EVERYTHING YOU WANTED TO KNOW ABOUT CARBON MONOXIDE BUT DIDN'T KNOW WHO TO ASK

John M. Freeman, Jr., M.S., P.E.
President and Principal Engineer
Advanced Engineering Investigations Corporation
Denver, Colorado 80222, U.S.A.

GTI International Conference on Odorization
July 17-20, 2000
Chicago, Illinois

ABSTRACT

With newer homes being constructed more tightly and older homes being sealed up with weather stripping, the margin for error with an improperly functioning gas appliance is reduced, resulting in a greater number of carbon monoxide incidents. In many cases the propane gas company or the natural gas utility becomes involved in a subsequent claim or lawsuit.

There are important steps that can be taken to minimize the number of losses of this type and there are proper ways to investigate the incidents that do occur. Time is of the essence when it comes to an investigation. Weather conditions that might be a major factor can change quickly. This paper will discuss the causes of carbon monoxide incidents, how to investigate them and ways to reduce the chance of an incident occurring.

EVERYTHING YOU WANTED TO KNOW ABOUT CARBON MONOXIDE BUT DIDN'T KNOW WHO TO ASK

INTRODUCTION

This paper will discuss how carbon monoxide (CO) is produced from various types of gas-fired equipment. It will also discuss codes and standards as they relate to that equipment. There are certain items that must be present for the typical carbon monoxide incident to occur.

Lighting an appliance, observing the burner characteristics and checking for proper drafting only tells part of the story. Equipment can be used to check the burner to make sure it is not producing high levels of carbon monoxide.

The key to proper evaluation lies in the ability to gather evidence and accurate information to evaluate a possible claim. This paper will discuss the proper procedures to investigate a carbon monoxide accident, the methods of testing and the types of equipment to use. It will also review the known effects of different concentrations of carbon monoxide on people.

DISCUSSION

Chemistry of Combustion

Carbon monoxide is one byproduct of combustion from the burning of hydrocarbon fuels, including natural gas and propane. It is colorless, odorless and tasteless. It is almost always present with gas-fired appliances but typically in low concentrations, below 150 parts per million (PPM). In some incidents, CO readings as high as 70,000 PPM (7% by volume) have been observed in the appliances. In order to understand how CO is produced one must understand the combustion process.

The normal products of combustion of a gaseous fuel are carbon dioxide, water vapor and the production of heat from an exothermic reaction. The overall combustion efficiency is determined by the amount of air mixing with the gas. The ideal mix between the air and fuel is called stoichiometric. For natural gas this is a mix of approximately 10% gas in air and for propane it is about 4% gas in air. These ratios typically work out to be approximately 100 BTUs of heat value per cubic foot of air mixed with the fuel. As an example, one cubic foot of natural gas has a heating value of 1000 BTUs. This requires about 10 cubic feet of air for ideal burning of 1 cubic foot of gas. Pure methane requires 9.528 cubic feet of air for a cubic foot of gas. Natural gas requires from 9.16 to 10.62 cubic feet of air per cubic foot of gas depending on the composition [1]. The equations for ideal combustion are shown below.

For natural gas (methane): $\mathbf{CH_4 + 2O_2 = CO_2 + 2H_2O}$

For propane: $\mathbf{C_3H_8 + 5O_2 = 3CO_2 + 4H_2O}$

Table 1 shows the products of combustion by volume for ideal combustion of one cubic foot of natural gas, which is 90% methane [2].

Table 1. Combustion Products for Natural Gas and Propane

GAS	CU FT AIR	CU FT H_2O	CU FT CO_2	CU FT DRY FLUE GAS	CU FT TOTAL FLUE GAS
Propane	**23.8**	**3.99**	**3.53**	**21.78**	**25.77**
Natural Gas	**9.44**	**1.95**	**1.0**	**8.51**	**10.46**

In the real world excess air is required to assure good combustion. Too little excess air results in incomplete combustion, the production of CO and inefficient combustion. Too much excess air results in an efficiency loss because all of the air is not used in the combustion process. The excess air not used in the combustion process results in cooler temperatures in the heat exchanger because of dilution. The excess air is heated and carries the heat with it as it exits through the flue. Typical appliances use about 25% excess air. If there is not enough oxygen (air) and too much fuel due to a rich mixture, carbon monoxide is produced. The equations become:

Natural gas (methane): $\mathbf{2501CH_4 + 5001.5O_2 = 2500CO_2 + 5002H_2O + CO}$
This corresponds to about 133 PPM CO.

Propane: $\mathbf{1250.35C_3H_8 + 6251.25O_2 = 3750.05CO_2 + 5001.4H_2O + CO}$
This corresponds to about 114 PPM CO.

In some cases with poor or incomplete combustion additional combustion products are produced. These include aldehydes, which have an odor not unlike gas. In high concentrations they can produce some burning of the eyes and nasal passages. With very poor combustion soot from unburned carbon is produced. Also, if the flame is cooled more than normal, as in a cold startup of an appliance, higher quantities of CO are produced. This is normal and short lived. Typically, the CO concentration drops as the appliance warms.

