chamber and one mounted directly in front of the valve being used for CO infusion to measure the temperature of the expanding compressed gas being added.

CO test gas was infused from a pressurized cylinder through a flow meter attached via tubing to one of the three valves at a rate of 30 L/min for 30 s in an attempt to achieve a CO concentration inside the chamber in the range of 50 ppm. CO measurements at the top, middle, and bottom of the chamber were then simultaneously monitored and recorded for 150 min after gas infusion. Infusions at each of the three levels were performed in triplicate. One-way analysis of variance was used to determine if there was a time at which there was no statistical difference between the CO concentrations measured at each of the three levels in each of the three experimental models.

RESULTS

Regardless of the infusion site of CO, the end result was the same. The concentration of CO eventually became equal at each of the three levels as measured by the interior monitors (Figure 1). The ultimate CO concentration was in the range of 60 ppm in all experiments, well within the range of accuracy of the monitors.

The time required for the equilibration of CO concentration was different depending on the level of infusion. It occurred most rapidly when CO was introduced in the middle of the chamber (2 min), at an intermediate rate when introduced at the bottom (40 min), and most slowly when introduced at the top (105 min). Nonetheless, the ultimate concentration was equal throughout the chamber, with no suggestion of any pooling on the floor, layering in the middle, or floating on top.

Temperature of CO gas entering the chamber was nearly thermoneutral, on average only 0.5°C lower than that measured at the chamber midpoint just before infusion. With infusion, chamber midpoint temperature declined an average of 0.1°C. Temperatures from the two probes returned to within 0.1°C of their baseline values an average of 90 s after CO infusion.

DISCUSSION

The result that CO concentrations equalized throughout the chamber was predictable. The Second Law of

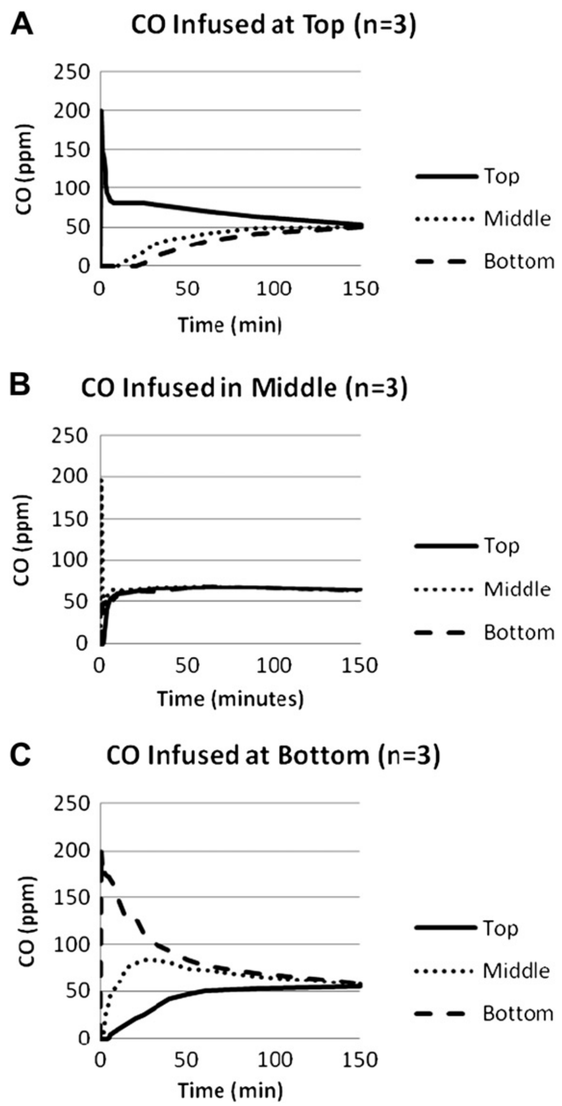

Figure 1. Concentrations of carbon monoxide (CO) in parts per million (ppm) measured at top, middle, and bottom of booth after CO was infused at the (A) top (8 feet), (B) middle (4 feet), or (C) bottom. Curves seen represent the averages of three trials.

Thermodynamics describes certain behaviors of gases. It states that a gas will continue to diffuse within the space in which it is confined, independent of other gases present, until its maximum entropy ("randomness") is achieved. When this occurs, concentration of the specific gas is equal throughout the space. Although factors such as molecular weight and temperature affect the rate of such diffusion, they do not influence the ultimate distribution of the gas.

Gases do not behave like immiscible liquids, layering upon one another like oil and water. If they did, oxygen should settle to the floor and occupy the lower 21% of the room height because it weighs more than nitrogen. In a room with 8-foot ceilings, anyone standing erect or sleeping in a bed more than 2 feet high would be at significant risk.

It is interesting to note that CO concentrations equilibrated more rapidly when the test gas was infused at the bottom of the chamber than the top, likely demonstrating its slightly lower molecular weight as compared to air. Despite the fact that the infused gas was marginally cooler than the air in the chamber, CO rose more rapidly than it sank, demonstrating that gas molecular weight played a greater role in rate of diffusion than the temperature difference present. Temperature probably did not play a larger role because by the time the CO flowed through several feet of hosing, through the flow meter, and then into the chamber, it was almost thermoneutral (see Results for temperatures).

What does this say about the placement of residential CO monitors? It would be reasonable to place them anywhere in the room and expect them to be effective. Every scenario imaginable in a home would only speed the mixing of the gas within a real room, as compared to a sealed chamber—people walking, forced air flowing from vents, CO entrainment with warm air being released into a room at floor level and then rising.

The belief held by many that CO sinks is clearly wrong. Statements such as "Carbon monoxide is heavier than air, and will pool in lower areas" need to be refuted with facts (5). Even if CO were significantly heavier or lighter than air, it would still distribute equally from ceiling to floor.

Limitations

The present model was constructed and studied to promote educational awareness of the issue and is admittedly a gross oversimplification of a large body of engineering literature that has studied and described the numerous factors involved in CO dispersion in residential environments (6,7). For example, the testing conditions used were static and testing was not repeated at varying ambient temperatures.

It should be noted that even though the CO did take different lengths of time to equilibrate after infusions at varying levels in this model, the concentration does not need to equalize in a room to activate a CO alarm. Most alarms are programmed to sound at levels of 35 ppm, a concentration that is far below that which is severely toxic. For that reason, we chose a CO infusion calculated to equilibrate just above that level. The National Institute for Occupational Safety and Health has established a recommended exposure limit for carbon monoxide of 35 ppm as an 8-h time-weighted average and 200 ppm as a ceiling (8). Had we selected an infusion calculated to equilibrate at 200 ppm in the chamber, each of the sensors would have reached 35 ppm and alarmed approximately six times faster than in our model.

CONCLUSIONS

It is important to continue to enhance public health efforts by endorsing the use of CO alarms to the public. Based on our work, the exact placement of these detectors does not seem to affect their performance.

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ARTICLE SUMMARY

1. Why is this topic important?

Accidental carbon monoxide (CO) poisoning is very common in the United States and suspected to be largely preventable through proper use of residential CO detector/alarms. There exists confusion about the density of CO relative to air and the role that this should play in the placement of home CO alarms.

2. What does this study attempt to show?

This study attempts to demonstrate the behavior of CO in air within an enclosed environment and provide guidance regarding CO alarm installation.

3. What are the key findings?

It demonstrates that, with time, CO diffuses equally throughout the space, rather than layering at the top or bottom of a room, as many suggest.

4. How is patient care impacted?

It is reasonable to place a CO alarm at any height in the room that is convenient and more important to focus on having a functional CO alarm in your home than where it is placed.