Standards for Carbon Monoxide

There are standards for exposure to carbon monoxide. The Environmental Protection Agency has set the standard for ambient air at 9 PPM for carbon monoxide. The Occupational Safety and Health Administration has set the standard for an eight-hour exposure in the workplace of 50 PPM.

Carbon monoxide detectors have become more popular with increased publicity about serious CO incidents, specifically the CO death of tennis star Vitas Gerulaitis. One of the early detectors on the market was so sensitive that it was sounding its alarm with concentrations of only 10-12 PPM. This caused many false alarms in cities with high pollution. In 1997 Underwriters Laboratories Inc. promulgated UL 2034 a standard for "Single and Multiple Station Carbon Monoxide Alarms." This standard indicates that the alarm should activate at 70 PPM CO in 60 to 240 minutes but should not activate at 30 PPM CO in 30 days.

The American National Standards Institute (ANSI) has published standards for all of the typical gas appliances that fall under the Z21 heading. For most appliances the allowable CO level in the air-free flue gases is 400 PPM.

Gas-Fired Appliances and Safety Equipment

The most common pieces of gas-fired equipment involved in carbon monoxide incidents include central furnaces, boilers, room heaters, wall furnaces, tank-free water heaters, conventional tank-type water heaters and pool heaters. Problems arise not only with conventional heating equipment but also with sealed combustion equipment like furnaces and boilers. Any piece of gas-fired equipment can be made to produce carbon monoxide.

Gas heating equipment has constantly evolved and improved. Over the years the Z21 standards from ANSI have changed to improve gas equipment safety. In the 1970's blower door interlock switches became mandatory on gas-fired forced air furnaces. In the 1980's blocked vent safety switches and flame rollout safety switches were required on boilers and furnaces. The blocked vent safety switch would shut down the appliance if it sensed the heat from the flue gases spilling out the draft hood. The rollout safety switch would shut down the appliance if the heat exchanger became blocked or if the appliance was starved of adequate combustion air. Induced draft appliances with a blower have pressure switches to confirm air flow before burner operation. Oxygen depletion sensors became a requirement on vent-free appliances to shut down the appliance if a low oxygen condition existed that could cause an increase in CO levels.

Causes of Carbon Monoxide Accidents

There are four causal elements that almost all carbon monoxide incidents have in common. First, poor combustion must exist with high levels of CO in the flue gas. Second, a condition must exist that prevents the combustion products from going up the flue and out of the house in a normal manner. Third, the flue products must be distributed and find a way into the living quarters of the residents or portions of the building occupied by people. And fourth, the appliance must run long enough to produce enough total volume of CO to cause elevated levels in the building with dilution and air changes in the structure.

Poor Combustion. The most important element of a carbon monoxide incident usually involves poor combustion. This is generally the result of too much fuel and not enough air. In the naturally aspirated burner, gas flows through an orifice of predetermined size into the air twyer (venturi) of the burner, aspirating air. This is called primary air. The air/gas mix flows into the burner and out through the burner ports where it burns and mixes with secondary combustion air. The combustion products flow up through the heat exchanger and out the ports at the top into the draft hood. The draft hood is open to the room air on the bottom and the top is connected to the vent connector to carry the combustion products, mixed with dilution air, up the vent pipe and out of the structure. Each burner of a furnace typically has an input of about 25,000 BTUs per hour.

The BTU input and the gas flow to the burner are controlled by the gas pressure and the size of the orifice. The table below shows the pressure and orifice size for propane and natural gas for a 25,000 BTU burner.

Table 2. Variables for a 25,000 BTU burner

GAS	BTU/FT^3	GAS PRESSURE IN W.C.	ORIFICE SIZE
Propane	**2500**	**10**	**#54**
Natural Gas	**1000**	**3.5**	**#42**

These values are for sea level. At higher elevations, the burner input must be reduced 4% for each 1000 feet above sea level starting at 2000 feet. In high altitude cities this extra installation step of changing the orifices becomes very important. Many appliances, such as water heaters, are derated at the factory when shipped to cities such as Denver.

Too much fuel flows to a burner if the orifice is too big or if the gas pressure is increased above the specified manifold pressure. This causes the burner to be over fired. This produces a rich mixture, sometimes less heat, incomplete combustion and carbon monoxide. Figure 1 shows what happens to the excess air and CO when the manifold pressure is increased to the burners in a normal furnace. This was a 60,000 BTU input, two-burner furnace tested at 5300 feet elevation. Figure 2 shows the flue gas temperature and CO levels versus pressure.

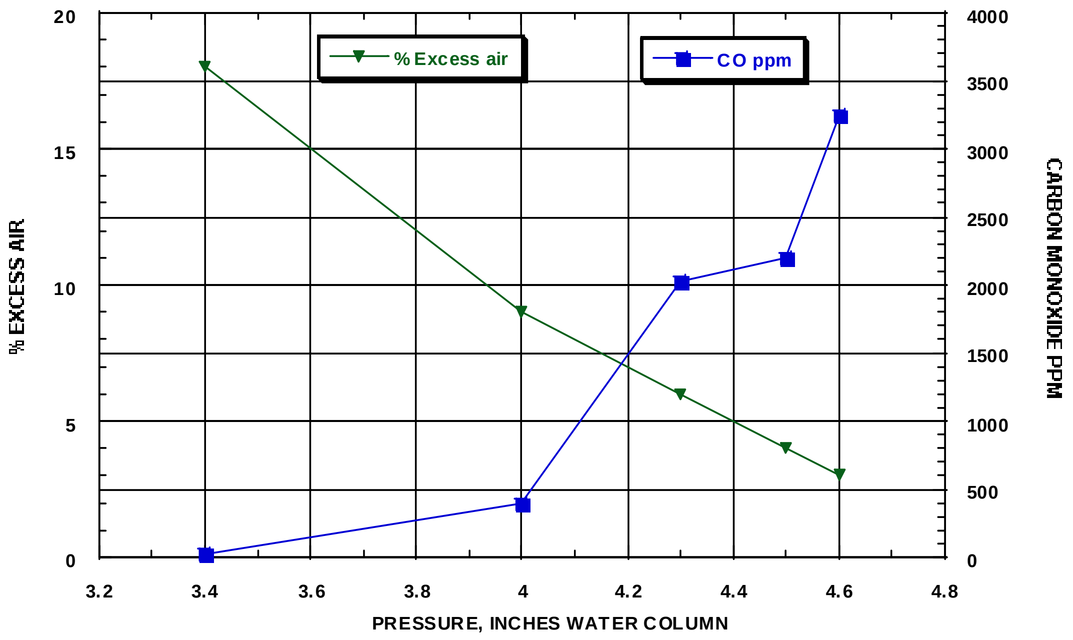


Figure 1. Excess Air and CO vs. Pressure, #46 Orifices, Natural Gas

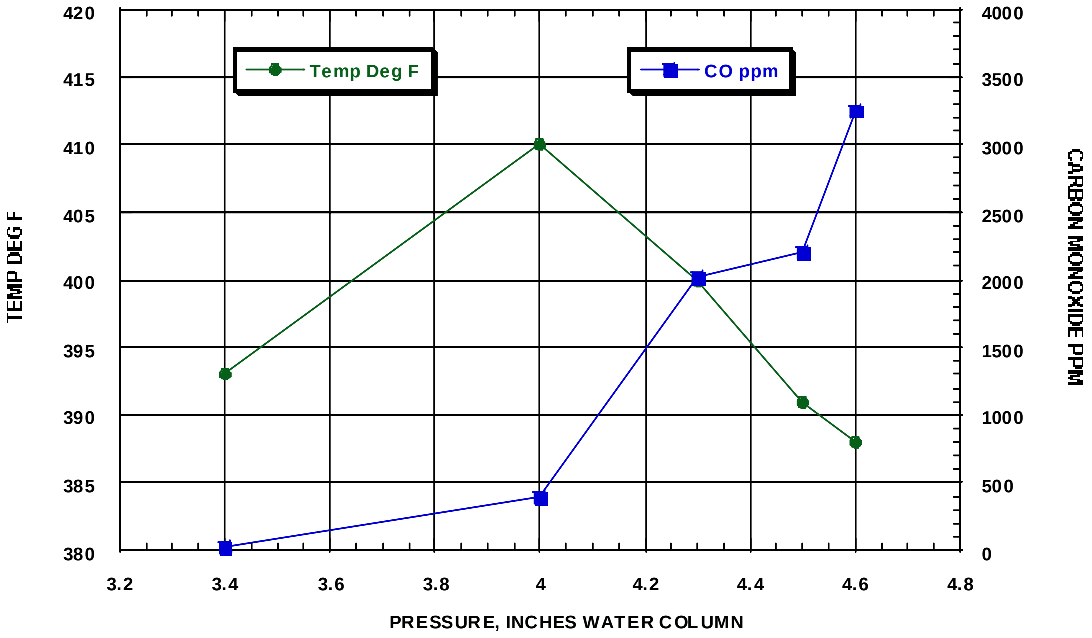


Figure 2. Temperature and CO vs. Pressure, #46 Orifices, Natural Gas

When the orifices in the same furnace were replaced with orifices that were two sizes larger, substantial CO was produced at a normal manifold pressure of 3.5" water column. Figure 3 shows the excess air and CO as a function of manifold pressure. Figure 4 shows the flue gas temperature and CO levels vs. pressure.

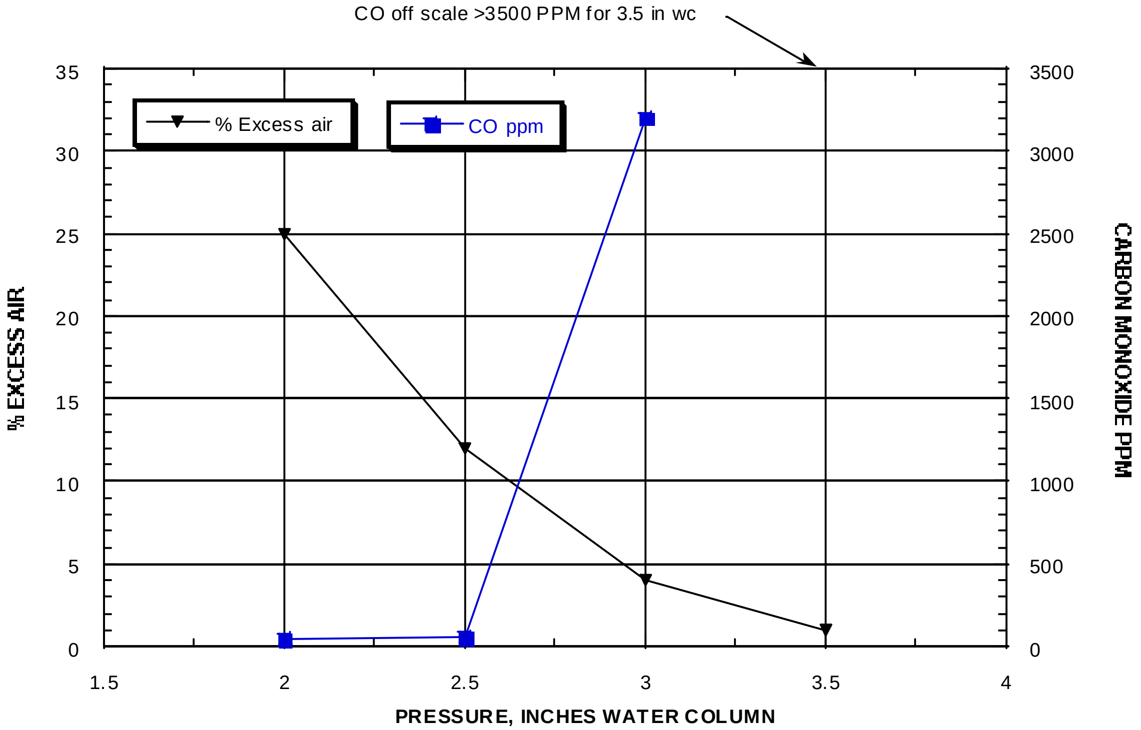


Figure 3. Excess Air and CO vs. Pressure, #44 Orifices, Natural Gas

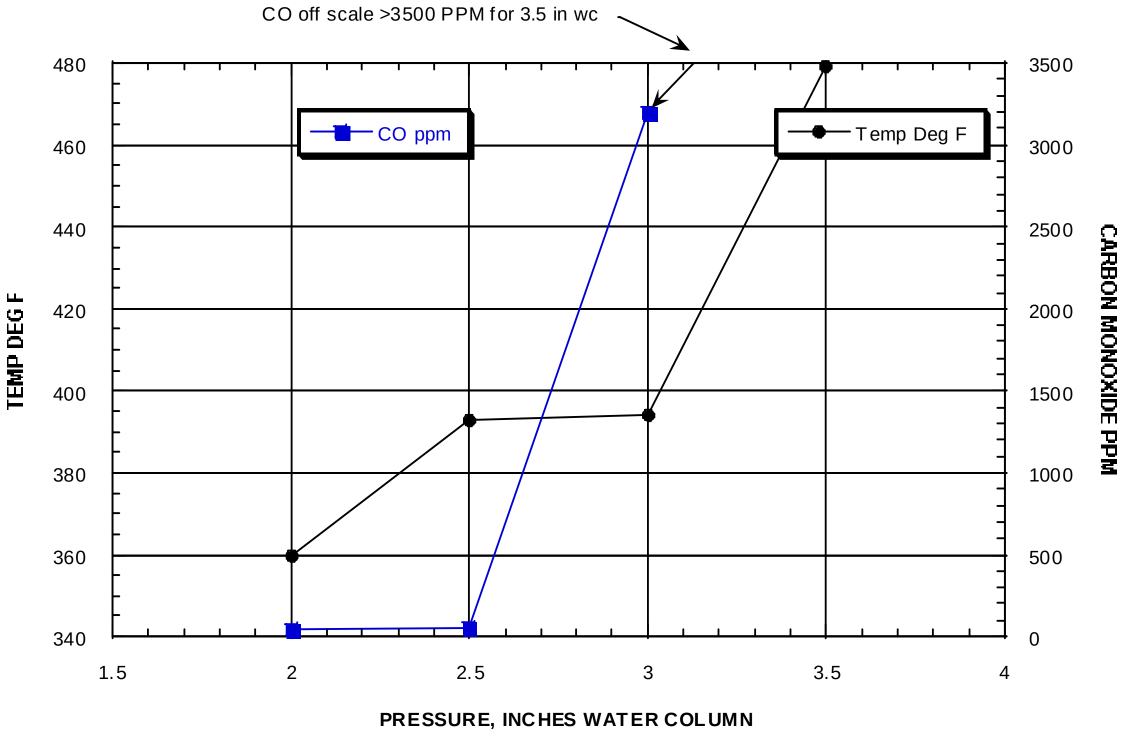


Figure 4. Temperature and CO vs. Pressure, #44 Orifices, Natural Gas

A prime example of a burner that will be over fired is one converted from natural gas to propane where the gas valve has been changed but not the orifices. Natural gas manifold pressure is usually 3.5 inches water column and propane pressure is 10 inches water column. The natural gas orifices are larger and will allow 284% more BTUs per hour.

Starving an appliance for combustion air can also produce CO. The flames will not draft normally into the heat exchanger. Instead of a nice draft that induces secondary combustion air to flow to the burner, the flames will be lazy because they have inadequate air. This causes poor combustion and CO production. Closing the air shutters on the burner or allowing them to become plugged with lint can also restrict air flow. Dirt in the burner ports or scale on the burners can also increase CO production.

Cracked heat exchangers on a forced air furnace can cause problems in a few instances. Cracks generally form slowly over time due to thermal stressing and rusting due to condensation of water vapor in bare steel heat exchanges. If the cracks exist at the lower portion of the heat exchanger there is usually a negative pressure on the burner side when the burner is not running. Products do not enter the circulation air side of the heat exchanger. If a large crack exists at that location air can flow from the circulation side into the burner area and disrupt the flame causing poor combustion. Some of the combustion products can be pushed into the vestibule area and enter the dwelling if not shut down by a rollout safety switch.

If a crack exists at the top of the heat exchanger, the more common location, combustion products can enter the circulation side when the blower is off and be carried to the dwelling when it comes on. Usually if cracks exist at this location, rusting and scaling of bare steel heat exchangers will have already occurred. Scale on the burners can produce high levels of CO. Also, flame disruption of the burners can occur with larger holes or cracks.

Another common problem that produces CO is the recirculation in the furnace room of some of the combustion products back into the burner venturi area. Instead of having air with 20% oxygen, the air will have some carbon dioxide and water vapor from the combustion present, reducing the amount of oxygen. It is important to note that not all appliances are subject to recirculation of combustion products due to blocked vents or draft reversals. Tank-type water heaters have the burners near the floor level. Since the products that are spilling are usually hotter than the surrounding air, they tend to rise. Tests conducted with clean burning water heaters (<30 PPM CO in flue gas) in small enclosures (400 cubic feet) produced no recirculation effects and produced CO levels in the room of about 5 PPM after 1 hour.

In another case a furnace that was producing zero PPM CO in the flue gas began producing 3000 PPM CO because of recirculation of combustion products in a small furnace room with inadequate combustion air. There was also an opening in the return air system in that room that caused a draft reversal as a result of a negative pressure in the furnace room. This prevented the combustion products from flowing up the flue.

Flue Gases Fail to Flow up Flue. High concentrations of CO in flue gases may be an accident waiting to happen, but as long as the gases exit the structure through the vent system it poses no immediate problem. However, as soon as the products of combustion fail to draft up the flue, you are very close to having a major problem.

A number of things can cause the spillage of combustion products. The most common one that is talked about is a blocked flue. This can occur from bird nests in the chimney or due to bricks or old mortar falling inside a masonry chimney and blocking the connection where the metal vent connector enters the chimney. This has not been very common in my experience.

The more common occurrence involves a negative pressure that is created in the furnace room because of an opening in the return air system. This can occur if return ductwork has gaps at the joints or the blower door is left ajar or completely off of the furnace. If combustion air ducts or grills connect to the furnace room this will reduce the likelihood of a problem. I have had several cases where a conventional wood-burning fireplace caused a negative pressure in the dwelling and a flue reversal resulting in enough CO to cause fatalities. In one of those cases the outside temperature was -30°F. In another case a whole-house fan was running in the wintertime when the furnace was operating which resulted in a CO fatality.

Cold weather presents some unusual problems. In addition to increasing the running time of an appliance, it can cause draft problems with the flue. The normal mechanism for natural draft of combustion products from appliances is the result of the heat of the flue gases. The fact that hot air rises is the driving force that carries the combustion products up the chimney. Once a draft is established in a chimney it is difficult to reverse. In cold weather the draft is stronger because of the greater temperature difference between the flue gas and the ambient outside temperature. However, a draft problem can be caused by a phenomenon known as a "cold block". In a typical structure in cold weather a negative pressure exists at the lower level of the structure and a positive pressure exists at the upper levels because the warm air at the top is rising due to the fact that it is less dense than the outside air. This air will leak out cracks at the upper levels of the structure, drawing cold air in at the lower levels. [3]

If an appliance in a basement is off for a period of time, rather than cycling normally, cold air can be drawn down the chimney, cooling the chimney and forming a "cold block". This is more severe in very cold weather. When the appliance fires again it can be difficult to establish a draft in the chimney and the combustion products will simply spill into the furnace room. This is usually a short-term phenomenon unless there is a large negative pressure in the area of the appliance. A CO incident is more likely to occur with the operation of a fireplace or other mechanical exhaust system, which cause long term spillage.

Once a draft is established it takes a much greater negative pressure in the appliance room to reverse it than it does to maintain an existing downdraft of cold air. Another way to phrase this is to say that overriding an existing updraft is more difficult than starting one initially. Many people have experienced this with a cold chimney with a wood-burning fireplace. A burning piece of newspaper held at the base of the chimney is typically used to start a draft. A negative pressure of 0.017 inches water column in a furnace room would not reverse an existing draft, but substantially less than that would prevent a draft from being established.

The fact that hot air rises makes it very difficult to have a carbon monoxide problem in a dwelling with a separated vent pipe in an attic. Combustion products rise and leave the attic through vents and other small openings. If flue gases leak into an attic for a period of time evidence of condensation of water vapor will be present.

Distribute Throughout Dwelling. In order for occupants to have an exposure to CO they must share the same space with the gas. Since most people do not sleep in a furnace room, (existing building codes do not allow gas appliances that use inside combustion air to be located in sleeping quarters) the CO must find a way to be distributed throughout the dwelling. This can be easily accomplished if a draft reversal condition exists because of an opening in the return air system. This provides two, if not three of the ingredients for a CO incident: distribution, draft reversal and possible poor combustion due to recirculation of the combustion products.

In many cases gas appliances are located in basements or on the first floor with sleeping quarters above. Carbon monoxide has a molecular weight of 28 and air is about 29. At the same temperature there is little difference in buoyancy. However, if combustion products spill into the house they will rise because they are typically 400 F when they come out of the heat exchanger before dilution in the draft hood. Natural migration, buoyancy and thermal affects within the structure will cause the flue gases to move throughout the dwelling although at a slower rate than that of a forced-air furnace system.

As mentioned earlier, a cracked heat exchanger can, in some instances, allow distribution of flue gases throughout the dwelling.

Carbon Monoxide Levels. The fourth ingredient required for a CO incident is the production of enough CO by an appliance into the dwelling to be harmful to the occupants. If the furnace has a blocked vent and is producing 2000 PPM of CO but the weather is mild, running times are reduced so that the total volume of CO produced may not cause levels in the dwelling to be above those required to activate a carbon monoxide detector.

Heating equipment is supposed to be sized to maintain a structure at 70°F under winter design conditions. These typically are for outside temperatures of -10°F and wind speeds of 15 mph. Under these conditions a furnace should run 100% of the time. In actuality, most heating contractors oversize heating equipment. Analysis of previous fuel consumption data and degree-day heating numbers can provide a better estimate of furnace run time at the time of the incident.

This allows for an estimate of the duty cycle of the furnace and a calculation of the quantity of carbon monoxide produced.

In cold weather we increase the running time of the heating system to approach 100% and we increase the chance of a "cold block" occurring and being maintained. If an opening exists in the return air system in the furnace room the likelihood of a CO incident becomes almost a certainty.

Investigating a Carbon Monoxide Incident

The most feared phrase to an engineer when retained to investigate a carbon monoxide incident is, "We have a claimed CO incident from a cracked furnace heat exchanger, but the furnace was replaced and the old one was tossed." Add to that, "There was no testing done to check carboxyhemoglobin levels in the victims and no CO measurements were taken in the house", and you have a CO incident that is difficult to quantify, much less to say if it existed. How can the engineer determine what the CO levels were in the dwelling, much less what the CO levels were in the furnace?

The CO levels in the furnace can vary depending on many factors. The size and location of the heat exchanger crack can determine how much, if any CO, gets into the dwelling.

The lesson is simple and it is the same one that applies to any aspect of forensic engineering. Document the conditions and preserve the evidence. A prompt response to the incident scene to document conditions is critical. Take copious photographs and video. Check the CO levels in the dwelling as well as those from all of the gas-fired appliances. If there is a suspected defective appliance, such as a furnace that needs immediate replacement during cold weather, make sure it is saved.

Another problematic item to an engineer is the request to conduct a test of a furnace at a dwelling in July when the incident occurred in January when the temperature was -30°F. Not only can the ambient conditions affect the outcome, but testing a furnace in July is not comfortable.

Testing should be done with equipment specifically designed for carbon monoxide measurements. An ambient air CO analyzer is fine for the dwelling CO measurements but may not be suitable for analyzing the flue gas. A combustion analyzer such as a Bacharach Model 300 should be used to check the combustion characteristics of all of the gas appliances. This measures the ambient temperature and that of the flue gas as well as the amount of oxygen and CO in the flue gas. In some situations stain tubes that read to 7% (70,000 PPM) CO need to be used. The appliances should be operated until an equilibrium condition is reached. If all of the potential parties cannot be present you should videotape the testing. Document weather conditions at the time of the loss including outside temperature and estimated wind speed and direction.

A sensitive instrument such as an electronic point gage should be used to check for negative pressures in the mechanical room. This will measure pressure differentials as small as 0.0025 inches water column. This can easily measure pressures that can interfere with the drafting of an appliance. Fans, clothes dryers or fireplaces should be operated if they were on at the time of the incident. Check the installation for code violations such as improper vent height or lack of combustion air.

Look for evidence of soot in the house or appliance. This occurs when high levels of CO are produced by the appliance, usually 10,000 PPM CO or more. Check for evidence of moisture in the house or condensation on the windows. Burning a gallon of propane (running a 92,000 BTU per hour furnace constantly for one hour) will produce more than three quarts of water in the form of water vapor. If the combustion products spill into the house there will usually be evidence of it.

Check gas pressures at the regulator outlet and at the manifold of the appliance. Check the orifice sizes of the appliances.

The Effect of Carbon Monoxide on People

Part of the investigation of a CO incident may involve some necessary feedback regarding the problems, or alleged problems, experienced by the victims. This is important for two reasons. First, it provides some indication of expected carbon monoxide levels in the dwelling. If fatalities occurred with carboxyhemoglobin levels of 60%, then it becomes obvious on initial testing that the reason for the incident has not been discovered if CO levels in the dwelling are found to be 150 PPM. CO levels of 900 PPM minimum would be expected. Further testing, investigation and adjustment of the variables is warranted.

Second, for your personal safety, and that of others, is it imperative that one be aware of what the effects of exposure to CO are at different levels for different time periods. During testing it is usually necessary to observe the combustion characteristics of the appliances and to verify air and flue gas flows. This necessitates some exposure to the flue gases. Table 3 shows the effects of CO on healthy individuals based on various carboxyhemoglobin levels. [4]

Table 3. Human Response to Various Concentrations of Carboxyhemoglobin

Blood saturation COHb (%)	Response of healthy adult	Response of patient ill with severe heart disease
0.3-0.7	Normal range due to endogenous CO production; no known detrimental effect	
1-5	Selective increase in blood flow to certain vital organs to compensate for reduction in oxygen carrying capacity of the blood	Patient with advanced cardio vascular disease may lack sufficient cardiac reserve to compensate
5-9	Visual light threshold increased	Less exertion required to induce chest pain in patients with angina pectoris
16-20	Headache; visual-evoked response	May be lethal for patients with abnormal severely compromised cardiac function
20-30	Throbbing headache; nausea; fine manual dexterity abnormal	
30-40	Severe headache; nausea and Vomiting; syncope	
50-60	Coma; convulsions	
67-70	Lethal if not treated	

To obtain specific levels of carboxyhemoglobin in the blood requires exposure to CO at certain levels for specified times. For each ambient CO level there is an equilibrium carboxyhemoglobin level in the blood that will not be exceeded regardless of the time of exposure. Carboxyhemoglobin levels versus time can be determined from the Figure 5 on the next page. [4]

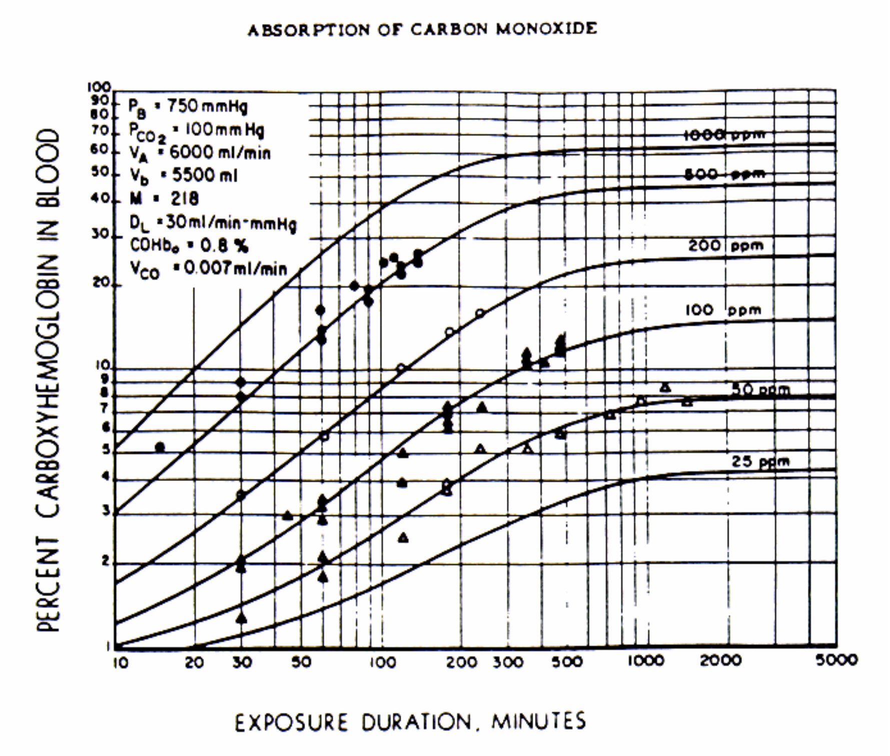
Be aware of how fast the body disposes of CO. This will affect you on site during testing, but also may be relevant to any carboxyhemoglobin levels of the victims measured at a hospital. If the carbonxyhemoglobin level of the victim was 20% but was measured after a 90-minute ride in an ambulance on oxygen, the original carboxyhemoglobin level would be closer to 40%. This is because CO has a half-life of 80-90 minutes by sedentary adults on oxygen by mask. The half-life breathing fresh air is 4-5 hours and hyperbaric oxygen at 3 ATA reduces the time to 24 minutes. [5] If specific questions exist regarding the medical aspects of CO and a particular incident, retain a medical expert on the subject to assist with the investigation.

Codes and Standards

There are numerous codes and standards related to safety of gas appliances, including manufacturing standards and installation codes involving combustion air and venting. Manufacturing standards include the Z21 standards from ANSI, adopted by International Approval services. These were discussed under safety equipment.

Building codes require a source of combustion air for gas appliances if they are installed in confined spaces or in a building of unusually tight construction. In most of the new houses combustion air is supplied from the outside using two ducts, one at the ceiling and the other near floor level. For vertical ductwork one square inch is required for each 4000 BTUs per hour of input of all appliances in the space and for horizontal ducts one square inch is required for each 2000 BTUs per hour of input.

Figure 5. Absorption of Carbon Monoxide



A vent pipe shall terminate 3 feet above the roof and 2 feet above any portion of the roof within 10 feet according to NFPA 54.[6] The 1997 Uniform Mechanical Code requires that the vent pipes up to 12" shall be permitted to terminate according to table 8-A. For a 12-12-roof slope the termination has to be a minimum of 5 feet above the roof. This puts the termination only 5 feet horizontally from the roof. For vents larger than 12 inches they may terminate 2 feet above the roof and 2 feet above any portion of the roof within 10 feet.[7] The requirement for termination of vents is obviously more stringent in NFPA 54. These termination requirements are primarily for wind conditions to prevent downdrafts and snow conditions in cold climates.

Prevention of Accidents

CO accidents can be reduced if proper maintenance is performed periodically on gas appliances. Most appliance manufacturers recommend annual inspections. Testing CO levels in the flue gas as part of the inspection by servicemen will ensure that the appliances are operating safely. In the past most servicemen did not have equipment to check CO. In recent years that equipment has become more readily available and economically priced. Portable equipment to check CO in the flue gas is currently available for about $450.

When conducting a safety inspection or doing a modification of an appliance, servicemen should either follow the procedure in the National Fuel Gas Code, NFPA 54, Appendix H, *Recommended Procedure for Safety Inspection of an Existing Appliance Installation*[6]. Or that listed in the manufacture's instructions. At a minimum, a serviceman should check the draft at the draft hood of an appliance when lighting it if there are no complaints of problems. This can be done with a match and takes less than a minute.

Carbon monoxide detectors should also be recommended to customers. These are less expensive than annual inspections and do provide protection against serious CO incidents.

CONCLUSIONS

Carbon monoxide incidents can be a serious problem for the customer as well as the gas industry. Gas company personnel should be knowledgeable about CO incidents; even what appears to be a minor incident should be taken seriously. A quick and thorough investigation is crucial to obtain the relevant information to evaluate and defend a possible claim. This should be done before disposal of crucial evidence (i.e. furnace).

Many of the problems encountered are the result of a poor installation and/or changes to the mechanical system. Servicemen should be observant for obvious hazards. CO analyzers should be used to check for proper combustion of gas appliances during installation and safety inspections. Customers also should be made aware of the availability of carbon monoxide detectors.

ACKNOWLEDEMENTS

Special thanks to Richard Stewart, M.D. for the use of his CO charts.

REFERENCES CITED

1. *Gas Engineers Handbook*, Industrial Press, New York, NY, 1965.
2. *North American Combustion Handbook, second edition*, North American Manufacturing Company, Cleveland, OH, 1978.
3. *1993 ASHRAE Handbook, Fundamentals*, American Society of Heating, Refrigerating and Air/Conditioning Engineers, Inc., Chapter 23.
4. Richard D. Stewart, M.D., M.P.H., *The Effect of Carbon Monoxide on Man* Technomic Publishing Co., Inc., Westport, CT 1976.
5. Richard D. Stewart, M.D., M.P.H., FACP, FAACT, *Carbon Monoxide Poisoning, What Every Lawyer Must Know*, Propane Gas Defense Association Meeting, 1996.
6. *National Fuel Gas Code, NFPA 54, ANSI Z223.1*, National Fire Protection Association, Quincy, MA 1996.
7. *1997 Uniform Mechanical Code*, International Conference of Building Officials, Whittier, CA.